ENERGY ECONOMICAL PERSPECTIVES OF SOLAR HEAT IN URBAN ENERGY SUPPLY SYSTEMS

Jan-Bleicke Eggers

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Aalborg, 27.09.2016

www.ise.fraunhofer.de

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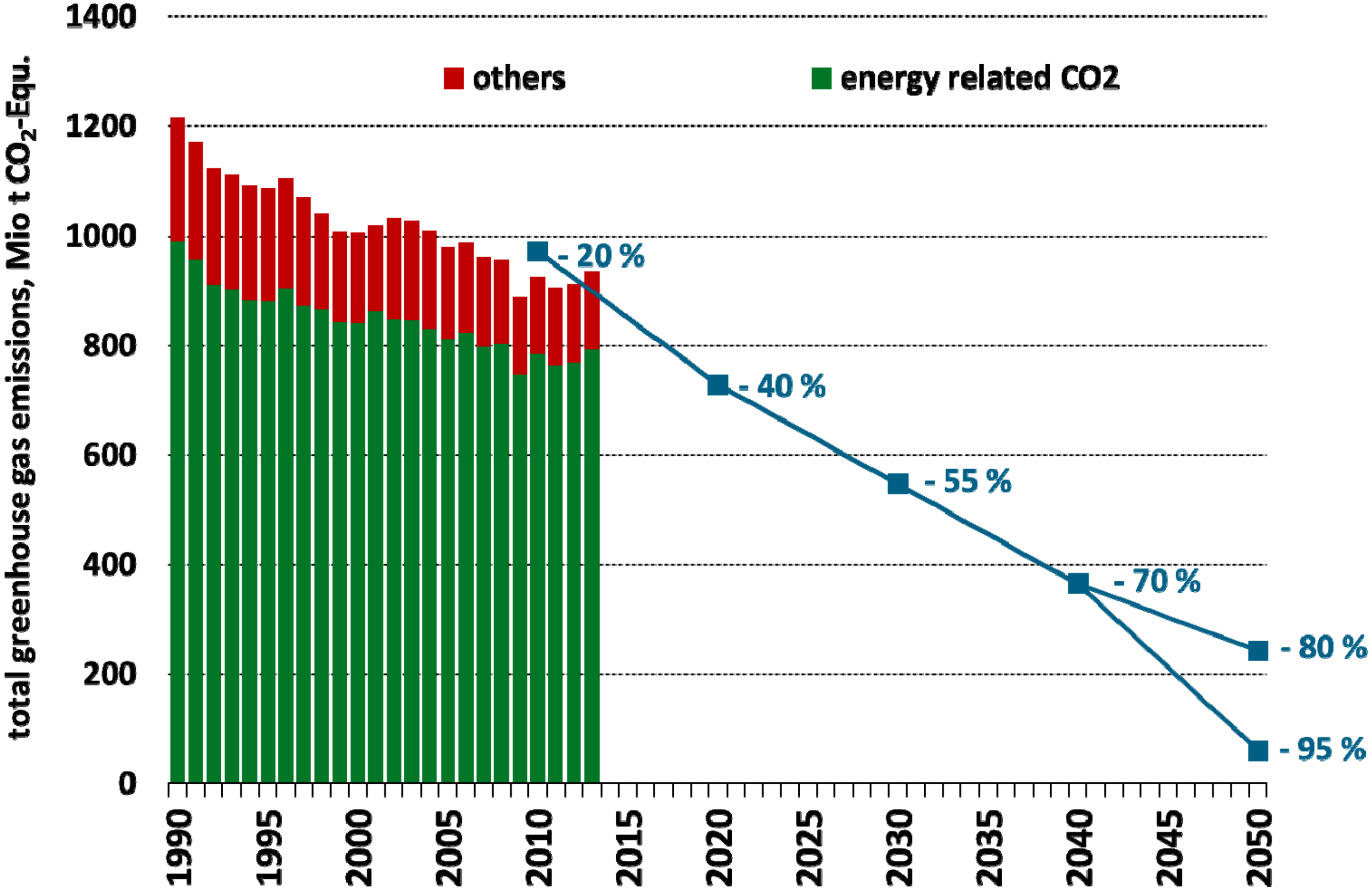
Development of German GHG emissions 1990 – 2013 & target values until 2050



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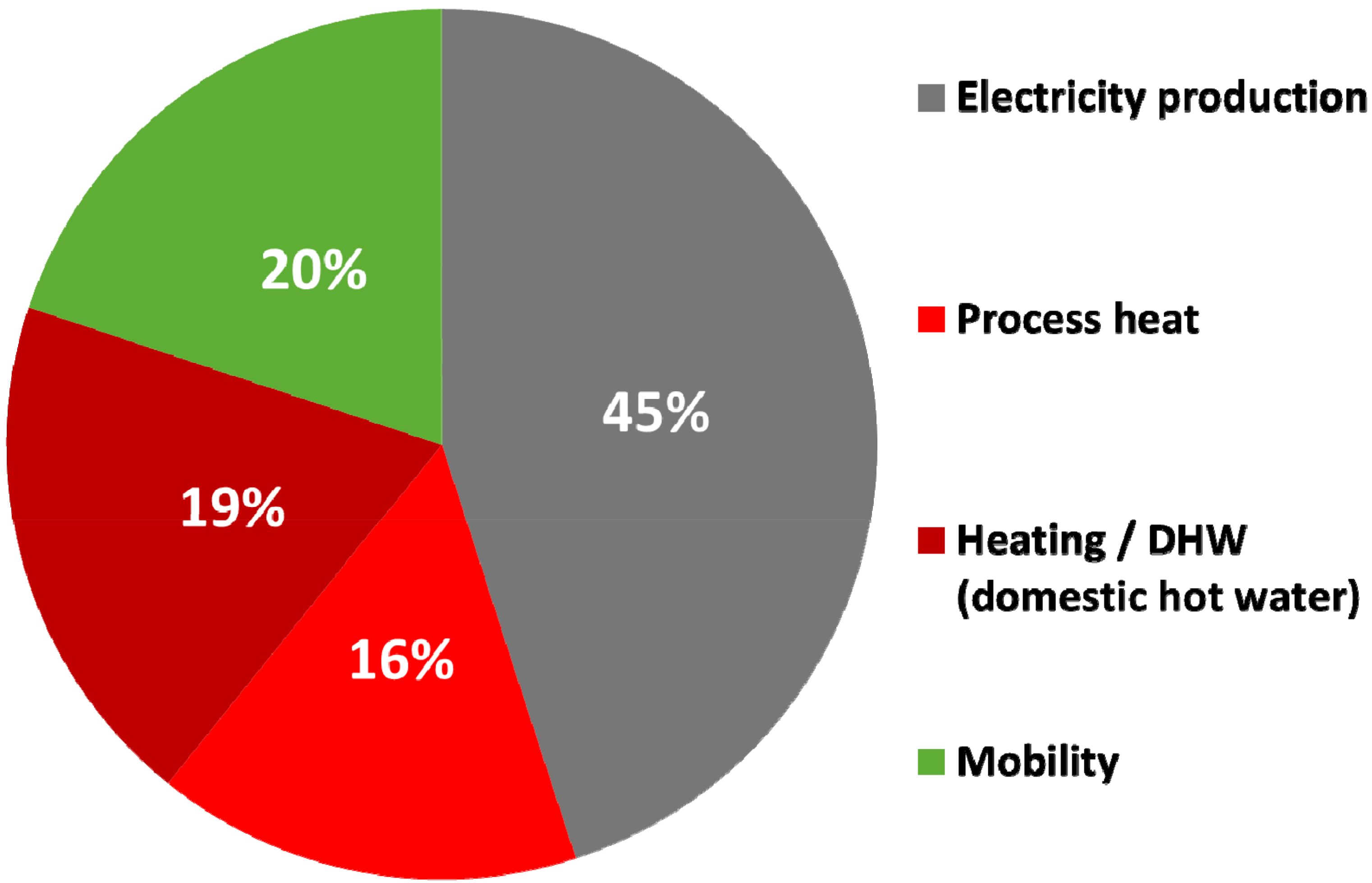
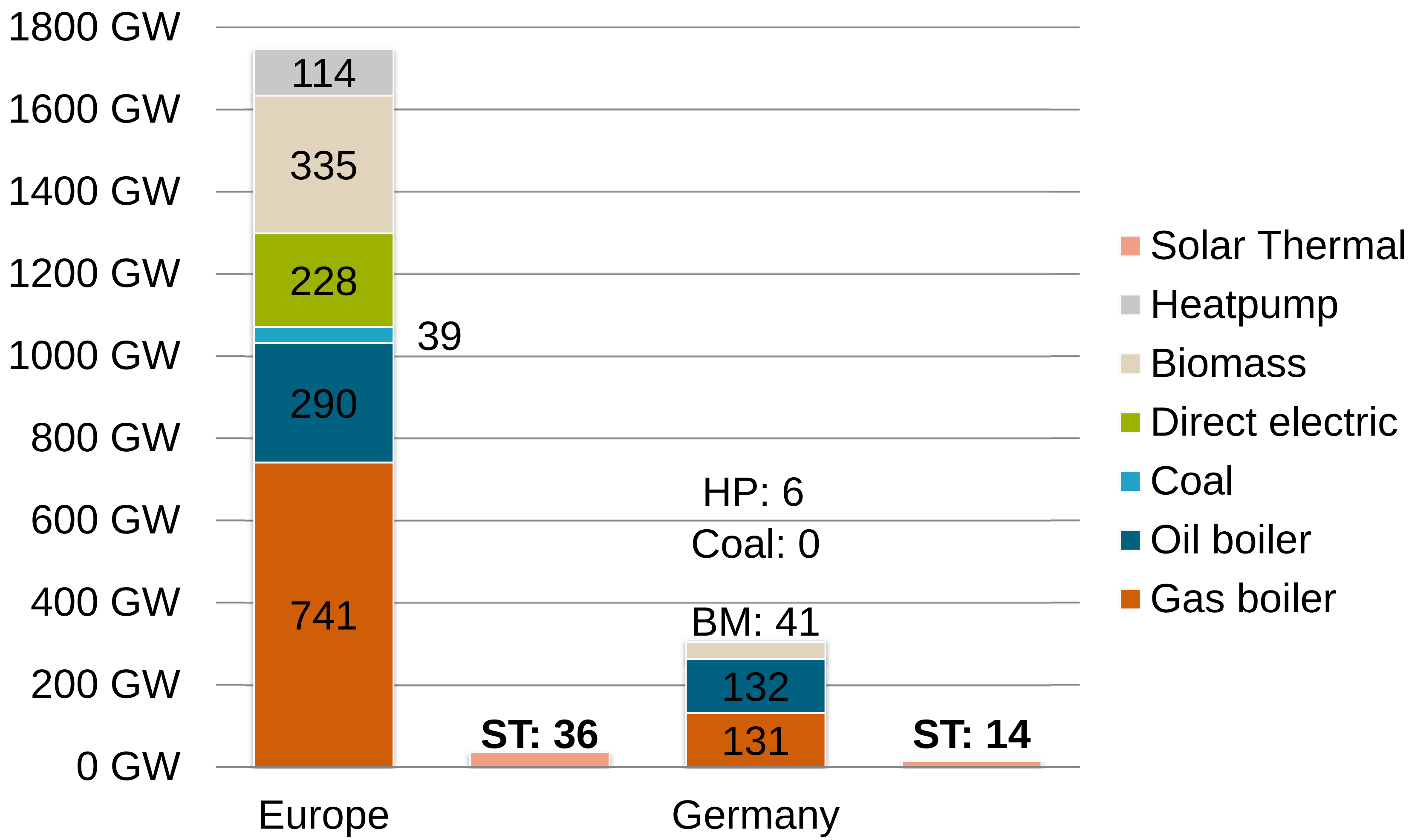
Energy related CO_2 emissions – Germany 2013



Heating Supply Stock Europe / Germany
Installed Capacity 2012



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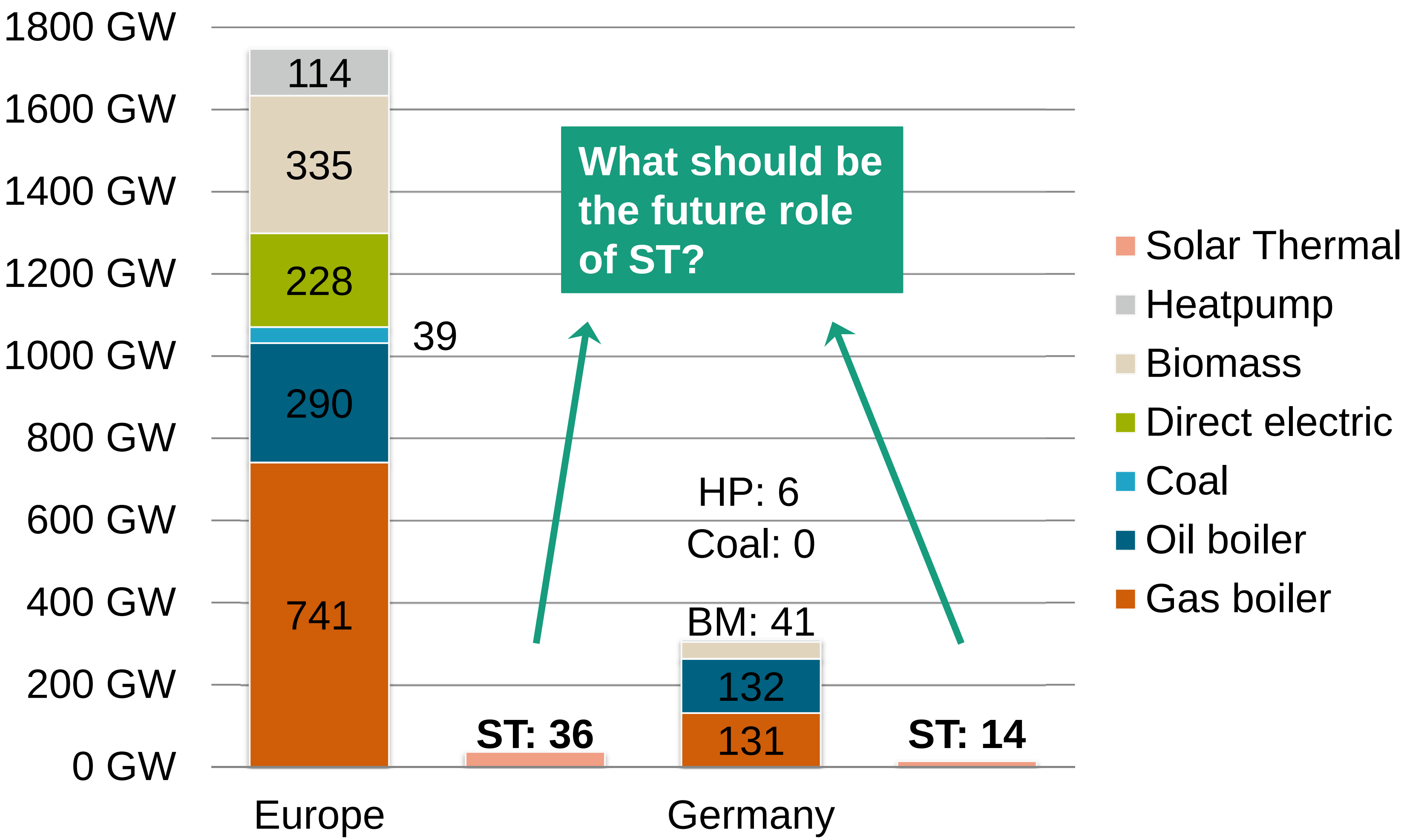
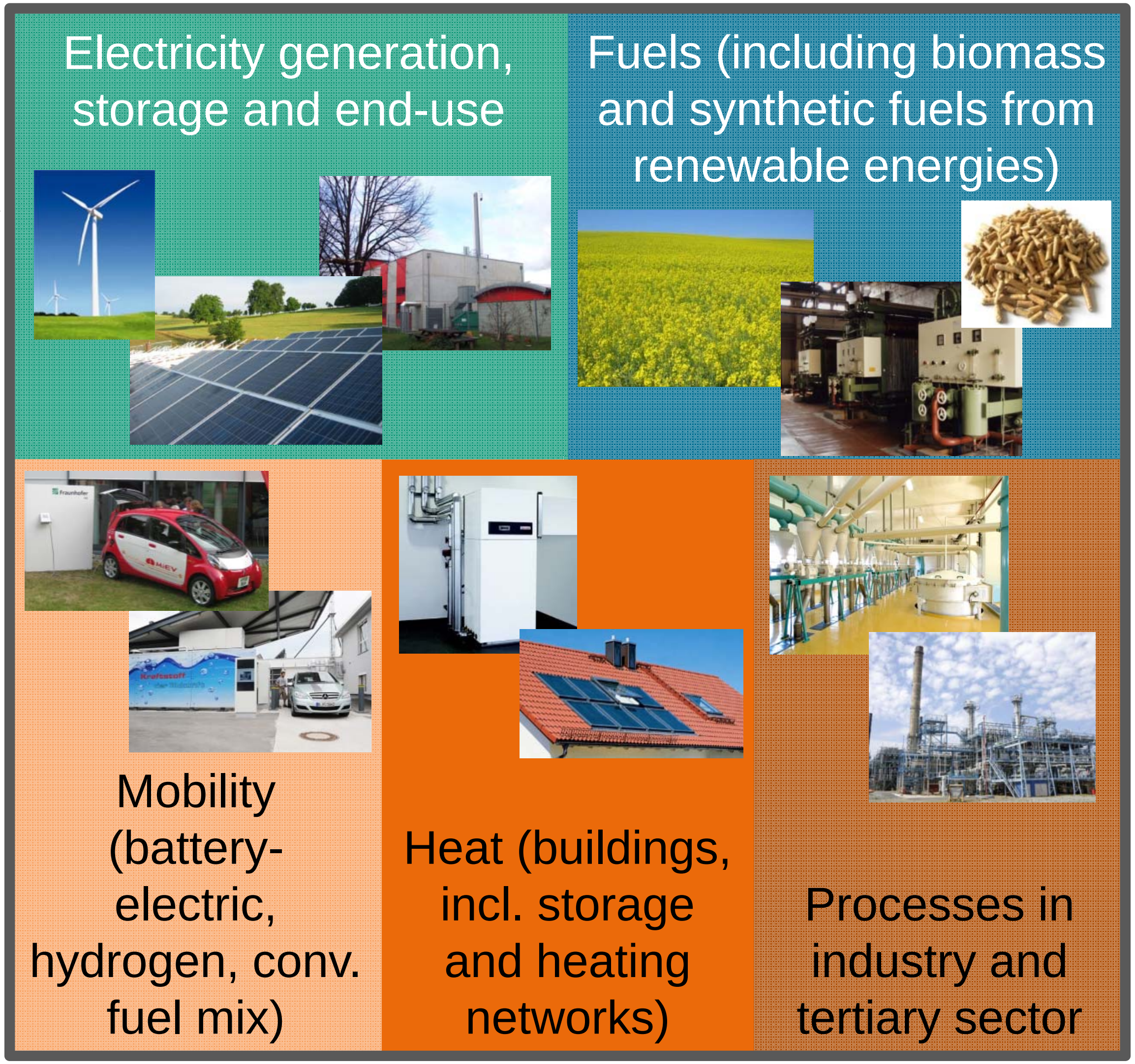


Methodology – Optimization of Germany's future energy system

Minimization of total annual cost (operation, maintence, …)



REMod-D

Renewable Energy Model – Deutschland

Techno-economic optimization based on comprehensive simulation (hourly time scale)

Scenario overview for sensitivity analysis

Generally fixed boundary conditions:

~50 % building retrofit,~20 % district heat, mobility mix: hydrogen, CH4, liquid fuels, batteries

1) Photovoltaics	2) Building retrofit	3) Investment costs	4) CO_2-Emissions
Installed power of PV [GW_{el}]	Reduction of heating demand	Cost reduction of ST [€/m²]	CO_2-emissions reduction target
		cen./dec.	
240	64 %	360/261	-85 %
210	55 %	320/232	-86 %
180	45 %	280/203	-87 %
150	35 %	240/174	-88 %
120	30 %	200/145	
90	25 %	160/116	

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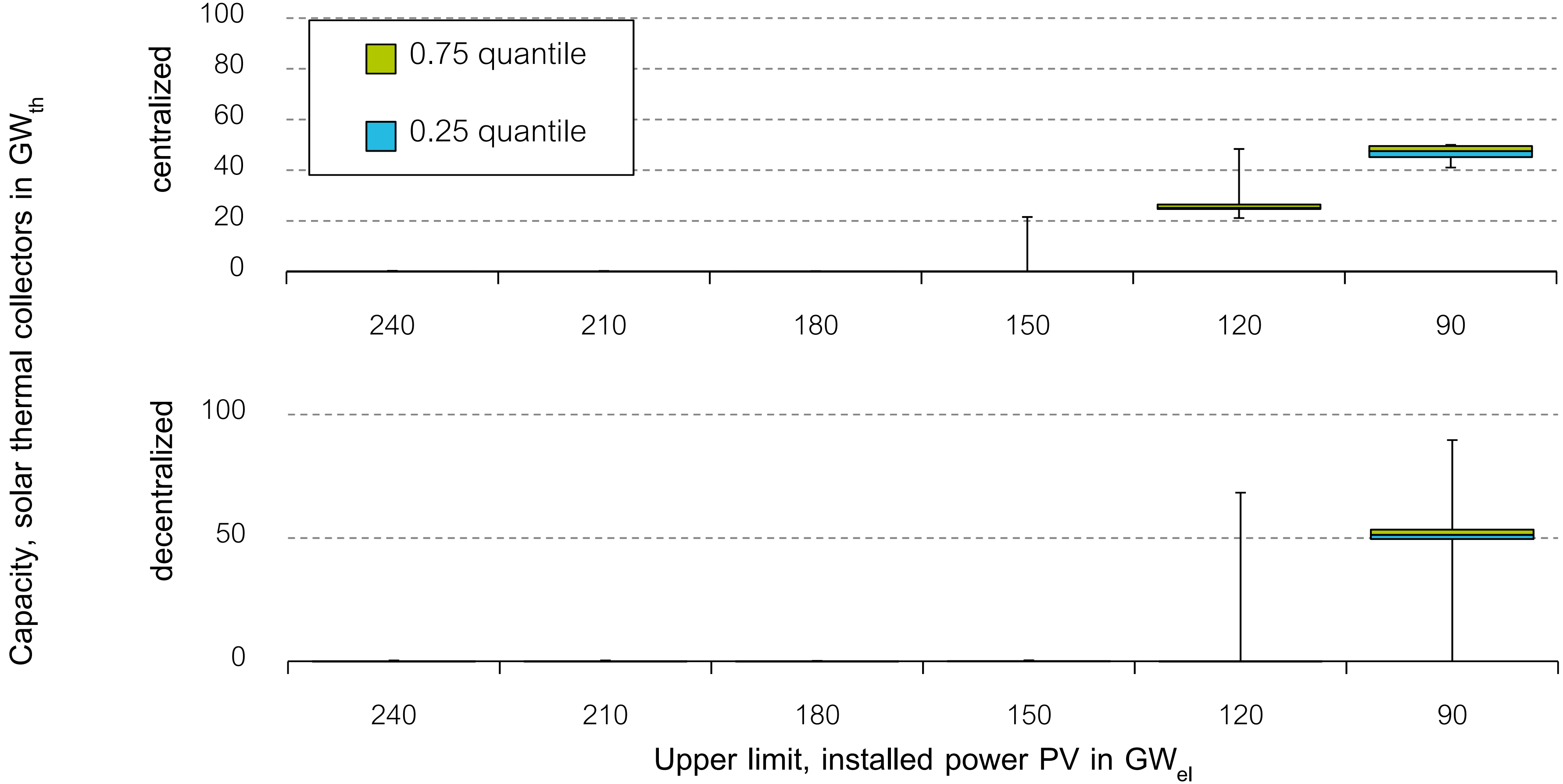
1) Influence of PV on the installed capacity of solar thermal collectors



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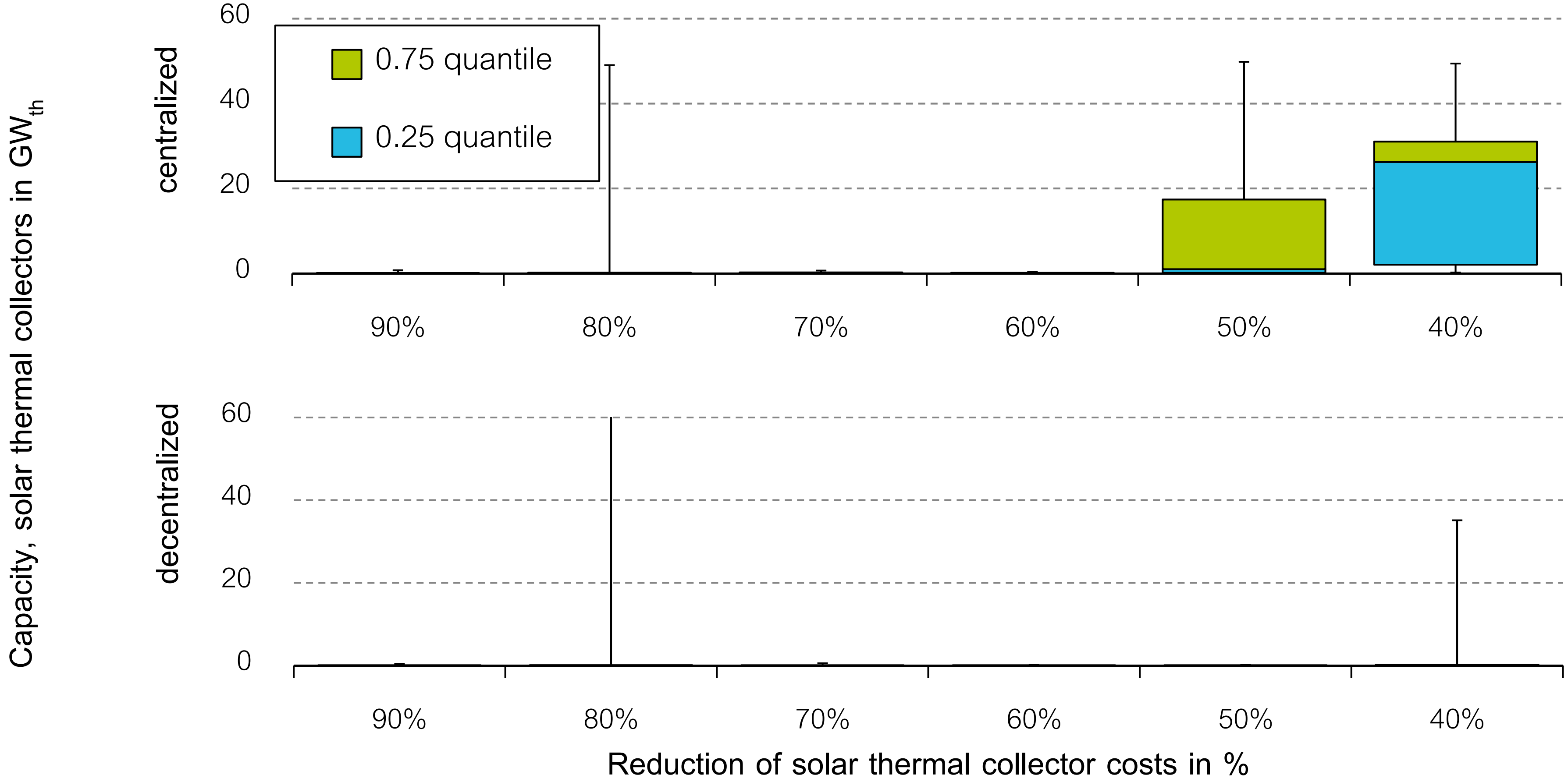
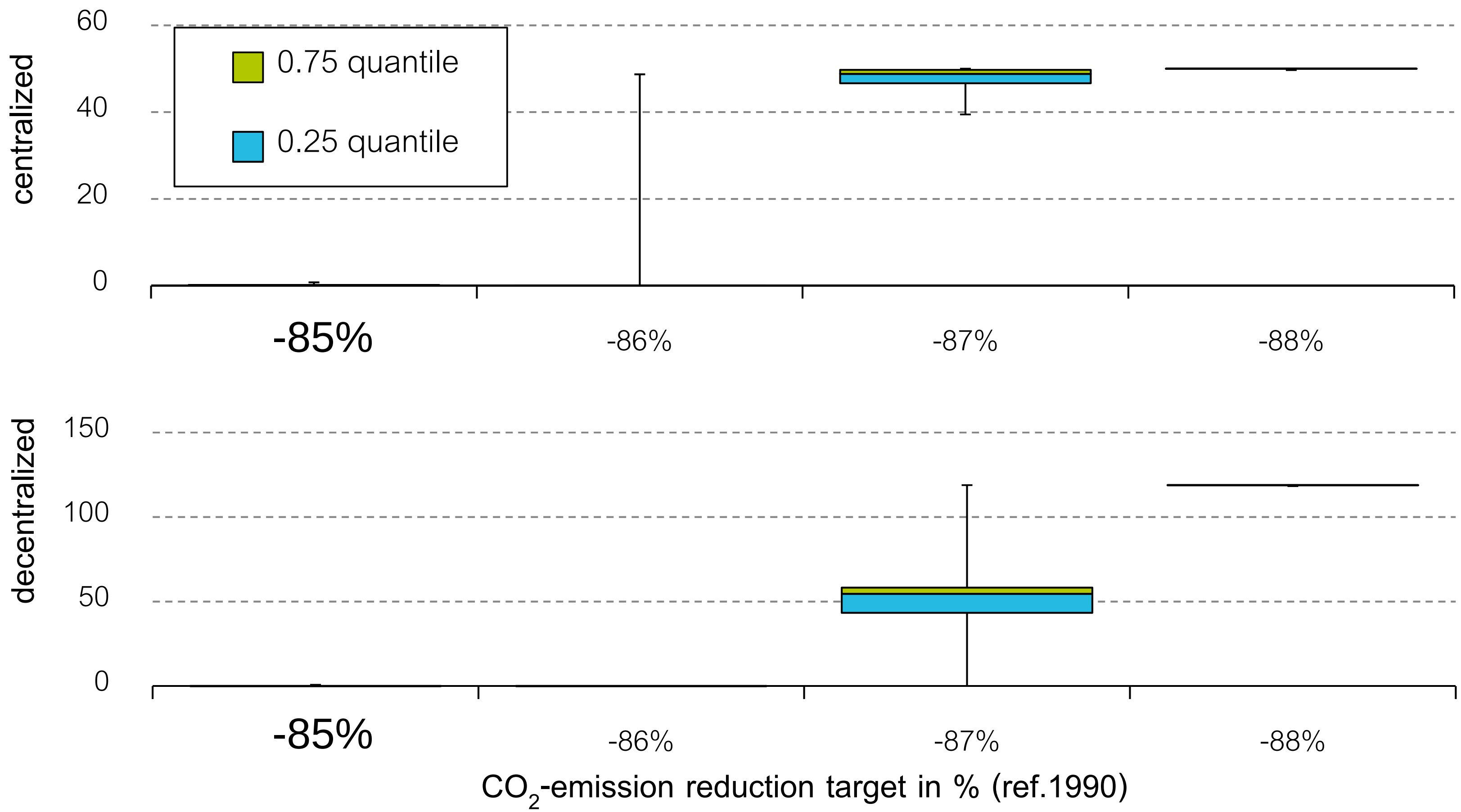
3) Influence of cost reduction on the capacity of solar thermal collectors

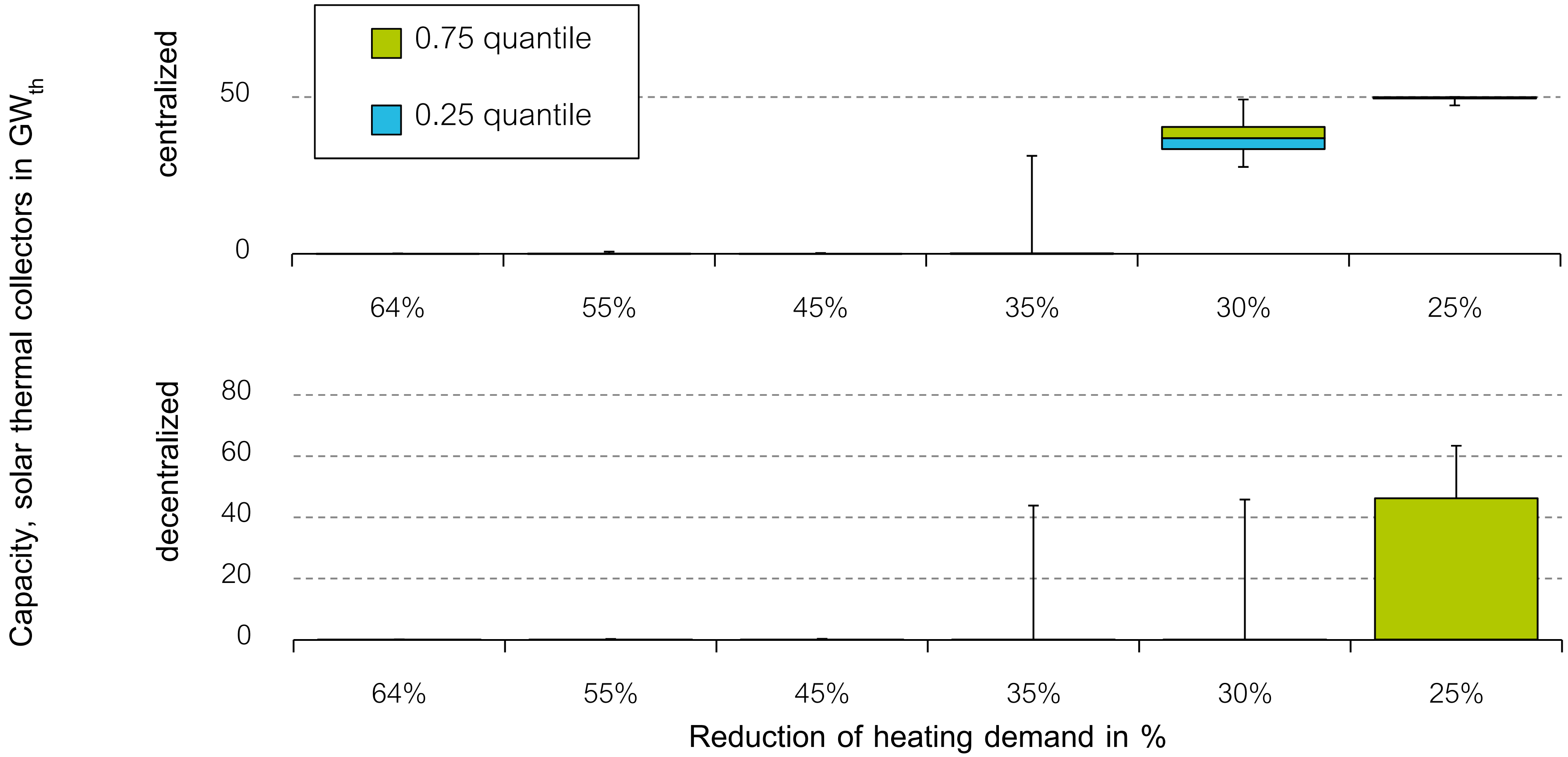


Initial cost assumptions (100 %): decentralized 400 €/m², centralized 290 €/m²

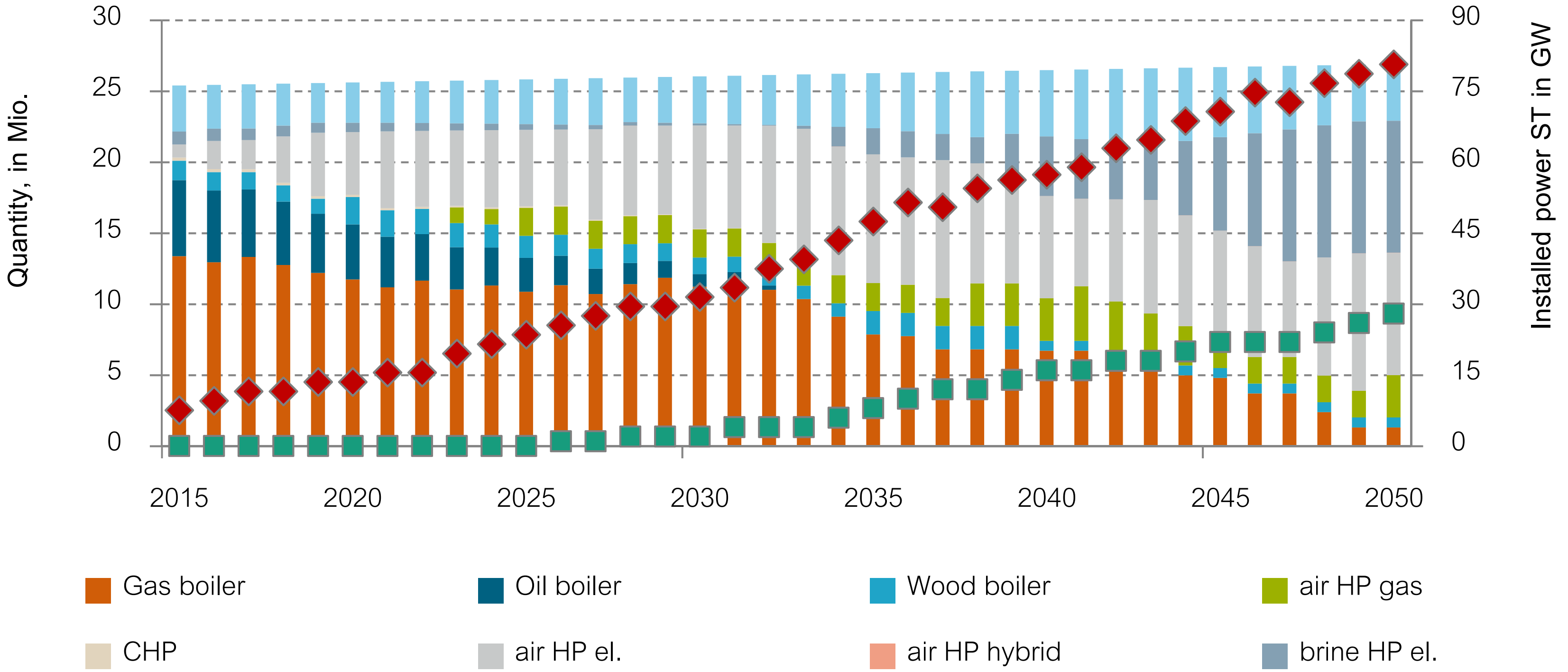
4) Influence of increased CO_2-emission reduction targets on the capacity of solar thermal collectors



2) Influence of energy retrofit for buildings on the installed capacity of solar thermal collectors



Development of heating supply technologies



Palzer, Andreas (2016): Sektorübergreifende Modellierung und Optimierung eines zukünftigen deutschen Energiesystems unter Berücksichtigung von Energieeffizienzmaßnahmen im Gebäudesektor. (genehmigte) Dissertation. Karlsruher Institut für Technologie, Karlsruhe. Online verfügbar unter http://publica.fraunhofer.de/documents/N-408742.html.

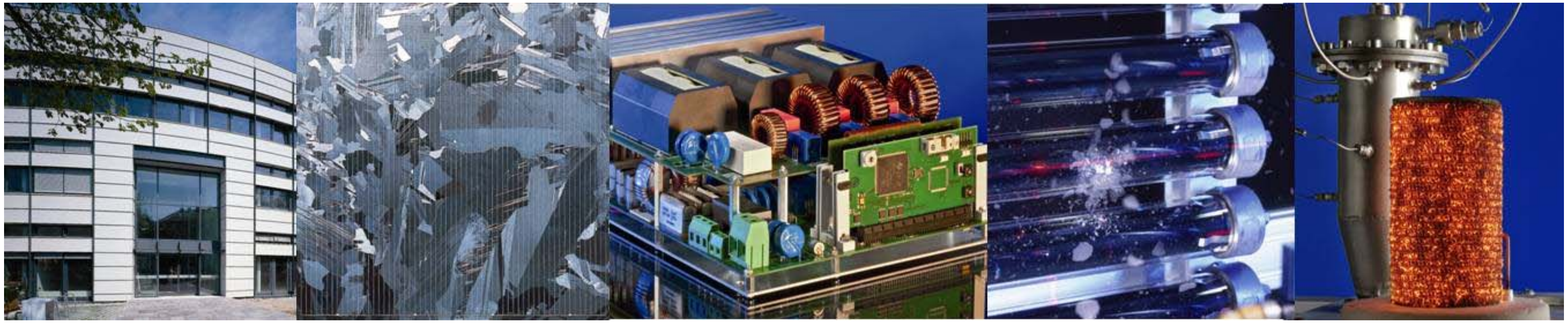
Summary & conclusions

- Compared to the reference energy system, solar thermal applications gain in importance if
  - electricity from renewables is short (i.e. due to capacity restrictions)
  - future achievements in retrofitting of buildings are low (<30%)
  - investment costs for ST can be reduced notably (approx. 50%)
  - CO_2 emission reduction targets are high

- In contrast, solar thermal application are continuously present if the whole transformation pathway is regarded

  Explanation: Due to bottlenecks in certain years along the path (high amount of fossil fuels, different weather conditions, slow retrofit rate) solar thermal collectors become necessary from time to time; once in the system they stay for their lifetime; restrictions in installation rates also play a role

Thank you for your attention!



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Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

Assumptions and parameters for the model
„Base Case Scenario“

Specified parameters

CO_2-Emissions ~200 Mio. t/a

El. Base load 375 TWh/a

Process heating 445 TWh/a

Photovoltaic maximal 300 GW

Offshore-Wind 32 GW

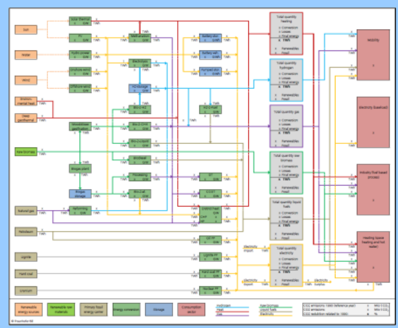
Onshore-Wind 120 GW

Available biomass 335 TWh/a

Composition of the mobility sector set

PSO Optimizer

(minimized total annual costs)



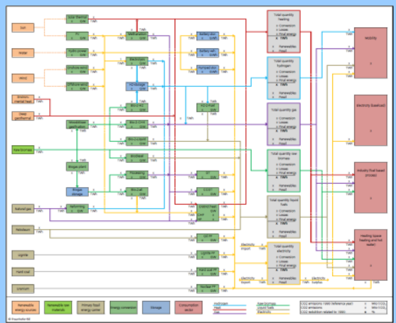
Free parameters: building energy retrofit, heat supply, CHP, Methanation, …

Modelling results
Analysis of the base case

PSO Optimizer

(minimized total annual costs)

197 Billion €



Results	Optimized System	Nowadays
Primary energy demand	~ 2,600 TWh/a	~ 3,700 TWh/a
Final energy demand	~ 1,800 TWh/a	~ 2,500 TWh/a
Electricity production	~ 960 TWh/a	~ 516 TWh/a
Heat production	~ 1050 TWh/a	~1,400 TWh/a

Overview

- Emission reduction targets up to 2050 for Germany and state of heating systems in Germany and Europe
- Methodology
- Sensitivity analysis for solar thermal systems
- Transformation pathway of the German energy system
- Summary & conclusions

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Guiding question

What is the cost-optimal transformation pathway of the German overall energy system including all end-use sectors under the boundary condition that the political goals of reducing greenhouse gas emissions are fulfilled – both for the target value and in each single year?

Here:

- Special focus on the future role of solar thermal applications
- Comparison of calculations with focus on a single year (2050) and on the total pathway from today to the year 2050

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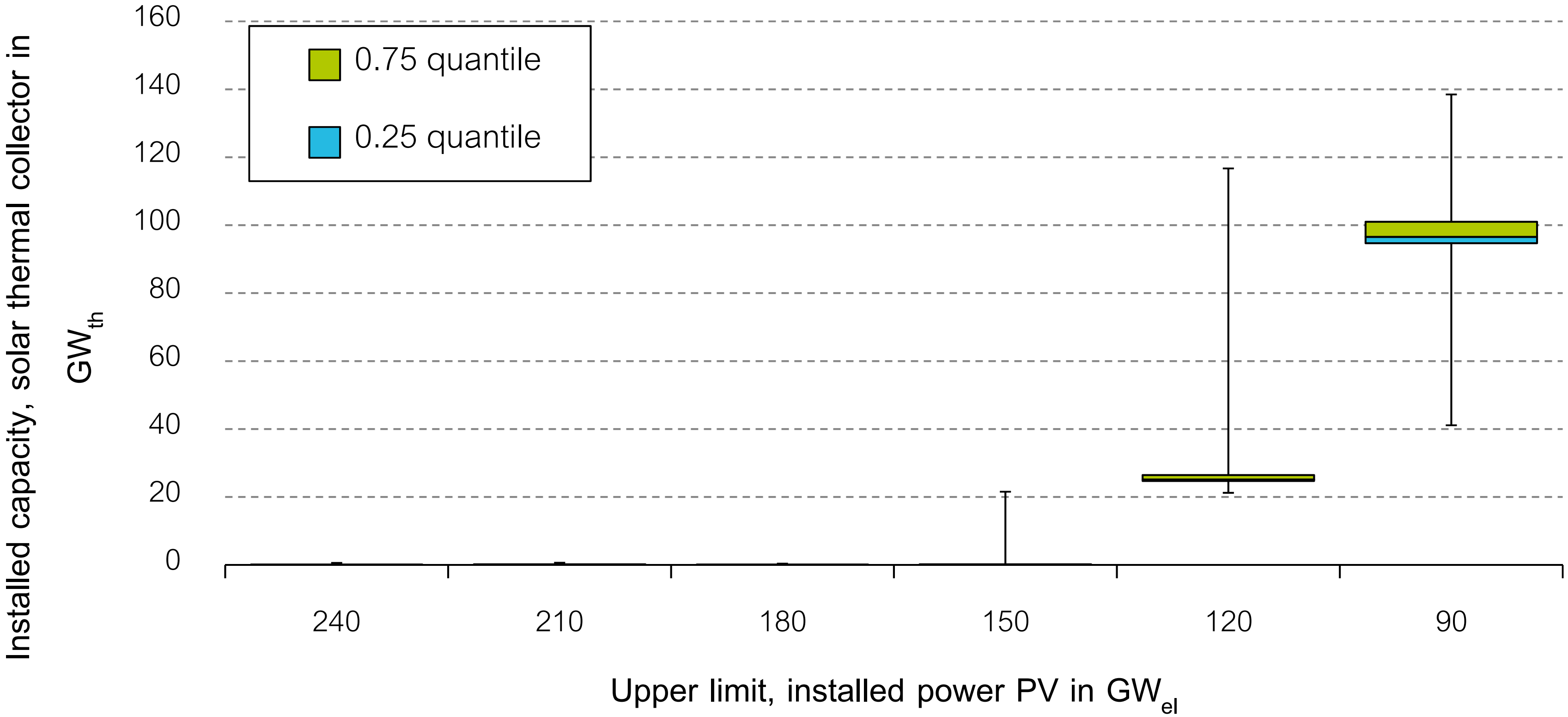
Conclusions from the calculations for a reference year

- Compared to the reference energy system, solar thermal applications gain in importance if
  - electricity from renewables is short (i.e. due to capacity restrictions)
  - future achievements in retrofitting of buildings are low (<30%)
  - investment costs for ST can be reduced notably (approx. 50%)
  - CO_2 emission reduction targets are high

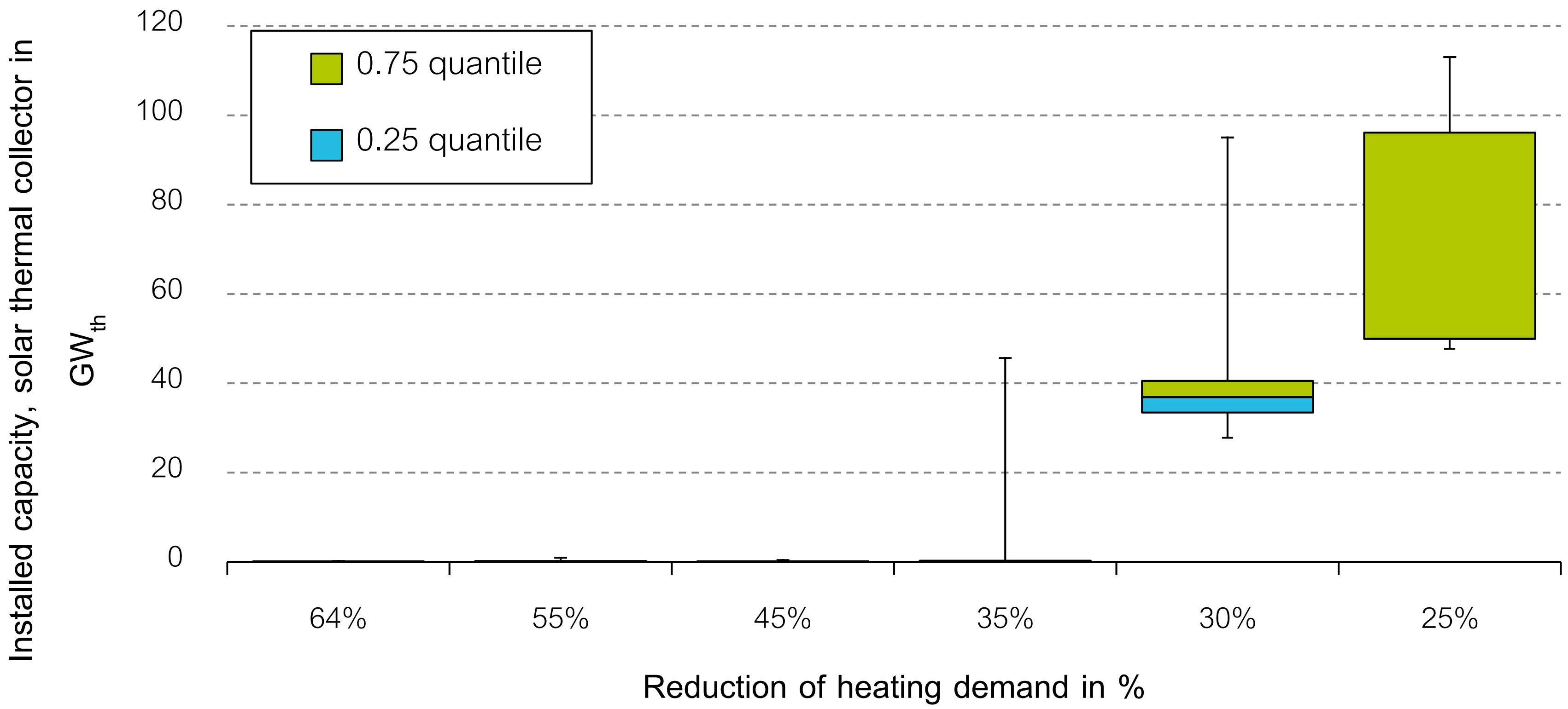
Conclusions from the calculations for the transformation pathway

- There is a difference in calculation single future years and the calculation of transformation pathways
  - Single year: no solar thermal collectors in the system without increasing the demands to the system (less PV, less energy retrofit, high CO2-reduction targets)
  - Transformation path: solar thermal collectors are part of the results during the whole path
- Explanation: due to high demands in the system in different years throughout the calculation (high amount of fossil fuels, different weather conditions, slow retrofit rate) solar thermal collectors become necessary from time to time
- Thus: 1. to reach a certain amount they need to be installed early enough, 2. once installed the collectors run in the system there total lifetime (approx. 20a)

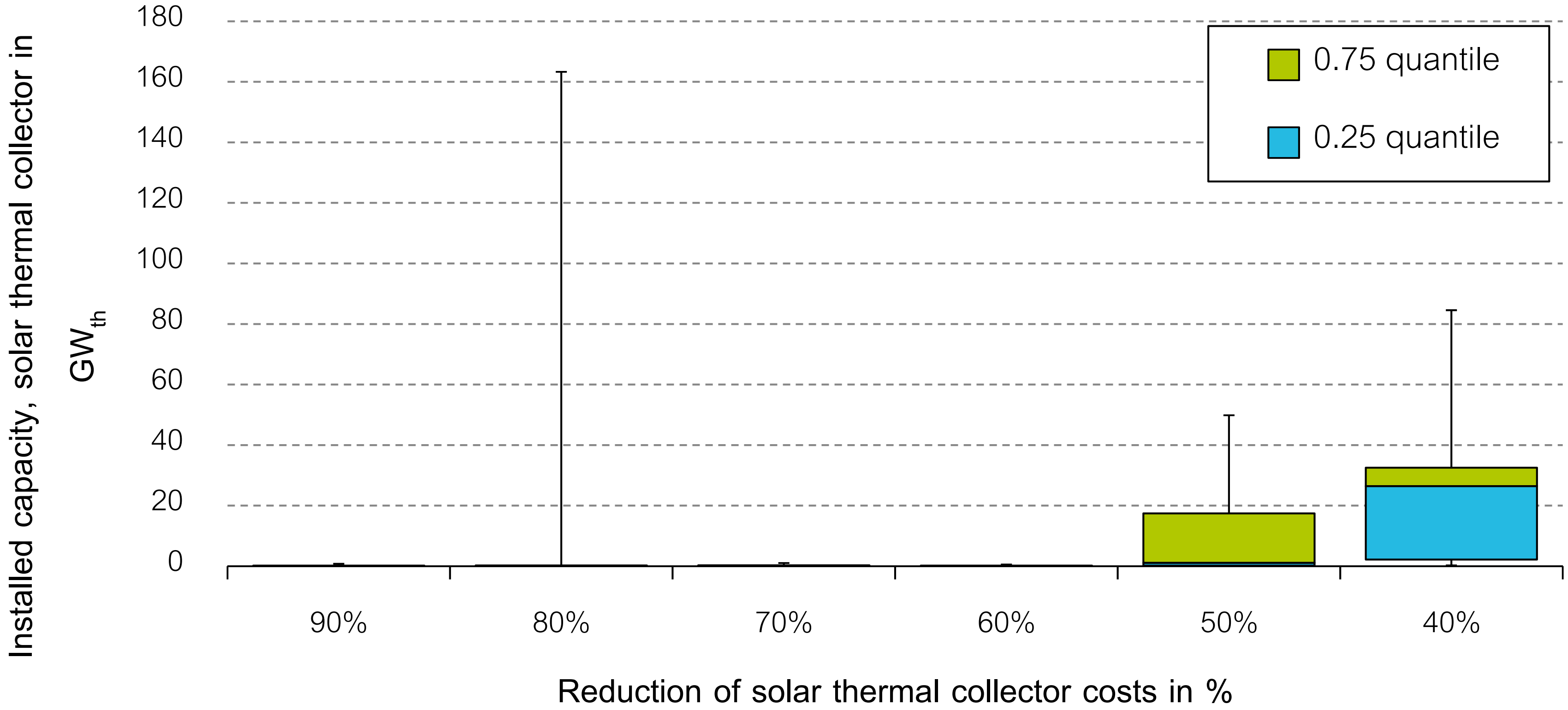
1) Influence of PV on the installed capacity of solar thermal collectors



2) Influence of energy retrofit for buildings on the installed capacity of solar thermal collectors

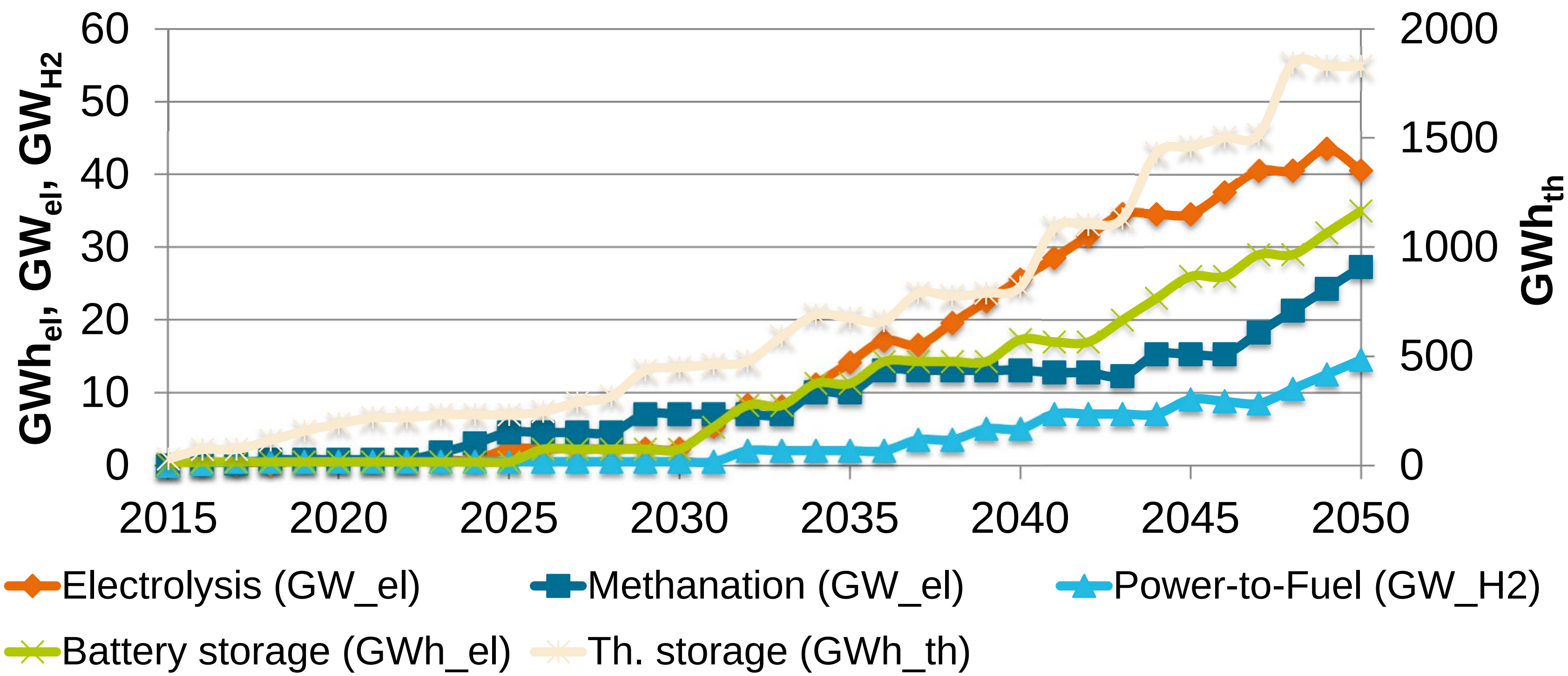


3) Influence of cost reduction on the capacity of solar thermal collectors



Initial cost assumptions (100 %): decentralized 400 €/m², centralized 290 €/m²

Development of power storage and converters of renewable energy into synthetic energy carriers



Source:

Palzer, Andreas (2016): Sektorübergreifende Modellierung und Optimierung eines zukünftigen deutschen Energiesystems unter Berücksichtigung von Energieeffizienzmaßnahmen im Gebäudesektor. (genehmigte) Dissertation. Karlsruher Institut für Technologie, Karlsruhe. Online verfügbar unter http://publica.fraunhofer.de/documents/N-408742.html.

Basics
REMod-D

Examples

Exogene parameters

CO_2-emissions ➔ available amount of fossil fuels

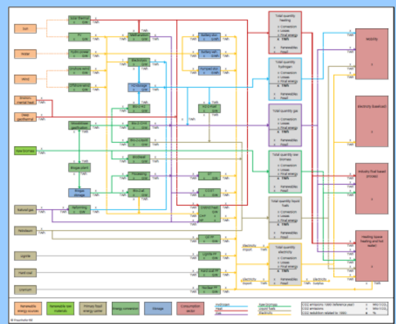
Demand for electricity (withouht demand for privat transport and heat)

Process heat

Capacity of conventional power plants

PSO Optimizer

(minimized total annual costs)



Examples results

Installed capacity of all components

Storage sizes

Degree of energy saving retrofit measures

Heating systems for four different building types

Composition of the mobility sector

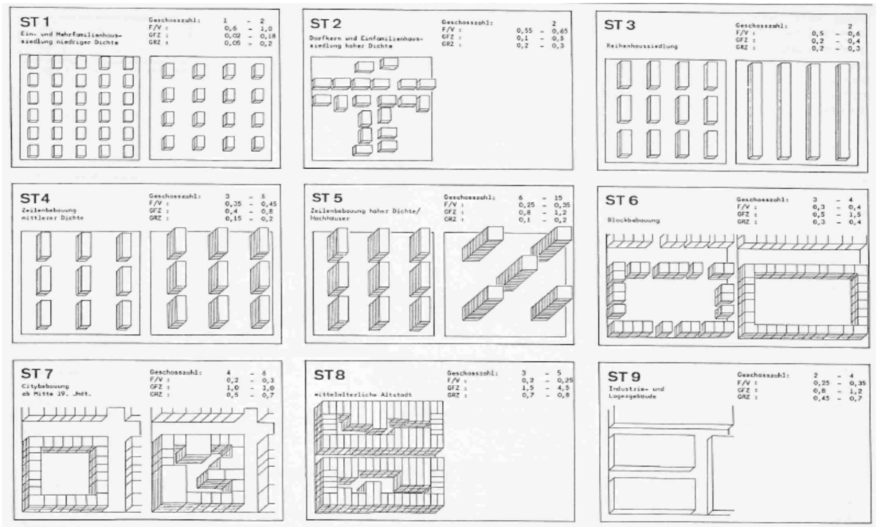
Andreas Palzer and Hans-Martin Henning: A comprehensive model for the German electricity and heat sector in a future energy system with a dominant contribution from

Renewable energy technologies—Part I & II, *Renewable and Sustainable Energy Reviews*, *Volume 30*, *February 2014*, *Pages 1003-1018, 1019-1034*

Basics

Settlement structure & building typology

Settlement structures based on Roth



Settlement structures based on Nast

Type	Definition
ST II	City suburbs, villages and small towns
ST IIIa	Urban cityscapes with medium density
ST IIIb	Dense urban cityscapes
ST IV	Industrial and manufacturing areas

Type	Definition	Heat load [kW]
SDFB	Single-/double family buildings	13.8
SMFB	Small multi-family buildings	34.5
LMFB	Large multi-family buildings	99.1
NRB	Non-residential buildings	45.7

Roth, U. und Häubi, F., "Wechselwirkungen zwischen der Siedlungsstruktur und Wärmeversorgungssystemen," Schweizer Ingenieur und Architekt, 1981

Nast, M., „Klimaschutzkonzept für das Saarland, Materialband 2 „Potenzial der Kraft-Wärme/Kälte-Kopplung und Nutzung regenerativer Energien", DLR, UBA, 1997

Derivation of the cost data

Specific costs of solar heat for the different build. types

- Methodology

Technical area potential of solar heat

Cost function for solar heat

Anticipated cost reduction by 2050

Building type	m²/ Building
SDFB	20.7
SMFB	31.8
LMFB	96.8
NRB	41.8

Kaltschmitt, M.; Erneuerbare Energienträger in Deutschland- Potentiale und kosten, Berlin: Springer-Verlag, 1993

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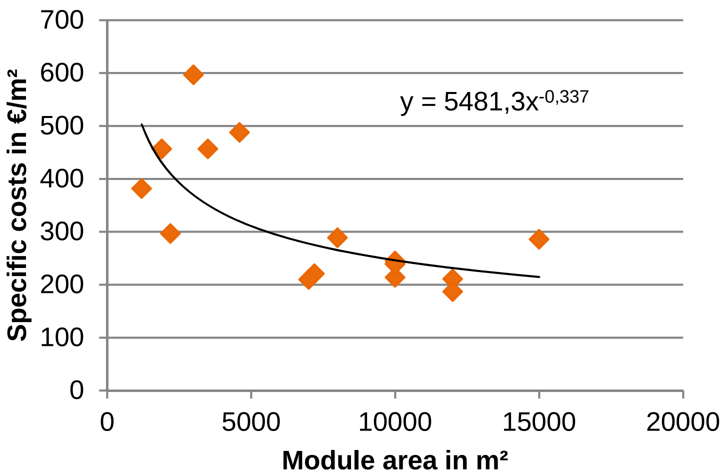
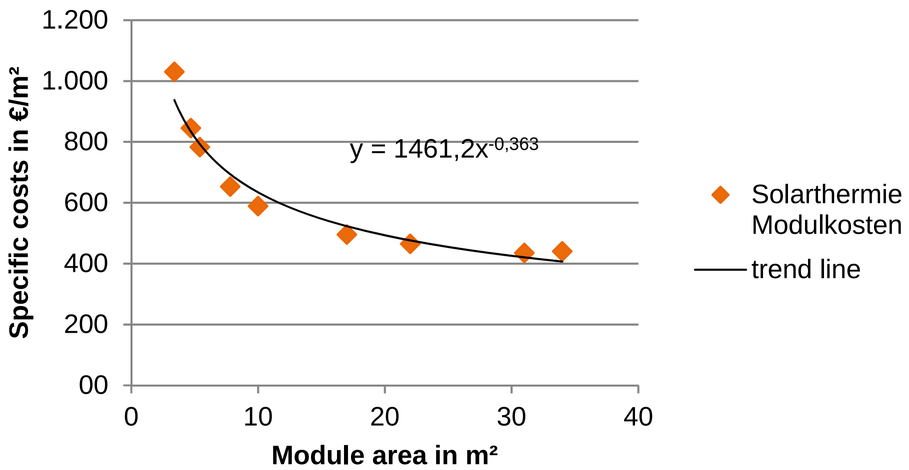
Centralized Solar heat



Decentralized solar heat



Kaltschmitt, M.; Erneuerbare Energien – Systemtechnik, Wirtschaftlichkeit, Umweltaspekte, Hamburg – TUHH, 2014

Mautner, F.; 2nd TM – Solar Heat % Energy Economics in Urban Environments, in Task 52 - AEE - Institute for Sustainable Technologies (AEE INTEC), Bern, 2014

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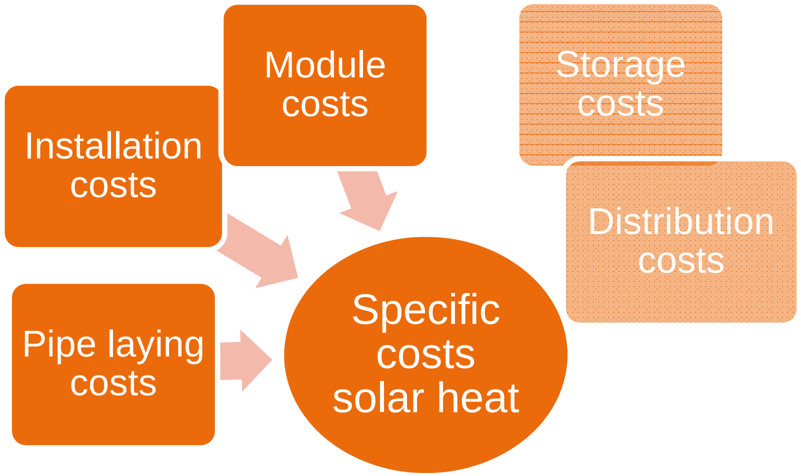
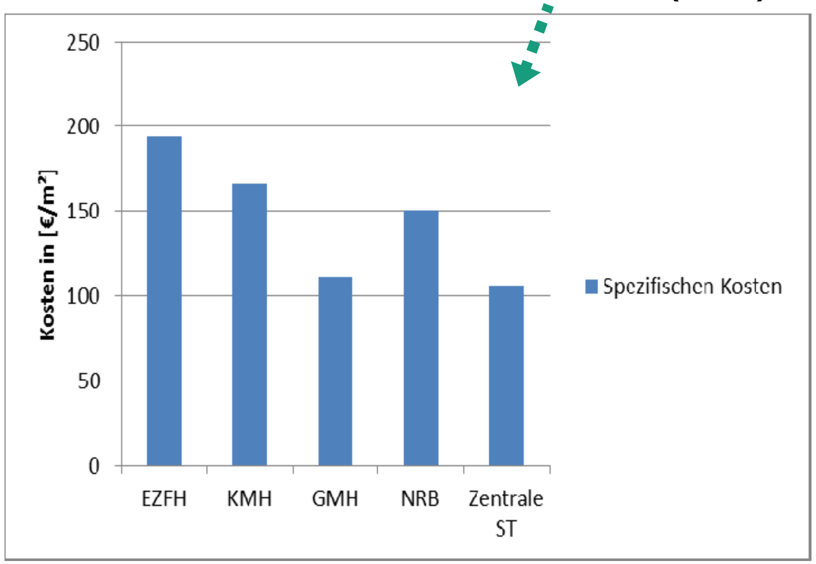


60 % reduction (IEA)

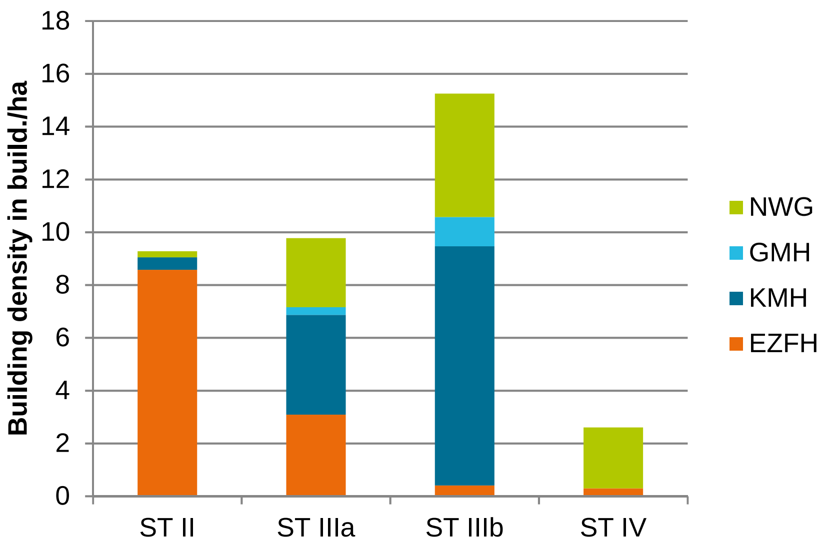


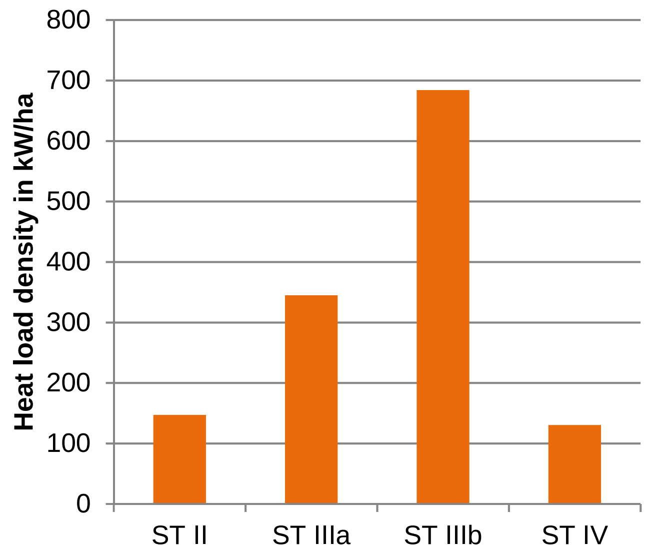
Derivation of the cost data

Specific costs district heating for settlement structures and building types

- Methodology

Heat densisty per ha	Pipeline length per ha	Grid costs	Costs for the heat transfer substation





Fischedick, M.; „Anforderungen an Nah- und Fernwärmenetze sowie Strategien für Marktakteure im Hinblick auf die Erreichung der Klimaschutzziele der Bundesregierung bis zum Jahr 2020, Endbericht", Umweltbundesamt, Stuttgart

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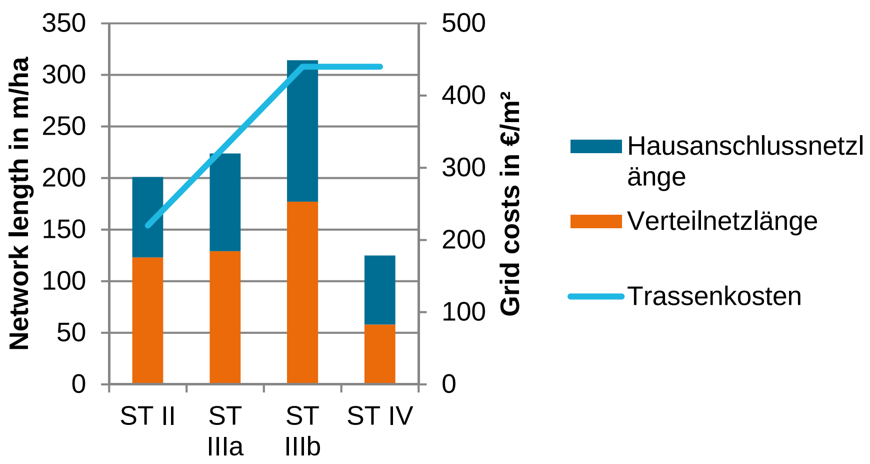

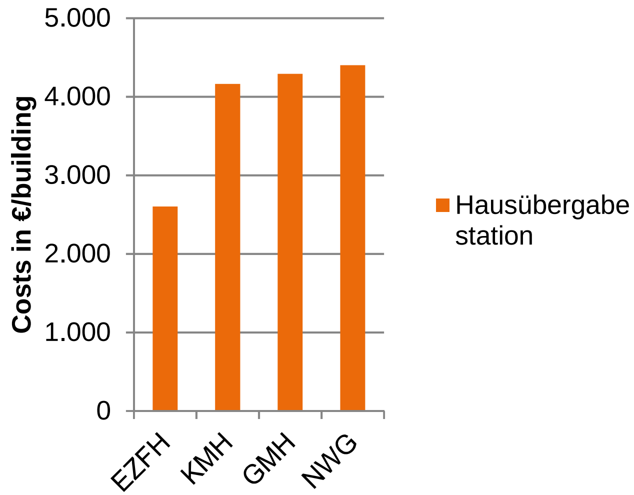

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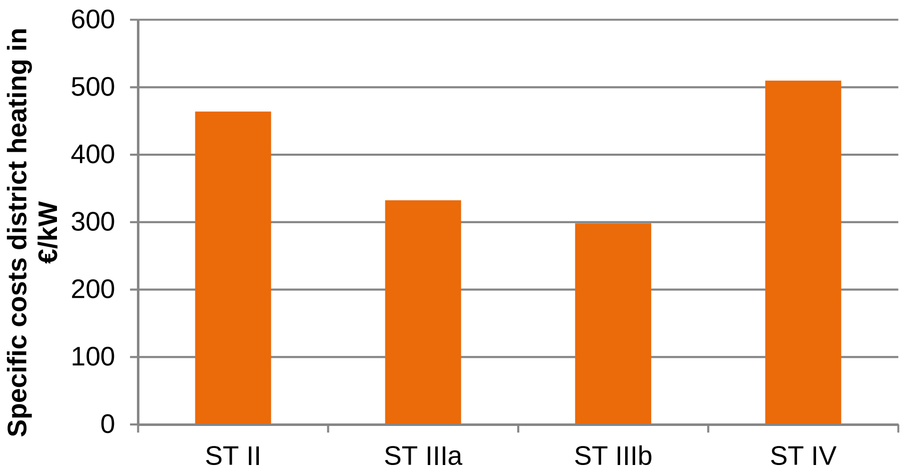

Assumptions and parameters for the model
„Base Case Scenario“

Specified parameters

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Process heating 445 TWh/a

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Composition of the mobility sector set

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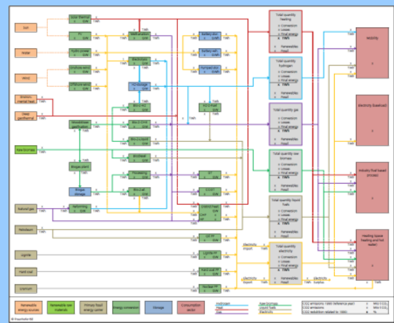


Free parameters: building energy retrofit, heat supply, CHP, Methanation, …

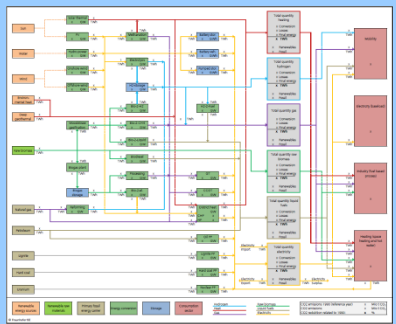
Modelling results

Analysis of the base case

PSO Optimizer

(minimized total annual costs)

197 Billion €



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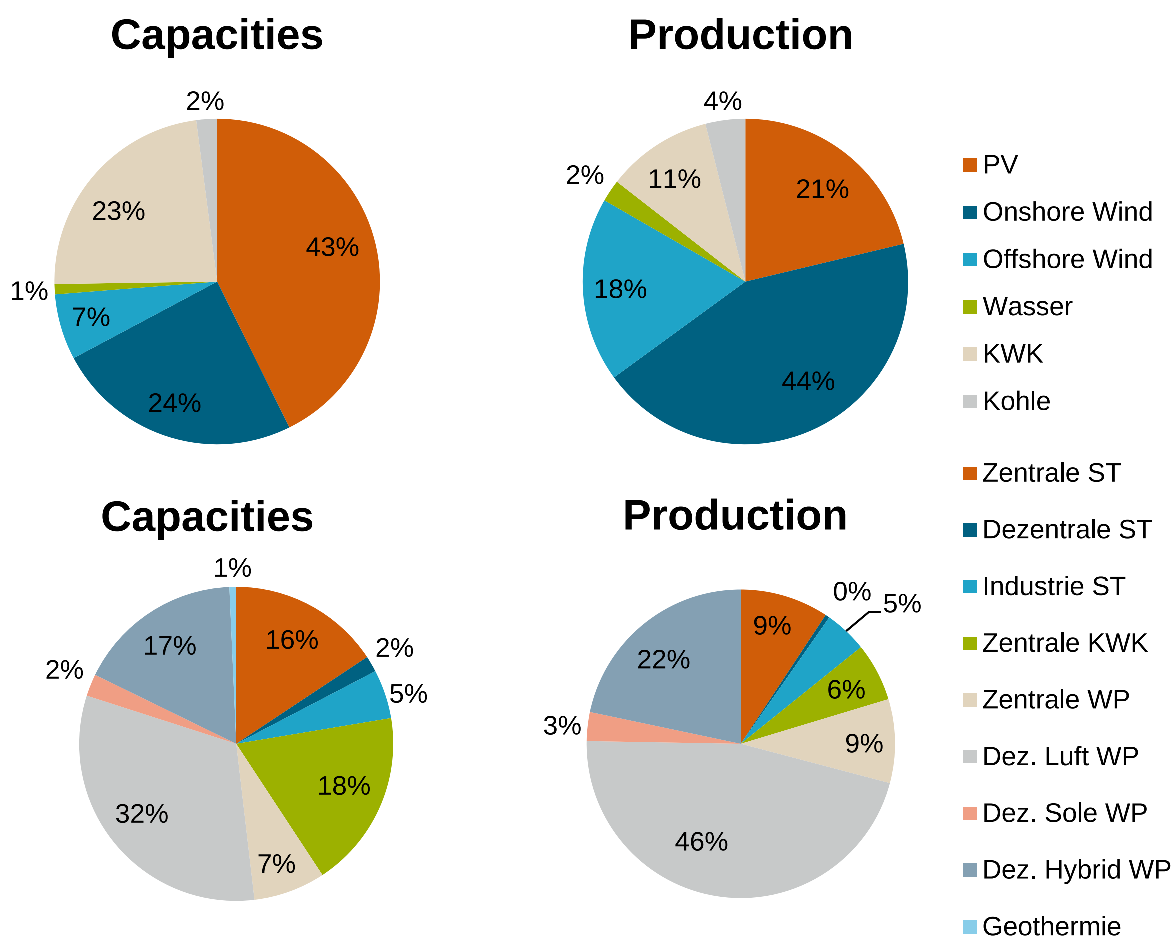
Final energy demand	~ 1,800 TWh/a	~ 2,500 TWh/a
Electricity production	~ 960 TWh/a	~ 516 TWh/a
Heat production	~ 1050 TWh/a	~1,400 TWh/a

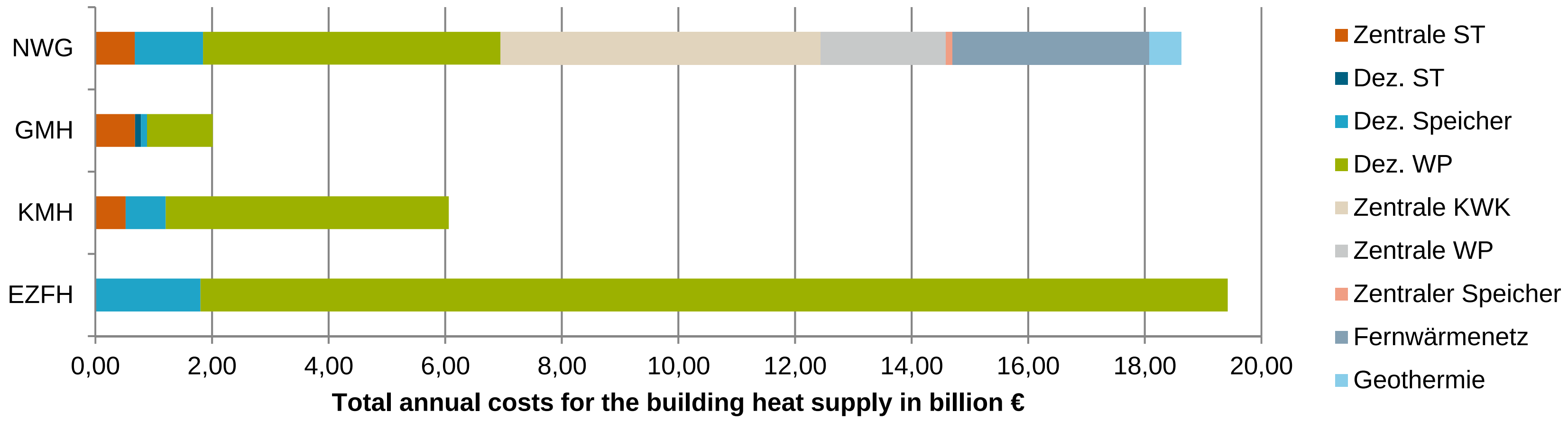
Modelling results

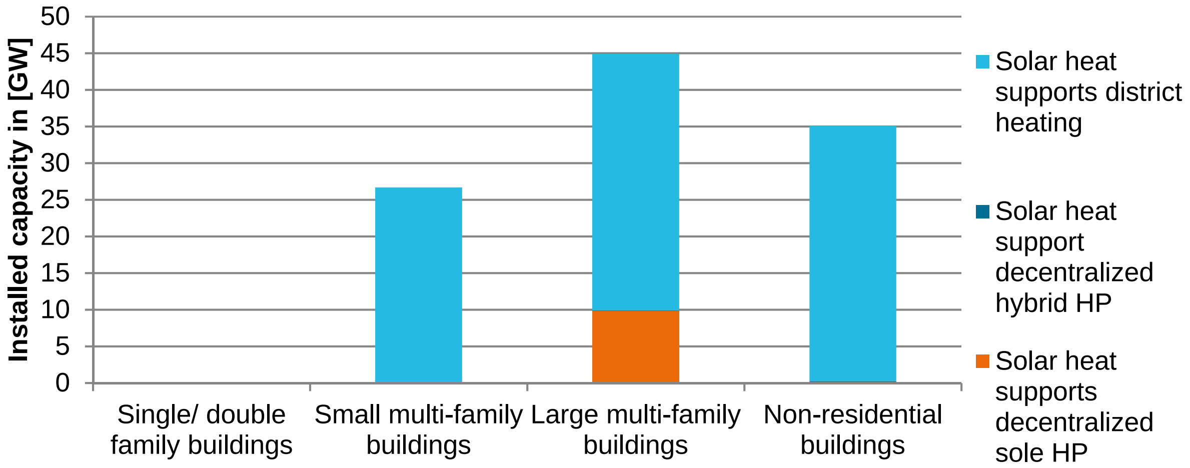
Composition of the components „Base Case“

- Electricity production
  - 960 TWh
  - 85% by FRE
  - 30% for heat
- Heat production
  - 1,050 TWh
  - 80% by FRE
  - 75% by HP



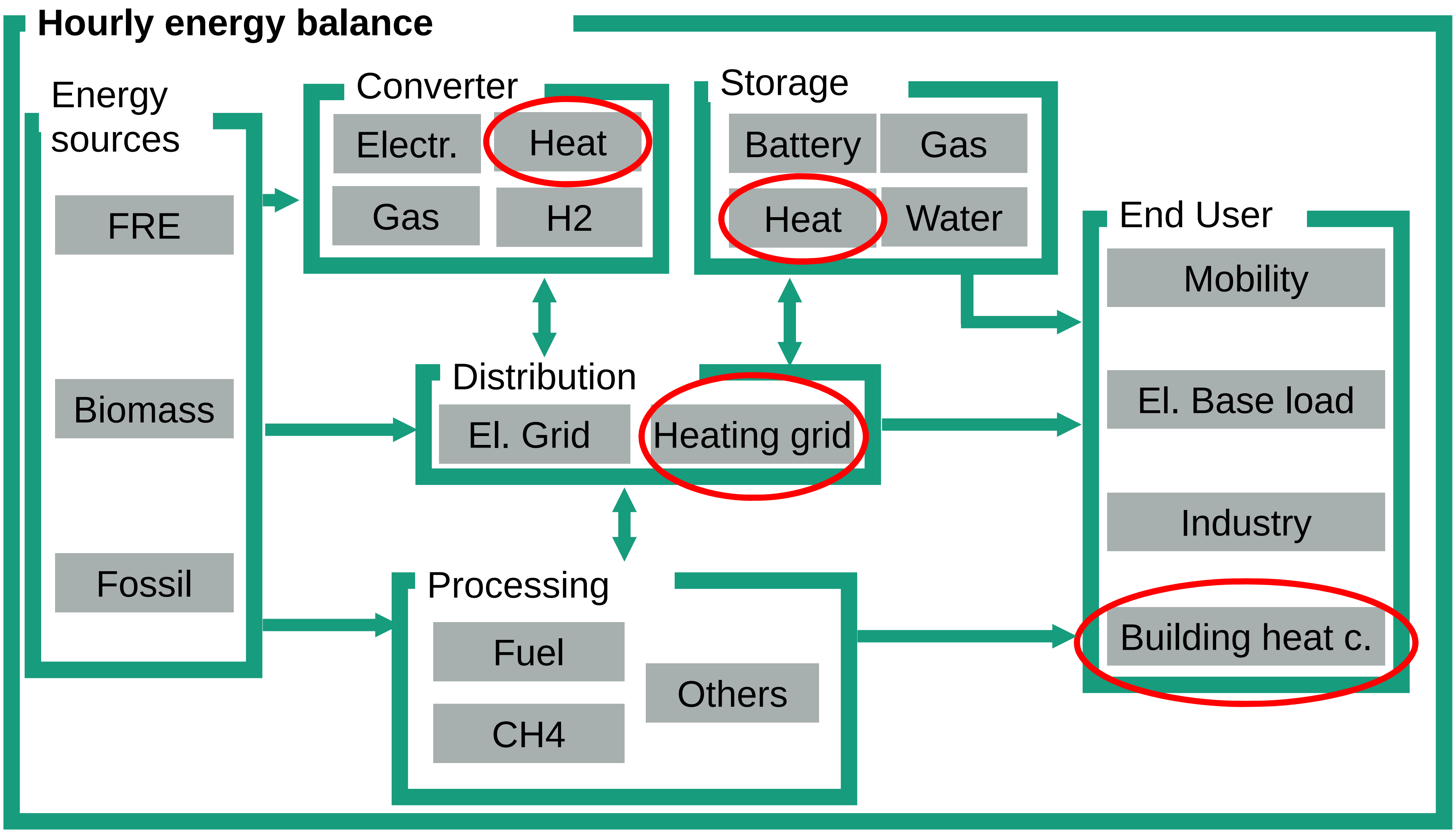
Modelling results
Building heat supply





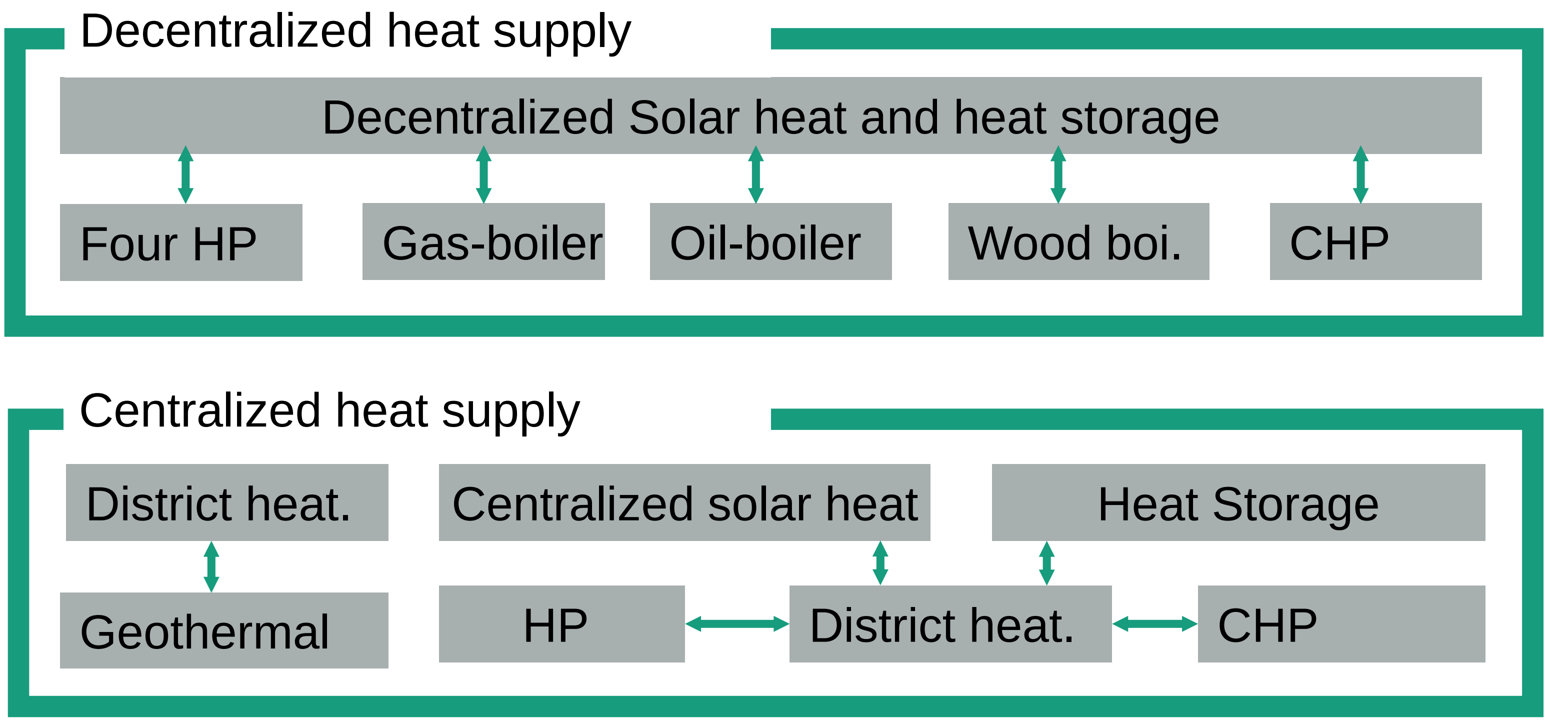
Basics

REMod-D overall system



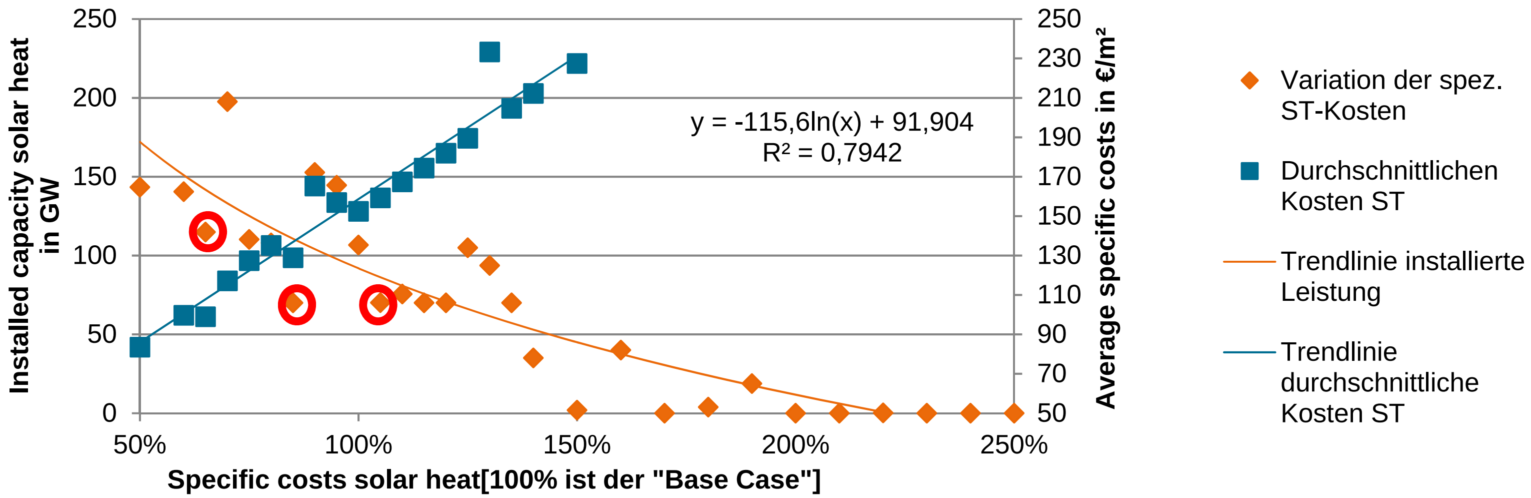
Basics
REMod-D Building heat supply

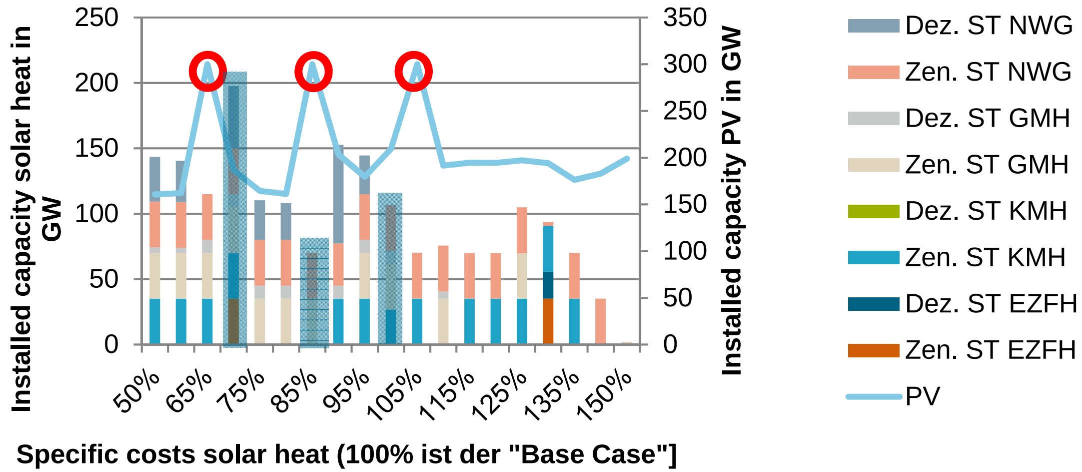
- For building types
- Low- and high temperature systems (35 °C / 65 °C)



Sensitivity analysis

Specific costs solar heat



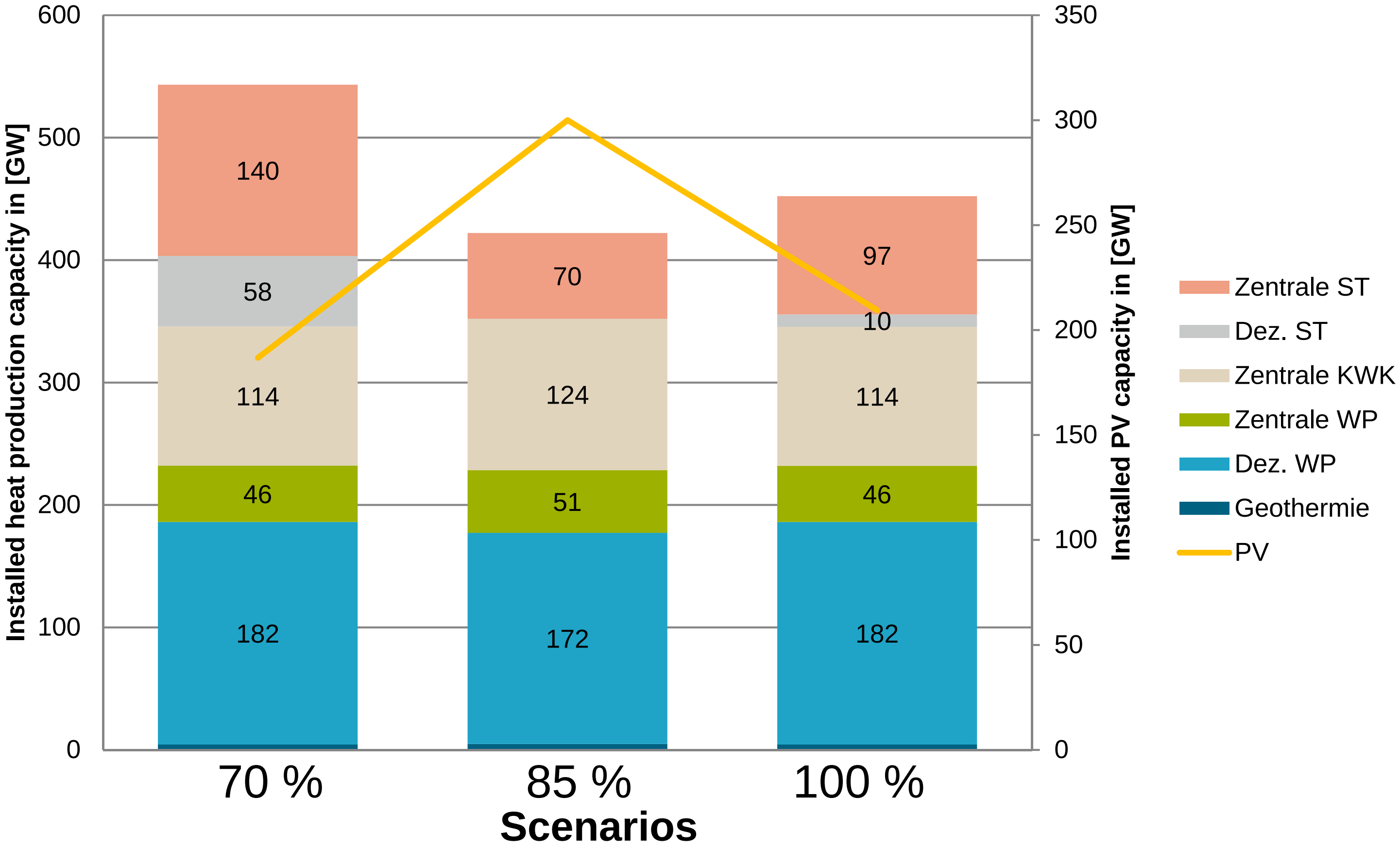


Specific costs solar heat in base case (100%):

106 – 195 €/m²

(w/o storage)

Sensitivity analysis
Comparison of different results I



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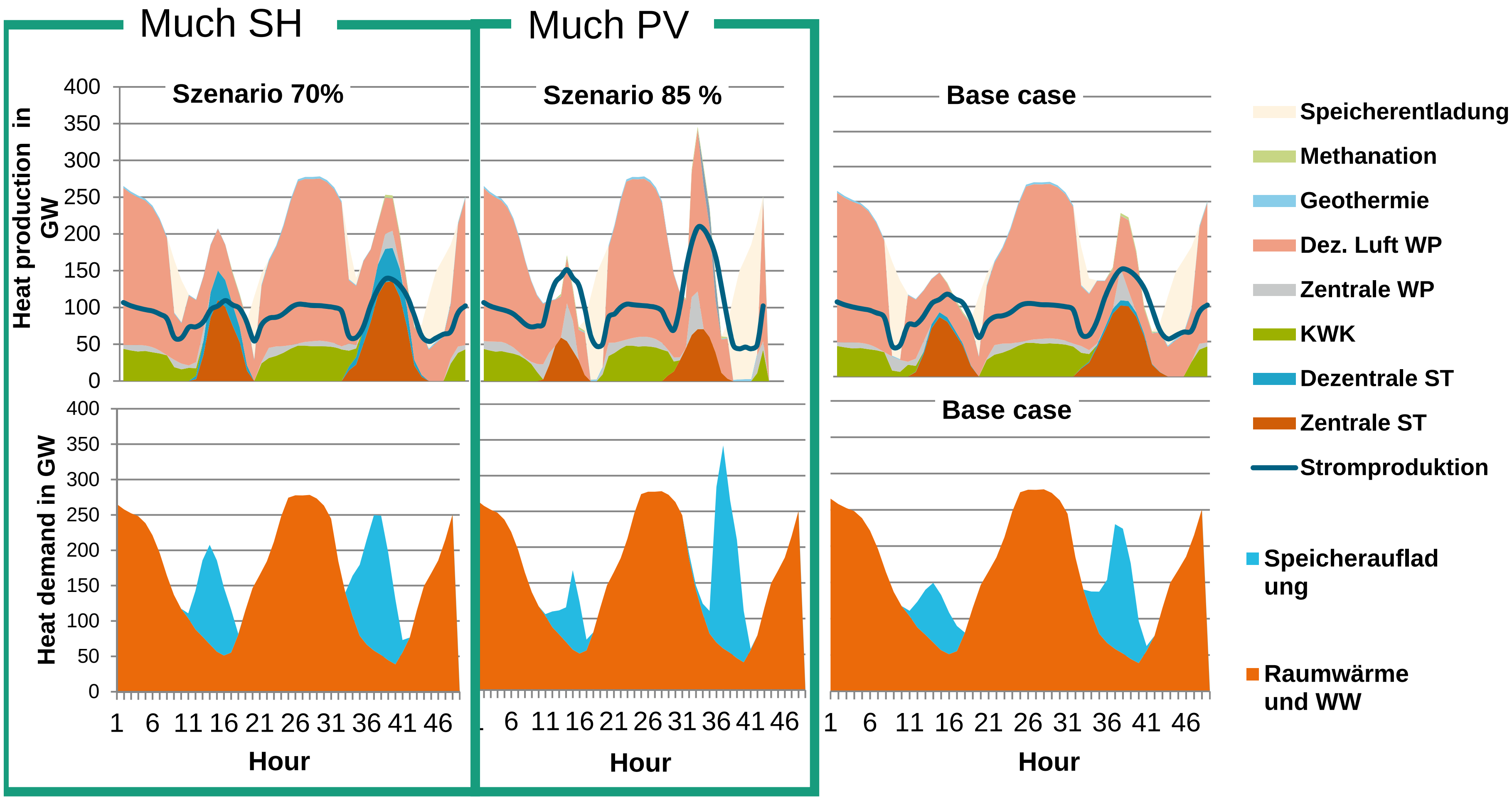
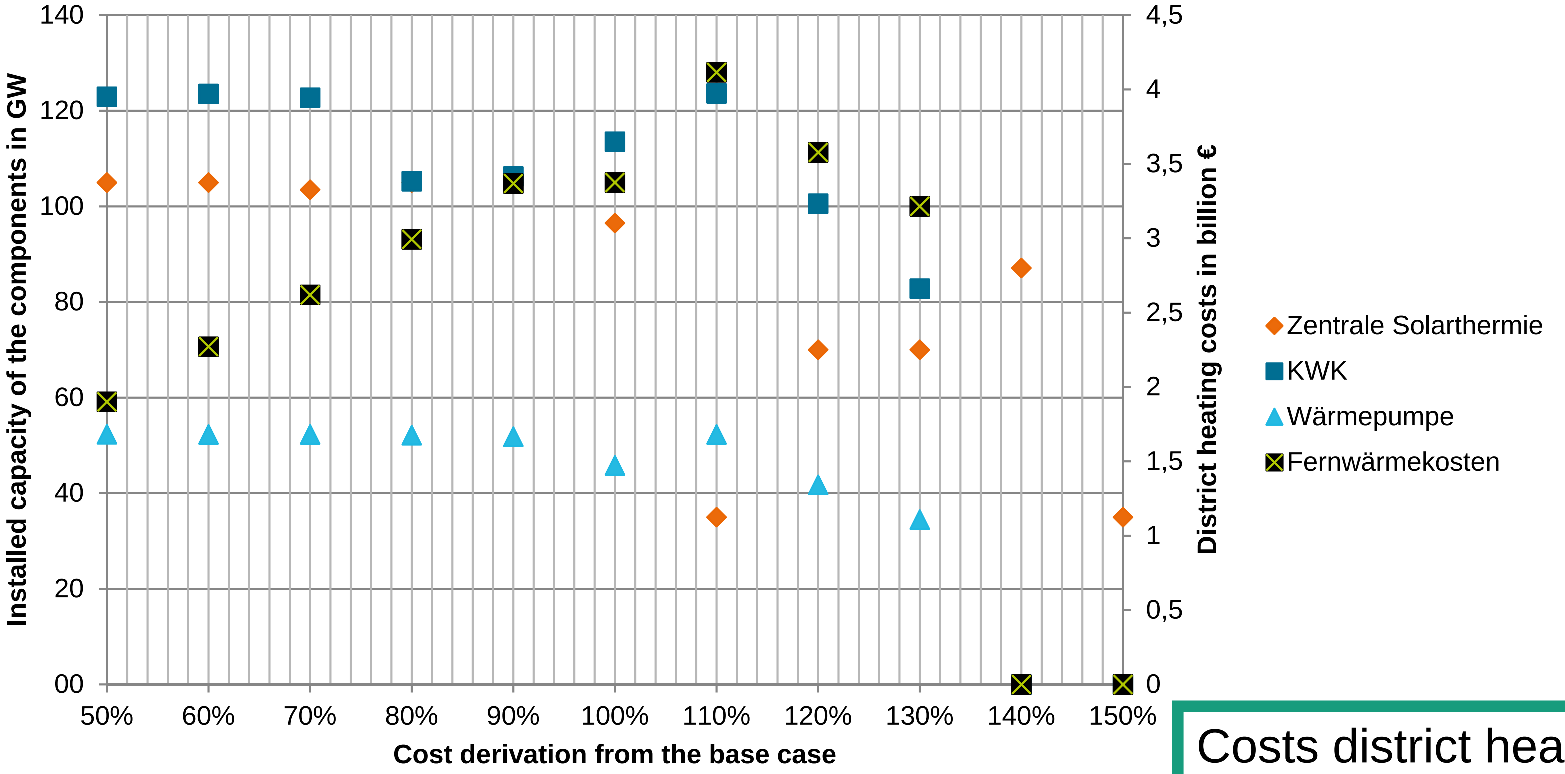
Sensitivity analysis
Comparison of different results II



Sensitivity analysis
Specific costs district heating

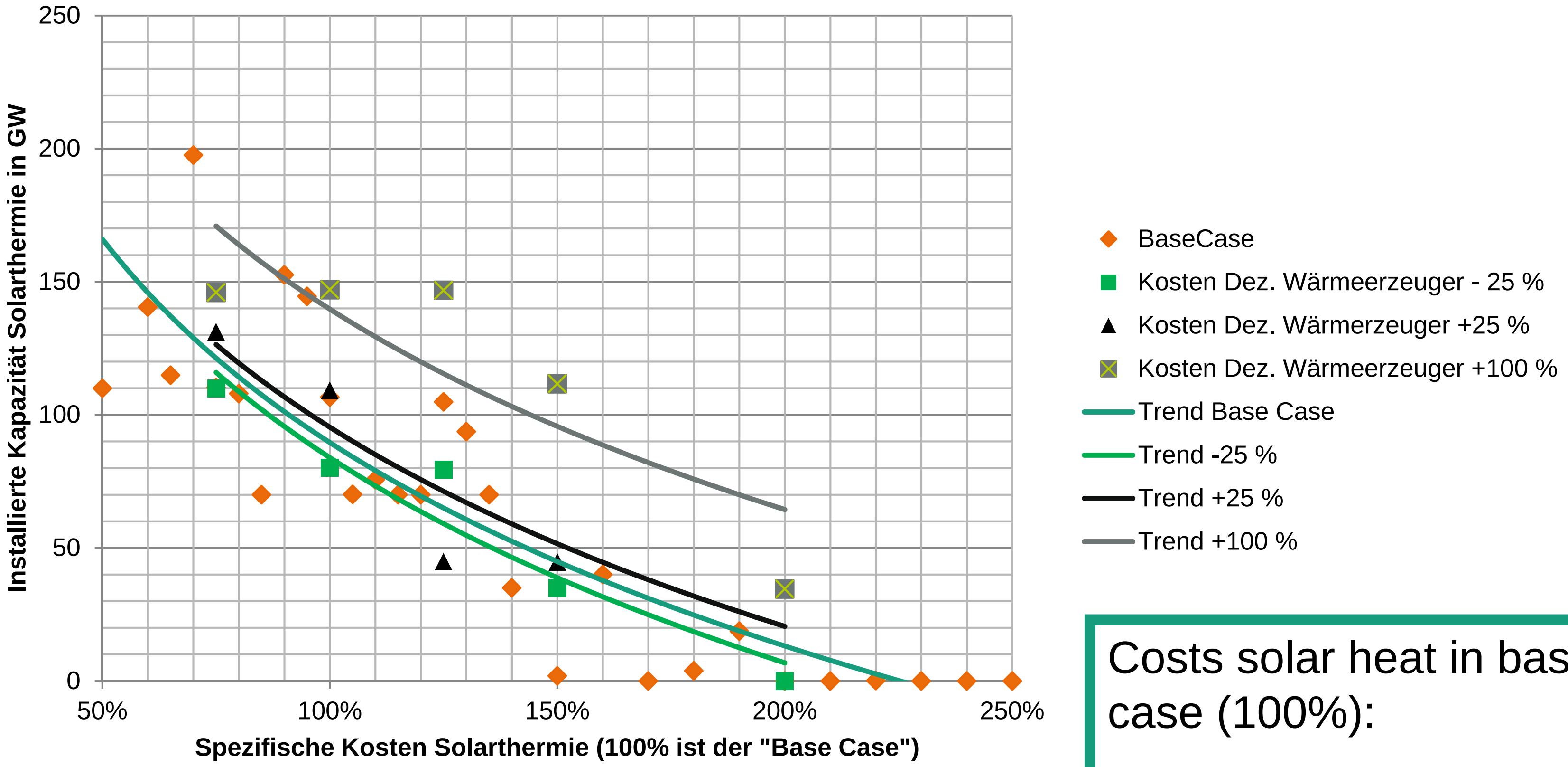


Costs district heating in base case (100%):

298 – 510 €/kW

Sensitivity analysis

Influence of the specific costs for decentralized heat suppliers



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106 – 195 €/m²

Summary and Outlook

- Results are highly dependent on the chosen boundary conditions and input parameters
- Limitations of the study
  - Cost reduction by 60 % for solar heat (IEA) is subject to a high uncertainty
  - Rough generalization for non-residential buildings
  - Estimations of the componentes varies significantly in different studies
  - No implementation of the costs for land and property for centralized solar heat
  - Classification of the building types to the settlement structures was derived in the model

Summary and Outlook

- Shallow solution space shows the scope of action for the development of the energy system
- Potential of solar heat shows a high correlation to the potential of PV and HP
- Centralized solar heat is more economic than decentralized solar heat
- Bigger buildings show a higher potential for decentralized solar heat
- The potential of solar heat varies between the different settlement structures
  - Highest potential for areas with dense urban city scapes as well as industrial and manufacturing areas
  - Urban cityscapes with medium density has the highest dependency on the cost development of solar heat
  - City suburbs, villages and small towns have a comparable lower potential (may change when integrating land and property costs!)

Summary and Outlook

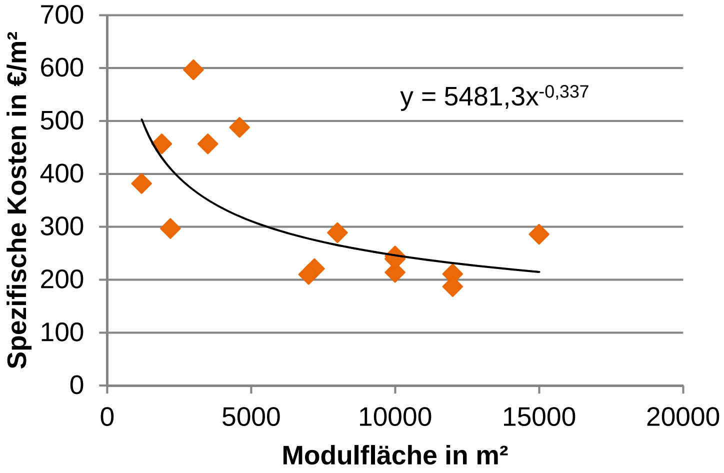
- Future Tasks
  - Maximum capacity for centralized solar heat for each settlement structure
  - Determine the impact of photovoltaic on the potential of solar heat
  - Determine the influence of the energy building retrofitting on the potential of solar heat

Herleitung der Kostendaten
Spezifische Kosten Solarthermie für Gebäudetypen

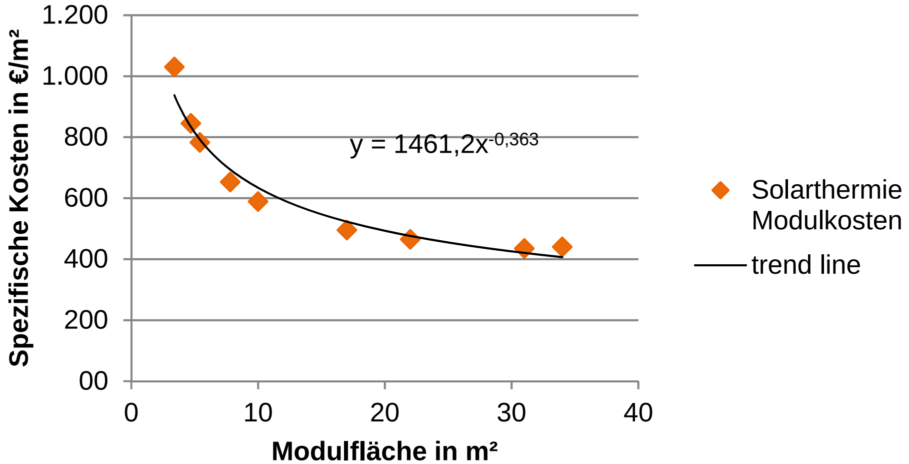
- Methodik

Technisch verfügbare Dachfläche je Gebäudetyp	Kostenfunktion für Solarthermie	Erwartete Kostenreduktion 2050

Zentrale Solarthermie



Dezentrale Solarthermie

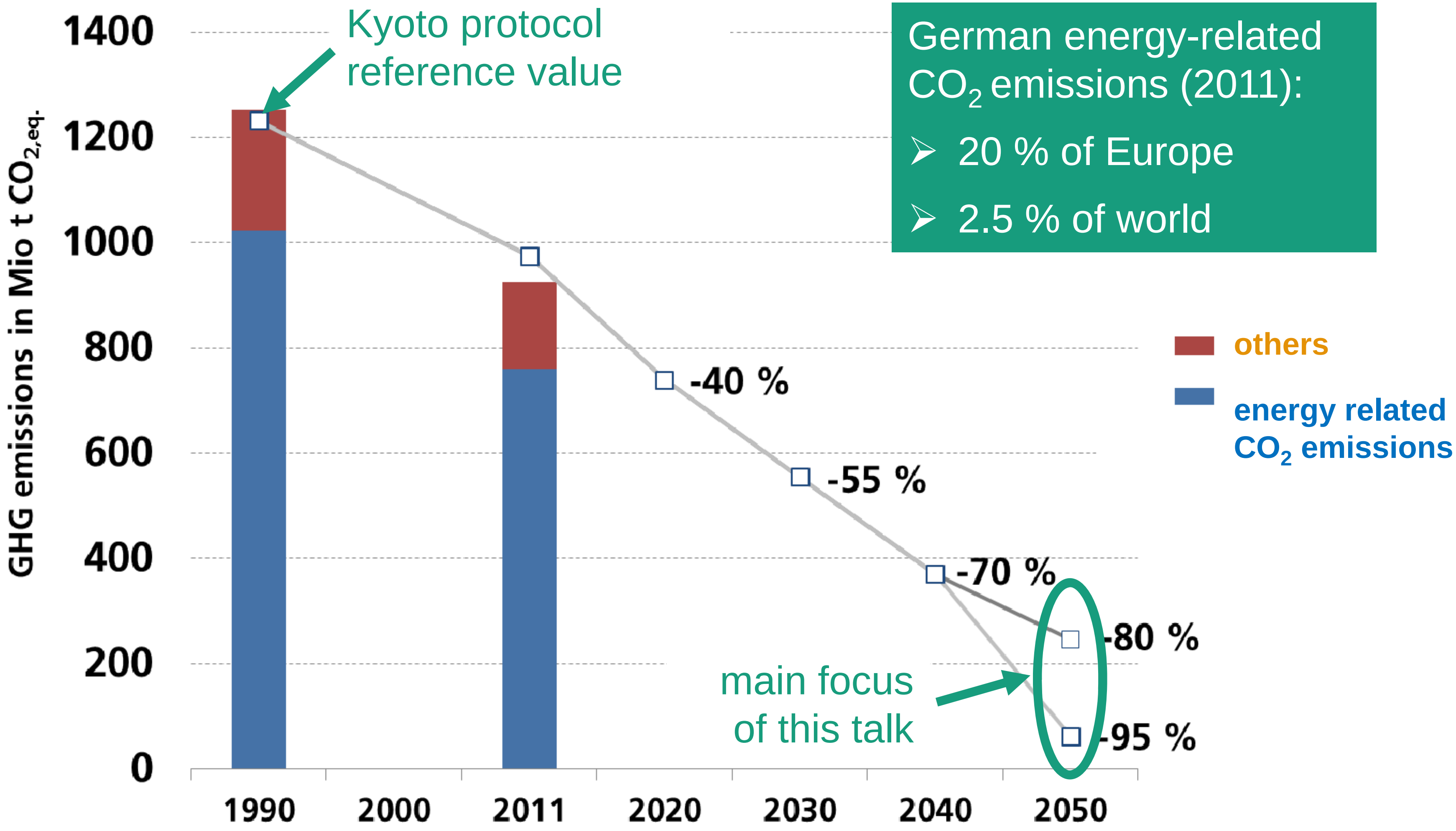


Kaltschmitt, M.; Erneuerbare Energien – Systemtechnik, Wirtschaftlichkeit, Umweltaspekte, Hamburg – TUHH, 2014

Mautner, F.; 2nd TM – Solar Heat % Energy Economics in Urban Environments, in Task 52 - AEE - Institute for Sustainable Technologies (AEE INTEC), Bern, 2014

Task 52 Solar Heat and Energy Economics in Urban Environments

German greenhouse gas emissions – history and targets



German energy-related CO_2 emissions (2011):

- 20 % of Europe
- 2.5 % of world

Model-approach optimization
A steady state energy system

Exogenous parameters

CO_2-emissions ➔ available amount of fossil fuels

Electricity demand (w/o electricity for privat transport and heat)

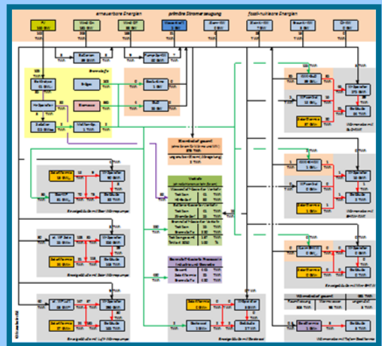
Process heat
Industrial processes

Energy mobility sector

Energy from biomass
335 TWh

Cap. conv. power plants

Optimizer
Optimizing Power-Heat-System
(Minimizing annual total Cost)



Results

Installed Capacity of all components

Storage size

Degree of energy saving retrofit measures

Heating technologies for the building sector (small, medium and large scale)

Andreas Palzer and Hans-Martin Henning: A comprehensive model for the German electricity and heat sector in a future energy system with a dominant contribution from Renewable energy technologies—Part I & II, *Renewable and Sustainable Energy Reviews, Volume 30, February 2014*, Pages 1003-1018, 1019-1034

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Solar Heat and Energy Economics
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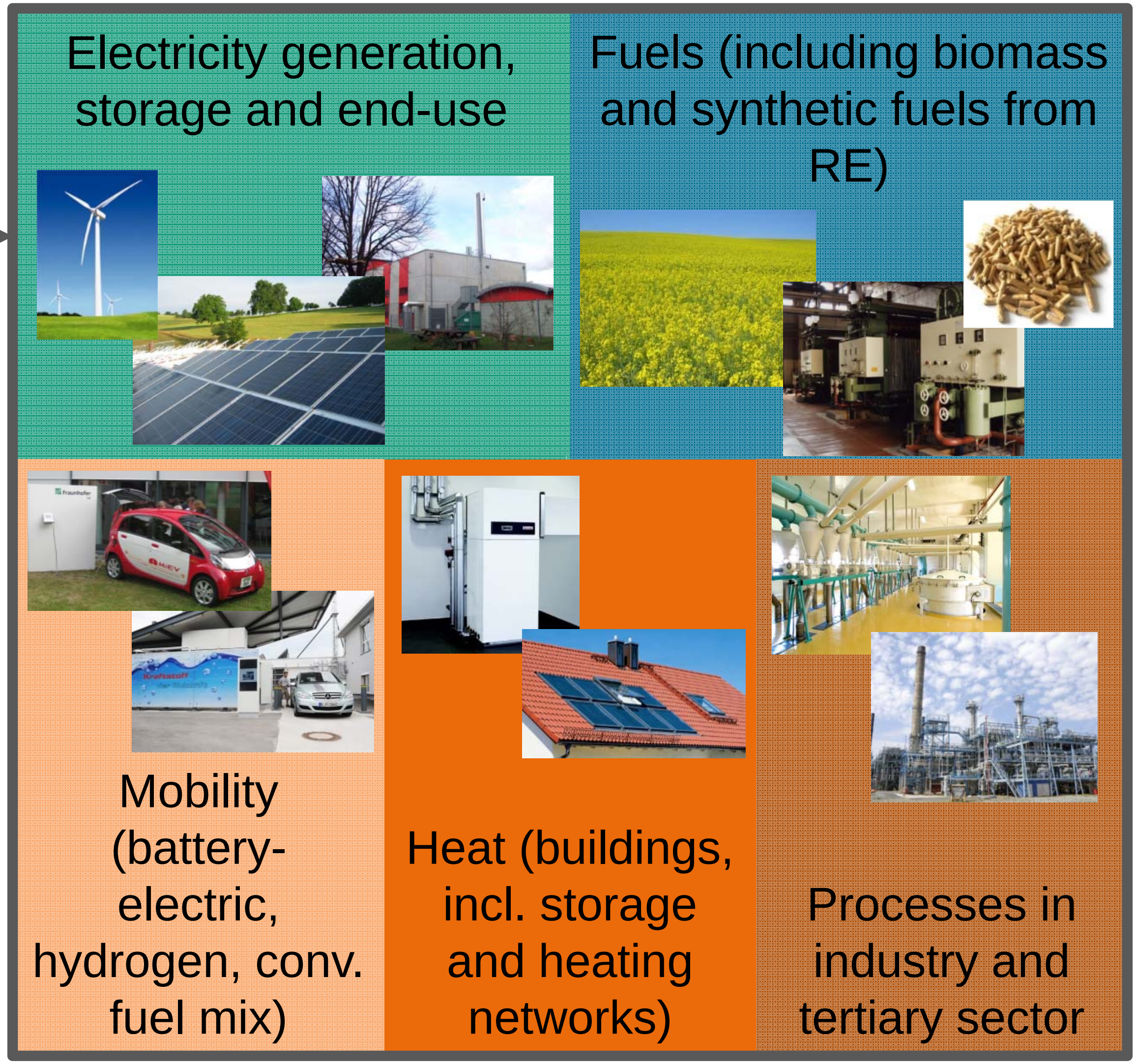
Optimization of Germany's future energy system based on hourly modeling

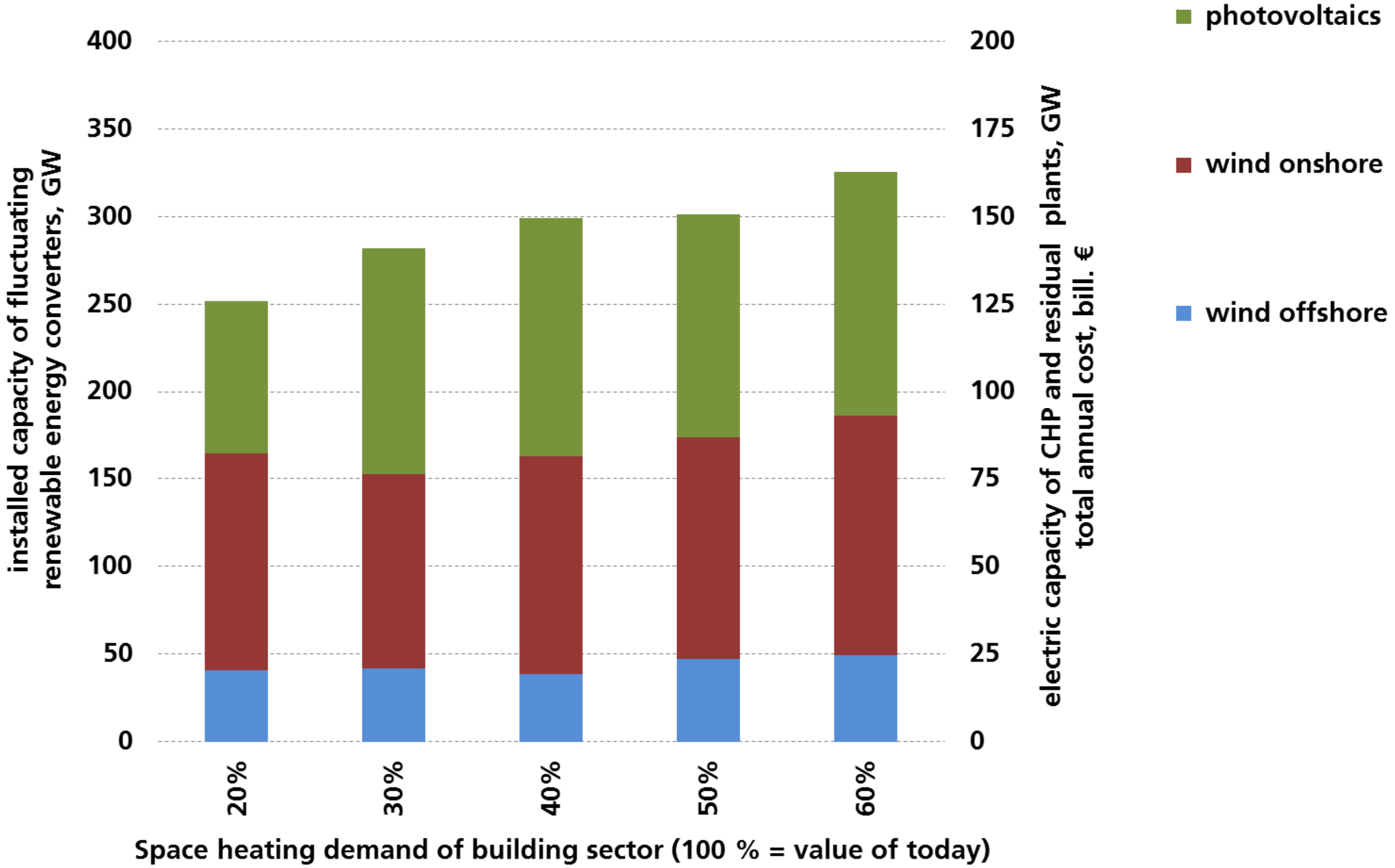
Comprehensive analysis of the overall system



REMod-D

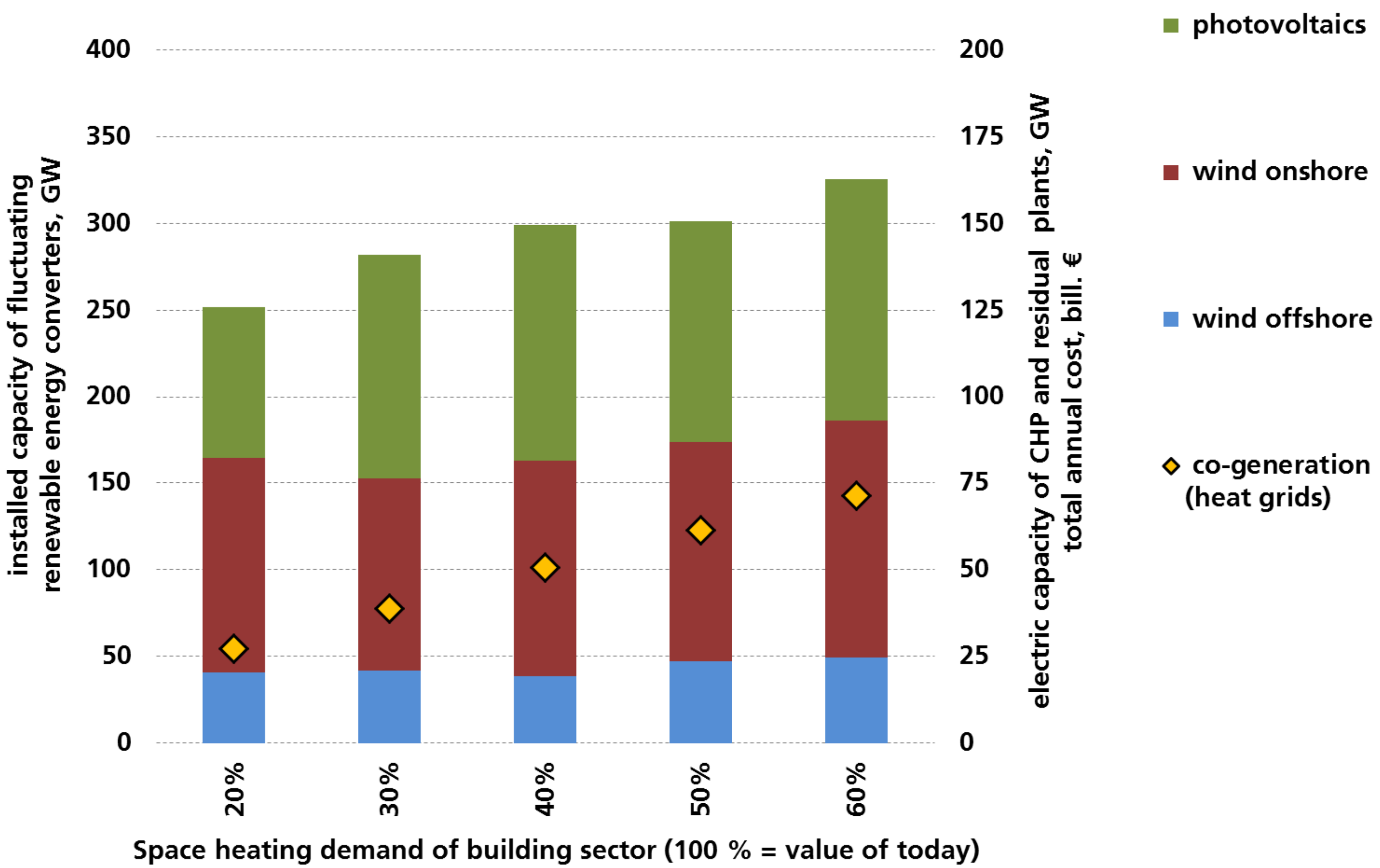
Renewable Energy Model – Deutschland

Fluctuating renewable energy sources
Installed capacity in GW_{el}



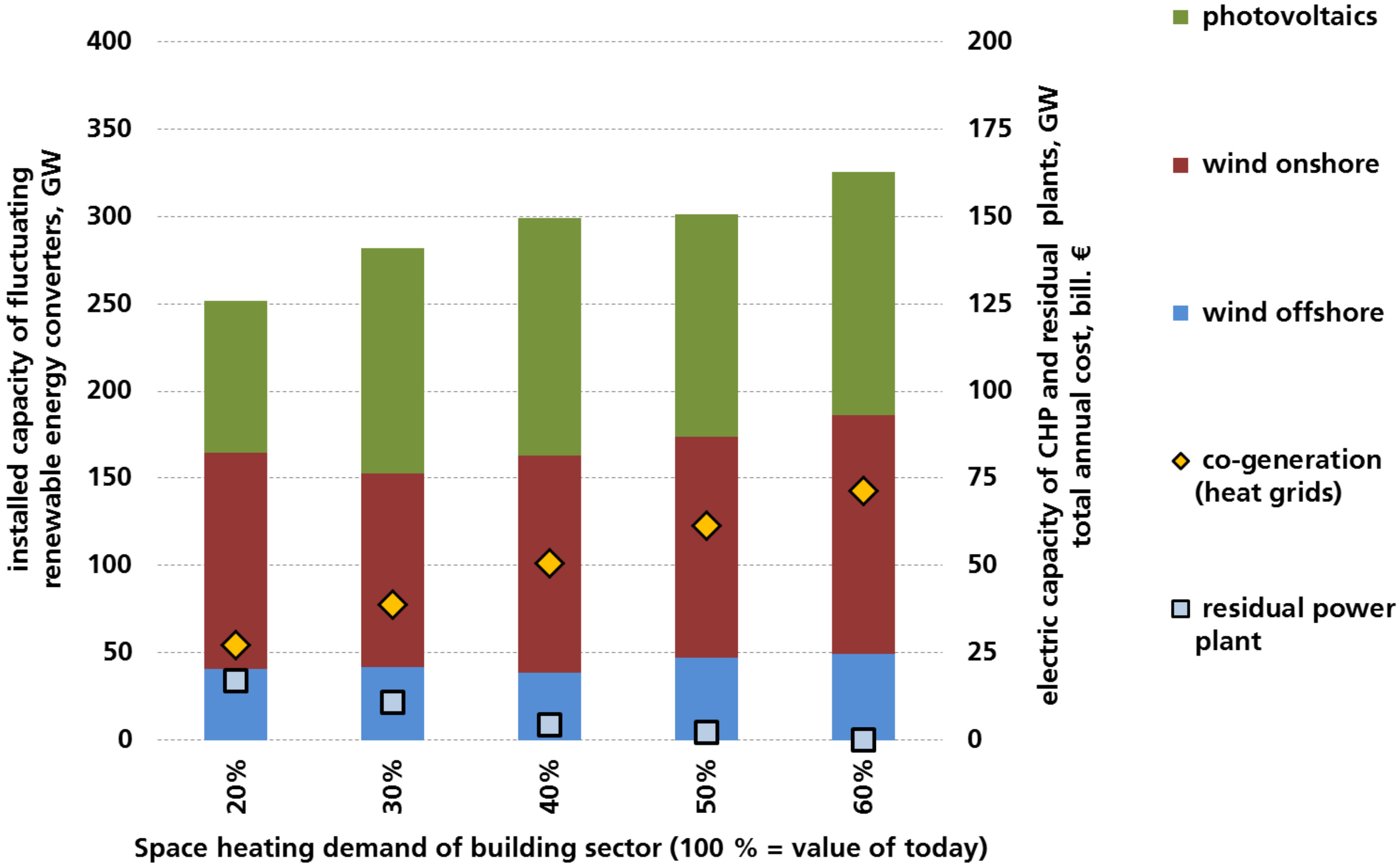
Medium and large scale CHP systems (district heating)

Installed capacity in GW_{el}

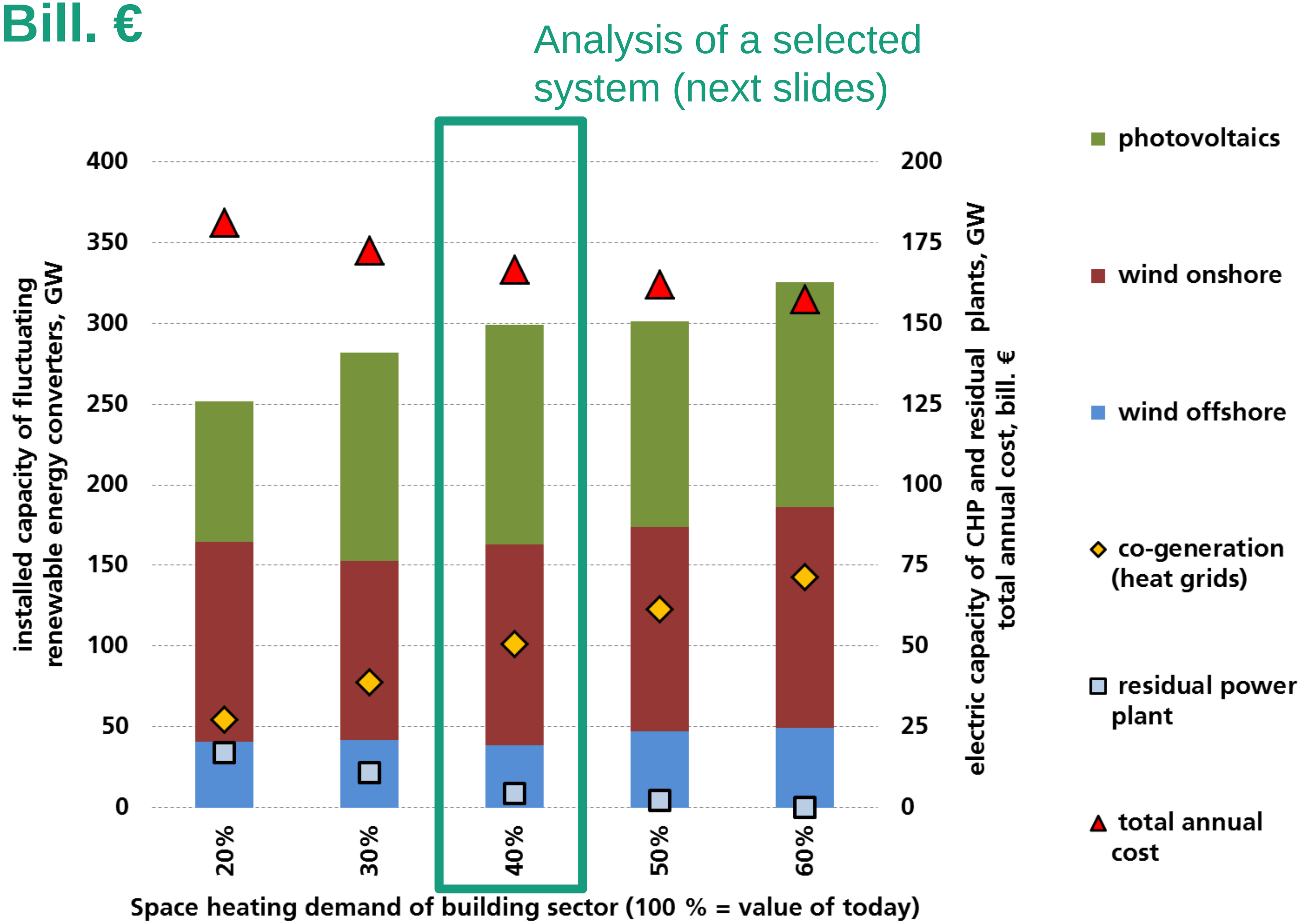


Backup power plants

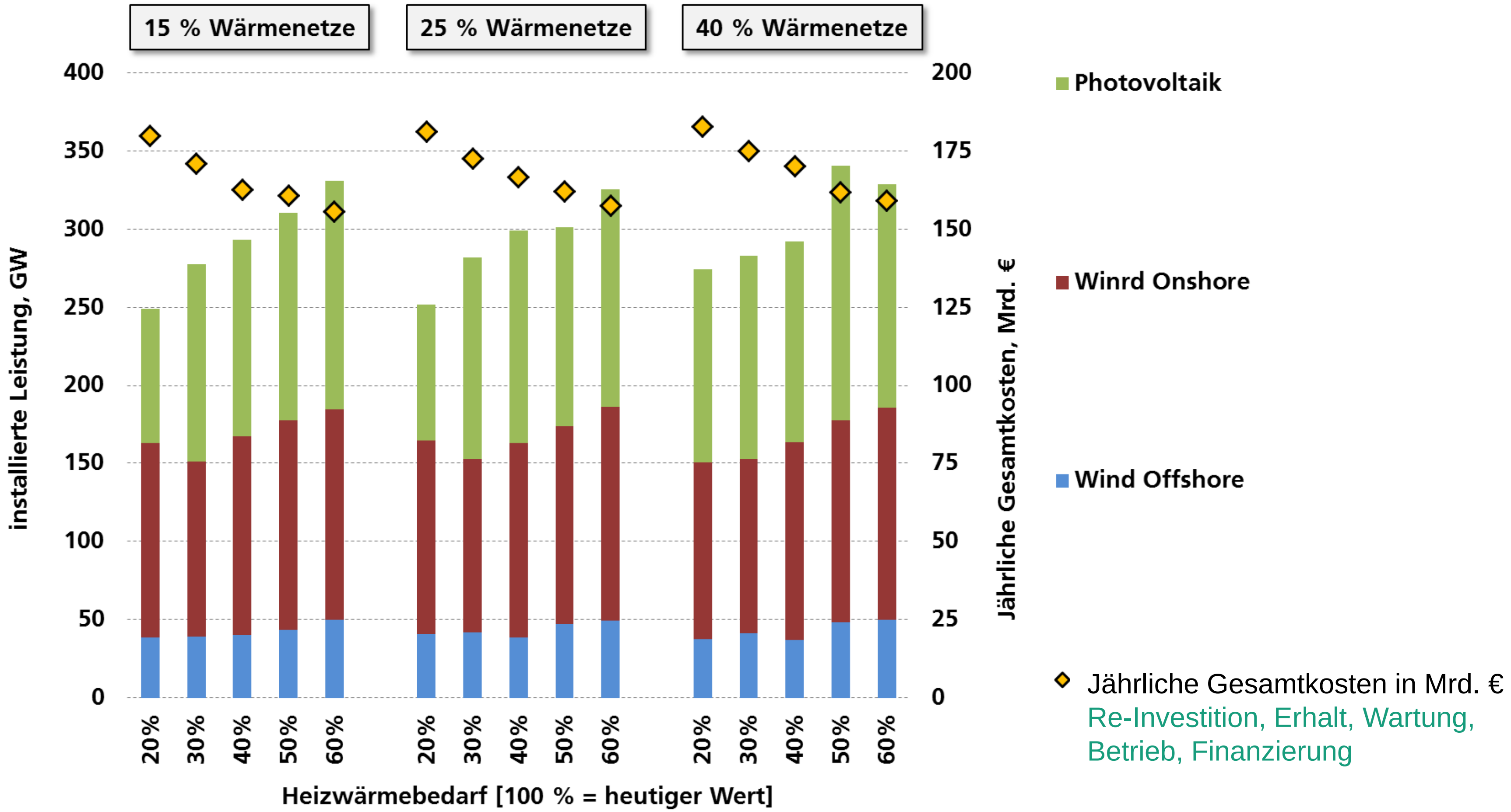
Installed capacity in GW_{el}



Total annual cost
Bill. €

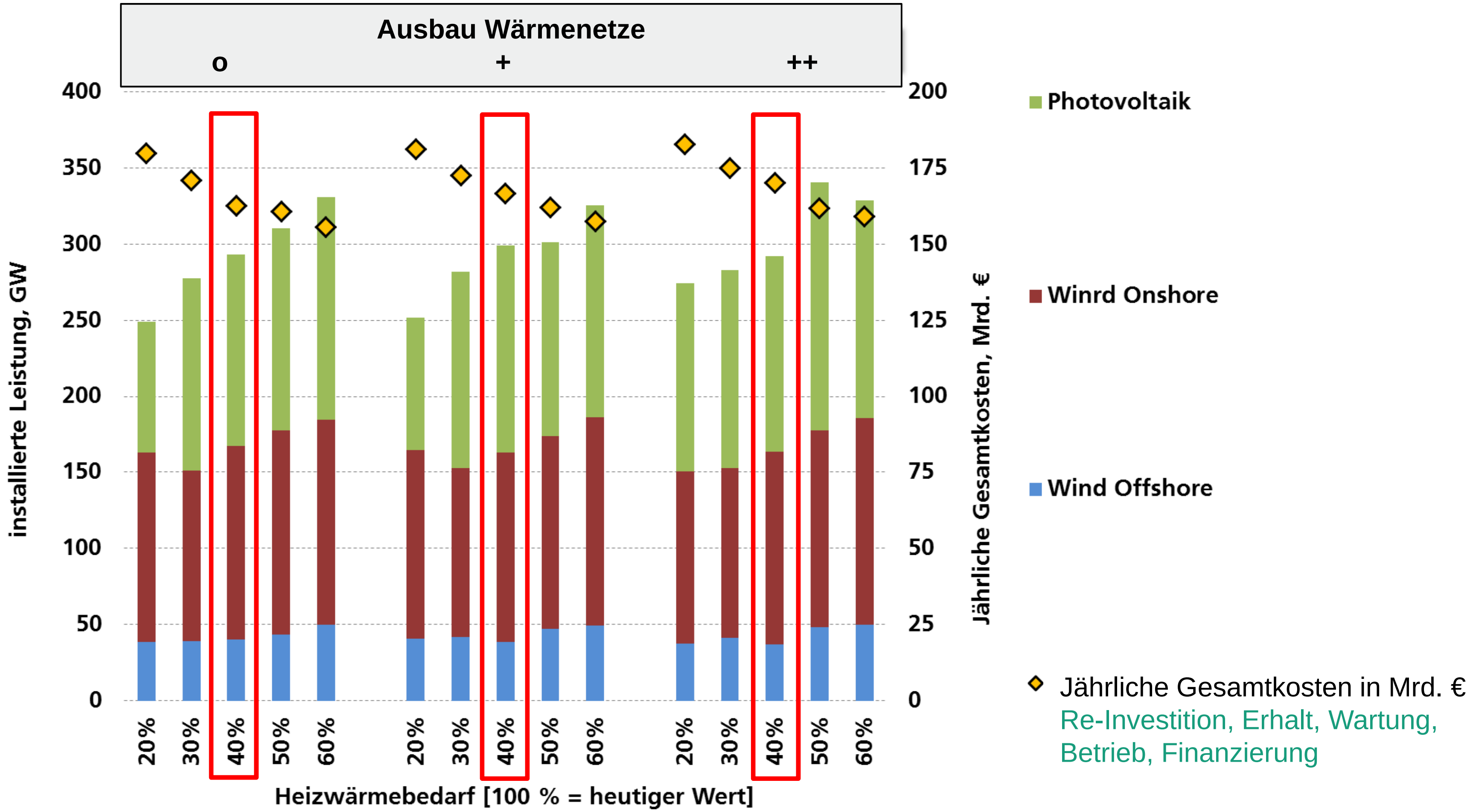


Analyse: Wärmenetze
Gesamtkosten Energiesystem



Hans-Martin Henning: Wärme- und Kältestrategie BMU, to be published

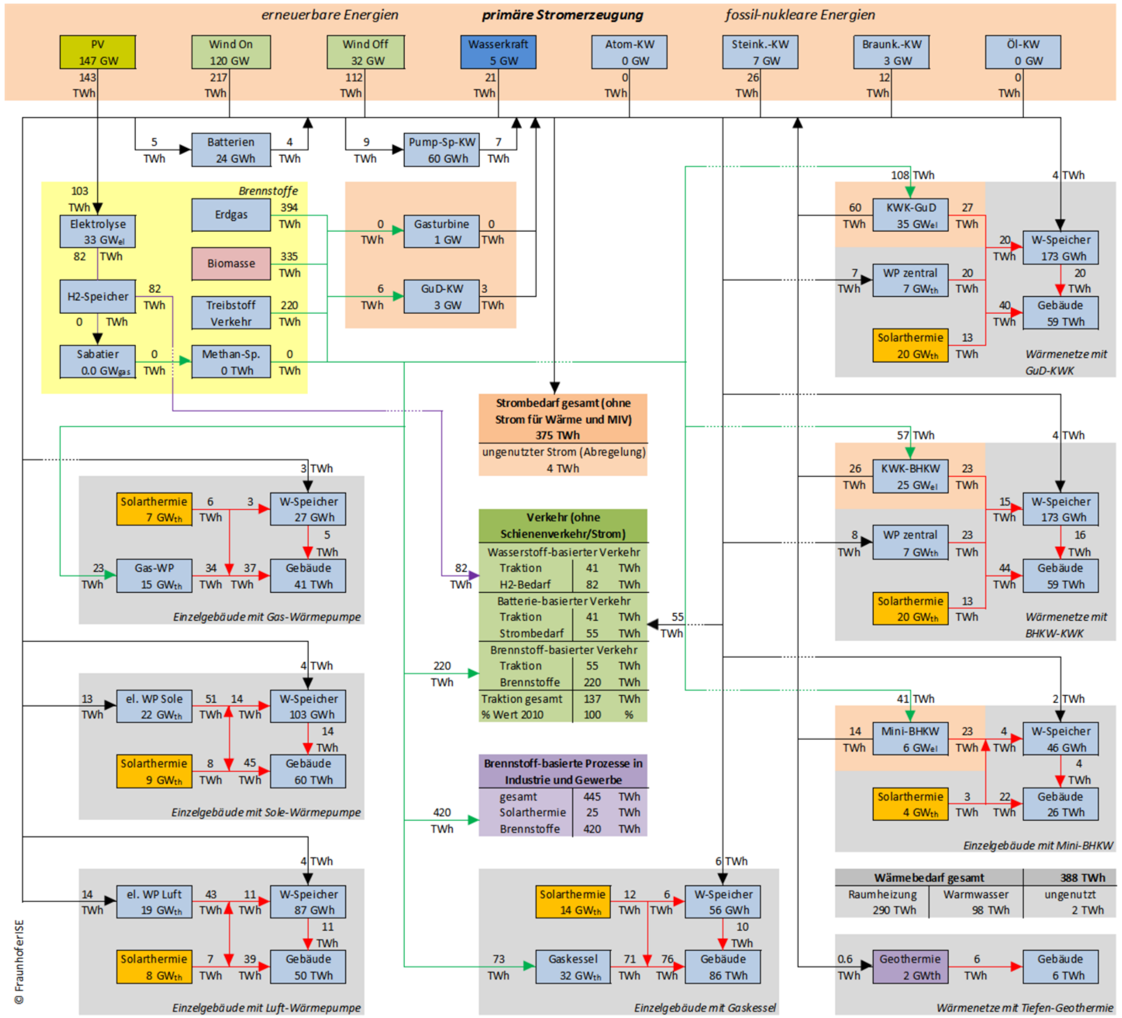
Analyse: Wärmenetze
Gesamtkosten Energiesystem



Hans-Martin Henning: Wärme- und Kältestrategie BMU, to be published

Analysis of a selected system

- Space heating demand 40 % of today‘s value (reduced by energy retrofit of the building stock)
- Cost optimized system for a reduction of energy-related CO_2 emissions by 81 % (compared to Kyoto reference value)



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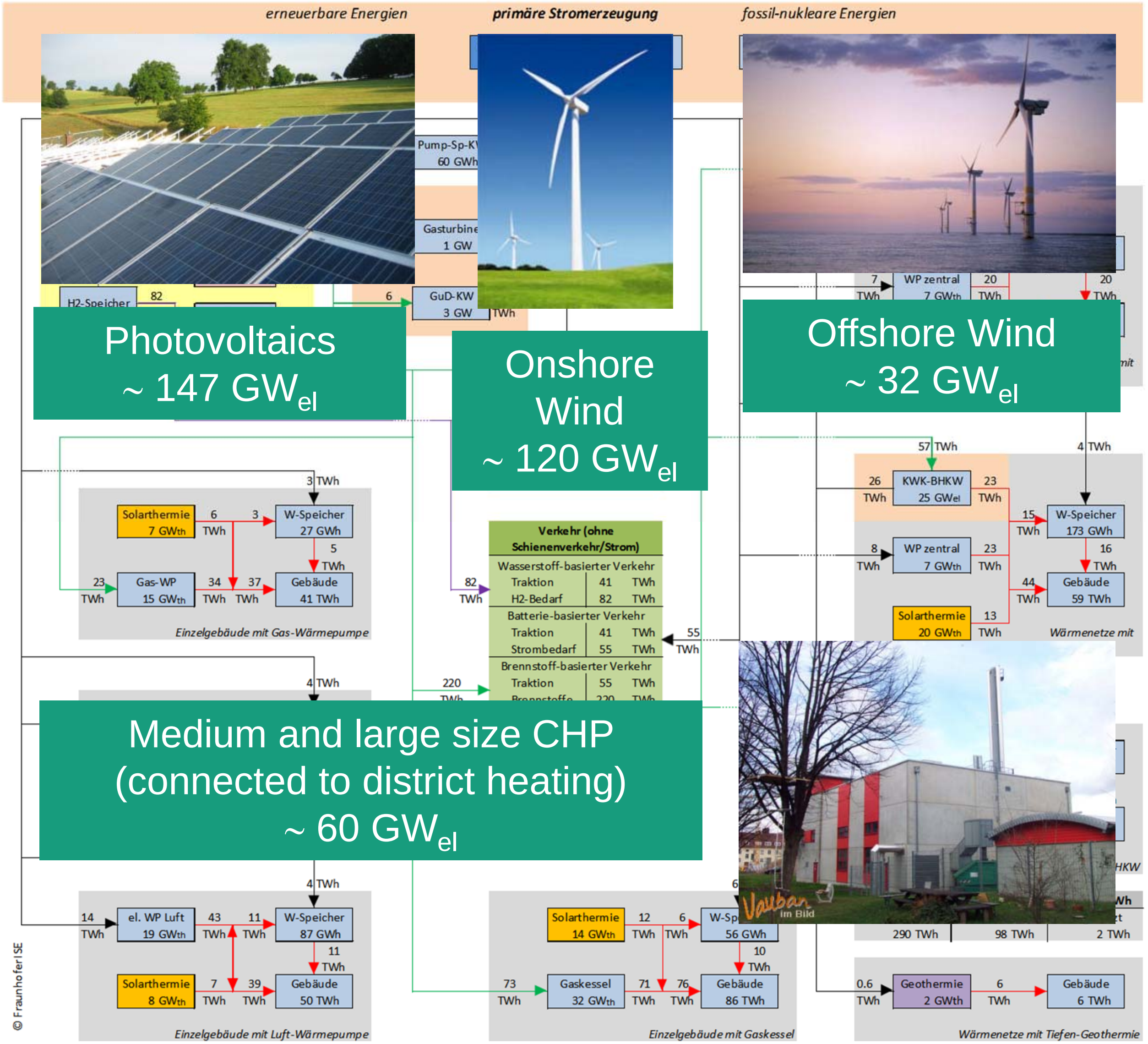
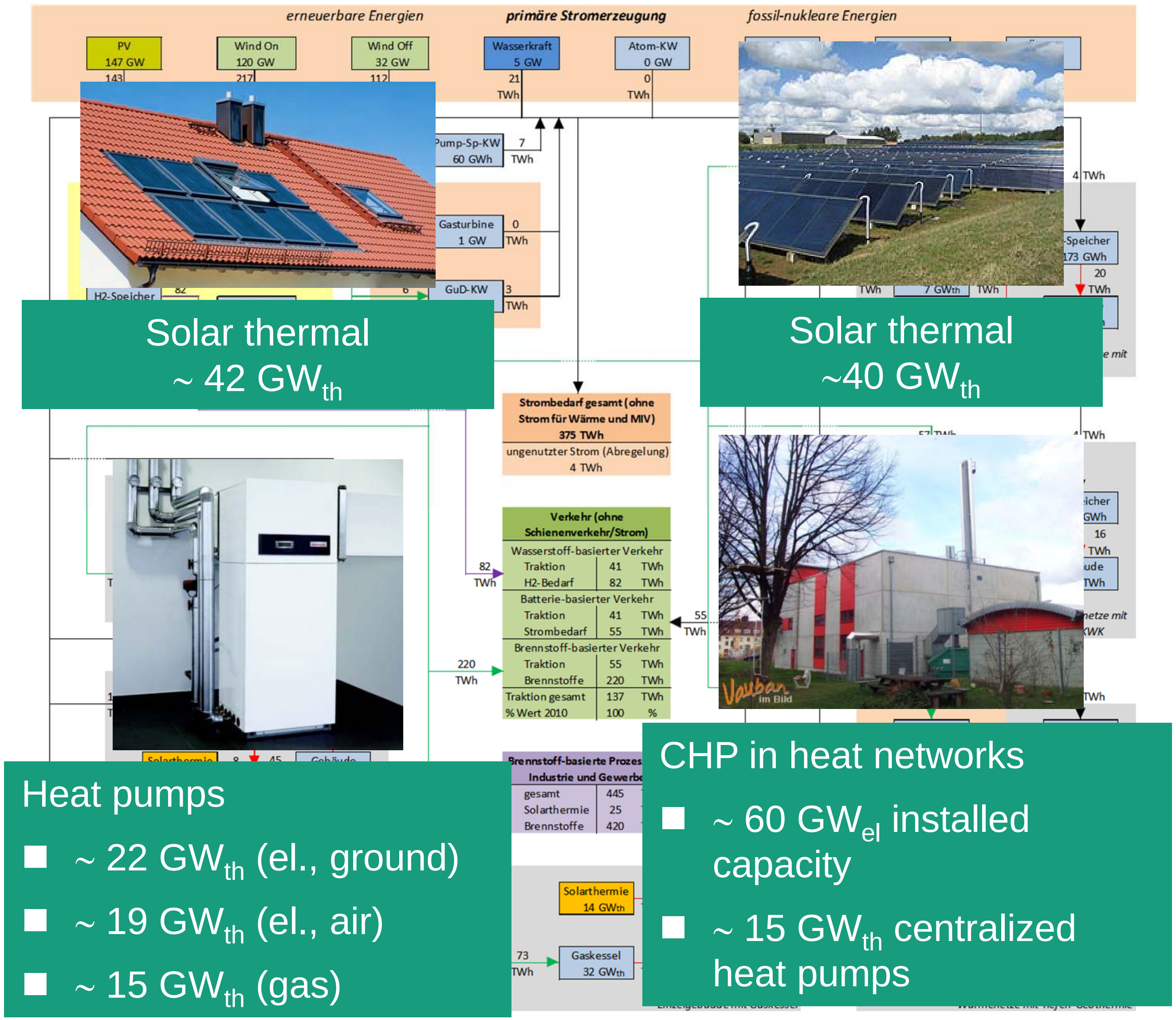
Electricity generation



Heat

decentralized

centralized



Solar thermal
~ 42 GW_{th}

Solar thermal
~40 GW_{th}

Heat pumps

- ~ 22 GW_{th} (el., ground)
- ~ 19 GW_{th} (el., air)
- ~ 15 GW_{th} (gas)

CHP in heat networks

- ~ 60 GW_{el} installed capacity
- ~ 15 GW_{th} centralized heat pumps

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)

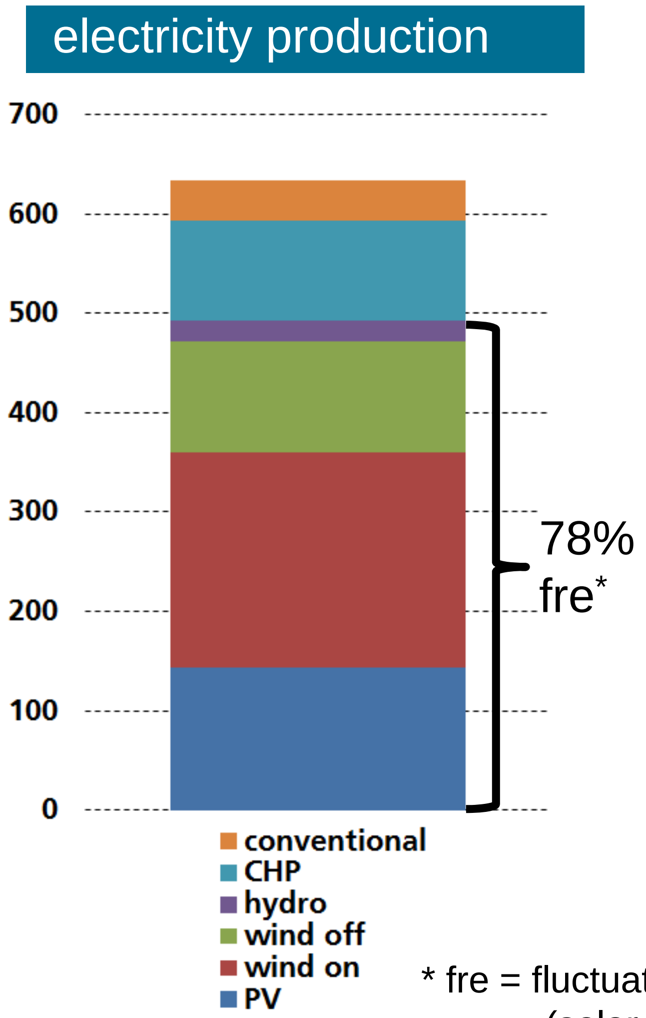
Heat buffers in buildings

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

Large scale heat storage in district heating systems

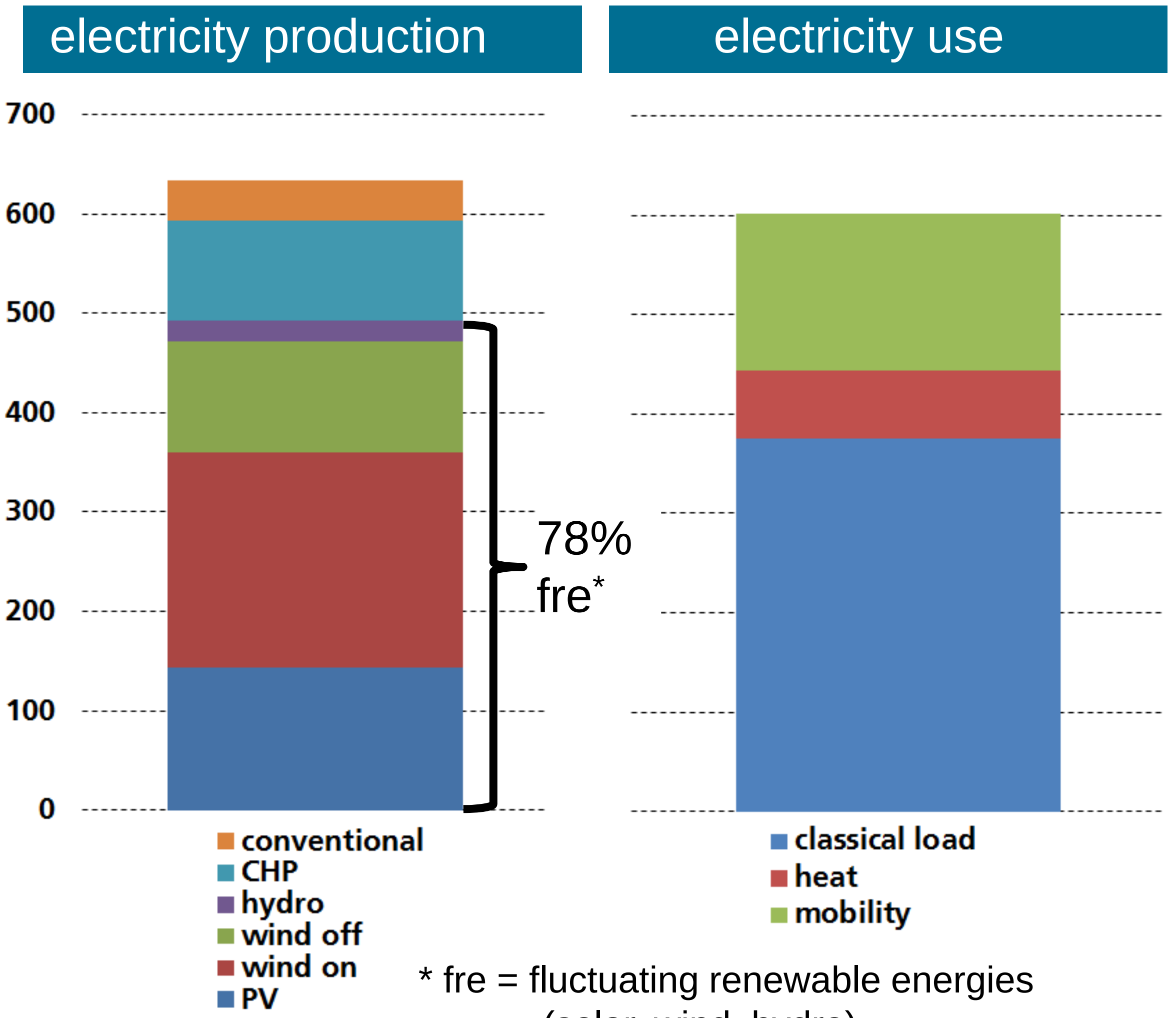
Total ~350 GWh (e.g. 150 units with 50.000 m³ each)

Annual energy balance (TWh)



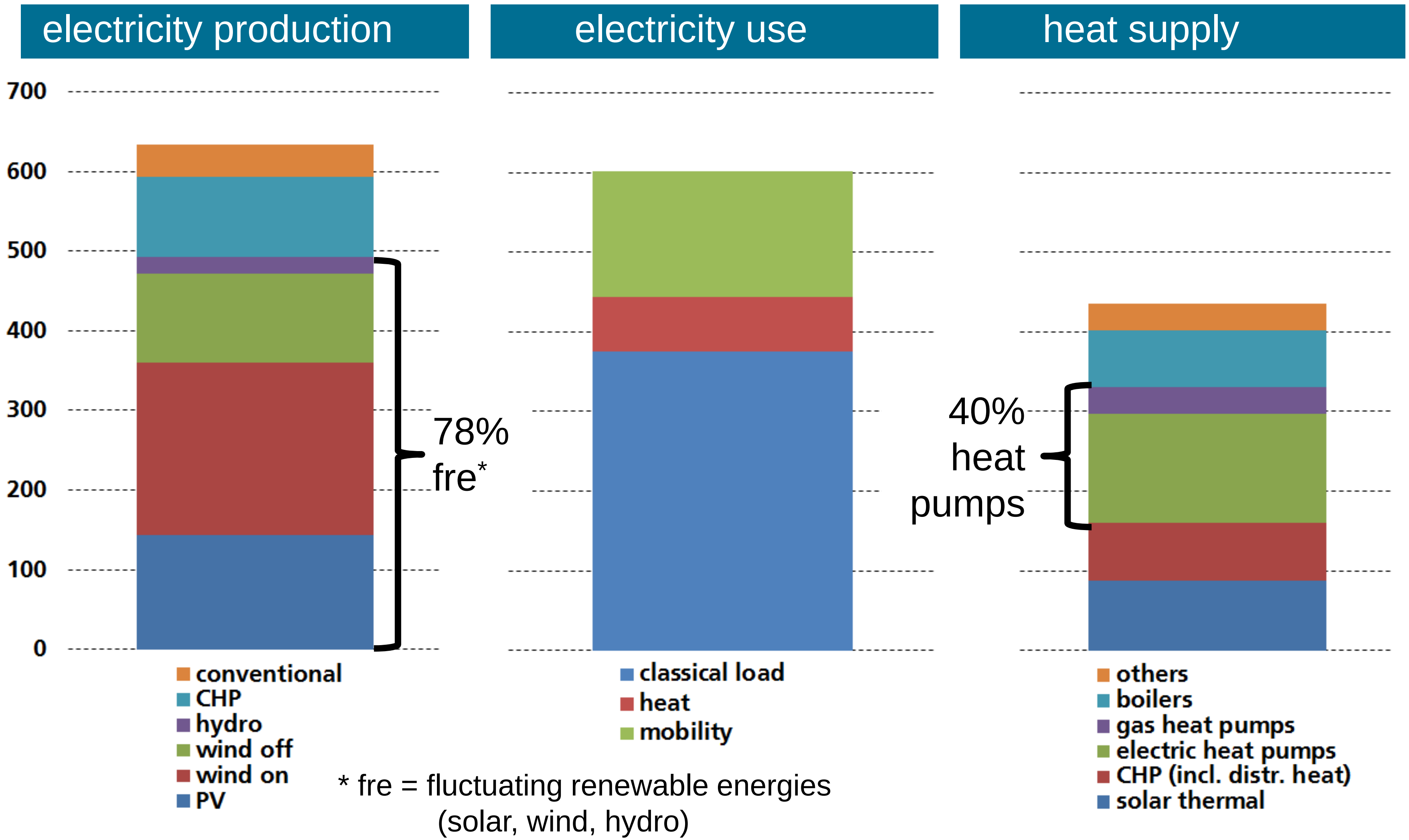
* fre = fluctuating renewable energies
(solar, wind, hydro)

Annual energy balance (TWh)



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

Annual energy balance (TWh)

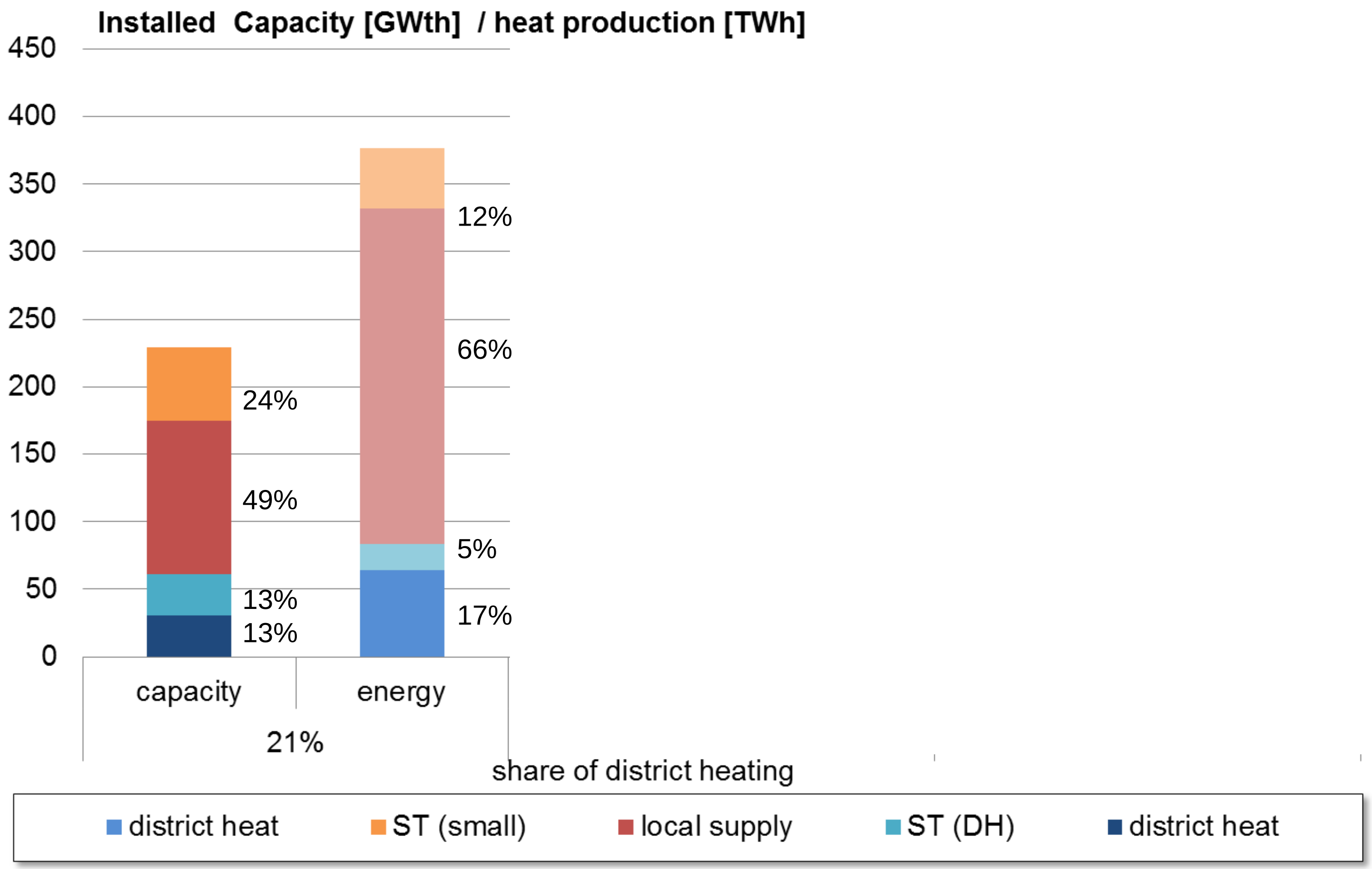


Szenarios Settings: Solar Thermal
Germany

- Heat load reduction in building sector -60%
- 82 % CO2-Reduction
  compared to 1990
- 3 Szenarios on heat grid:
  21%, 34%; 49% share of installed heating capacity
- Comparison of installed capacity, energy and cost
- Cost function:
  - Heat grid: 400 [€/kW]; lifetime 50 [a]; distribution losses 15%
  - Solar thermal: decentral 270 [€ /m²]; central 190 [€ /m²]

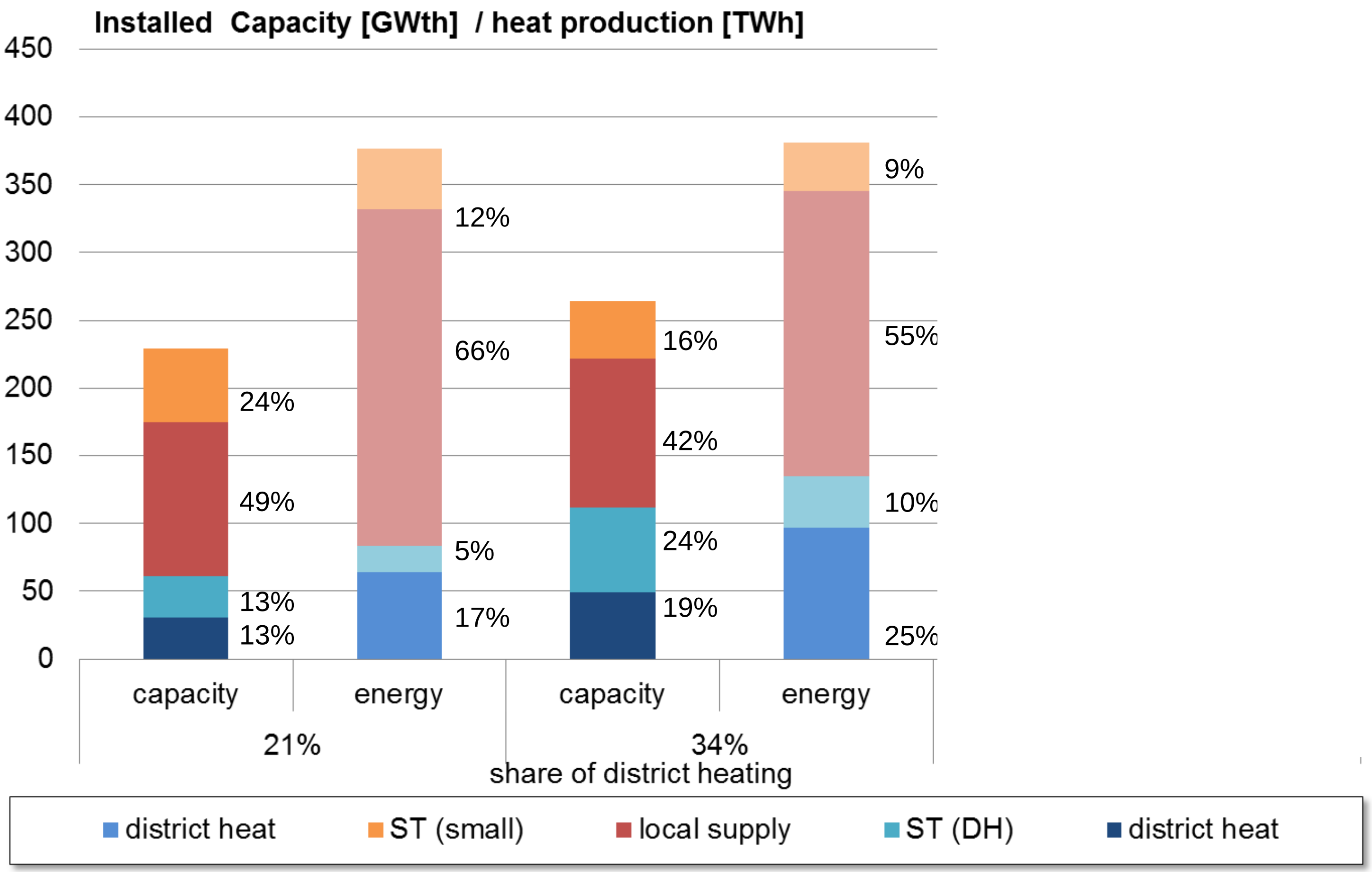
Datengrundlage und Modell: A. Palzer, H.-M. Henning: Wärme- und Kältestrategie BMU, to be published

Szenarios Solar Thermal heat supply
Germany 80% CO2 Reduction



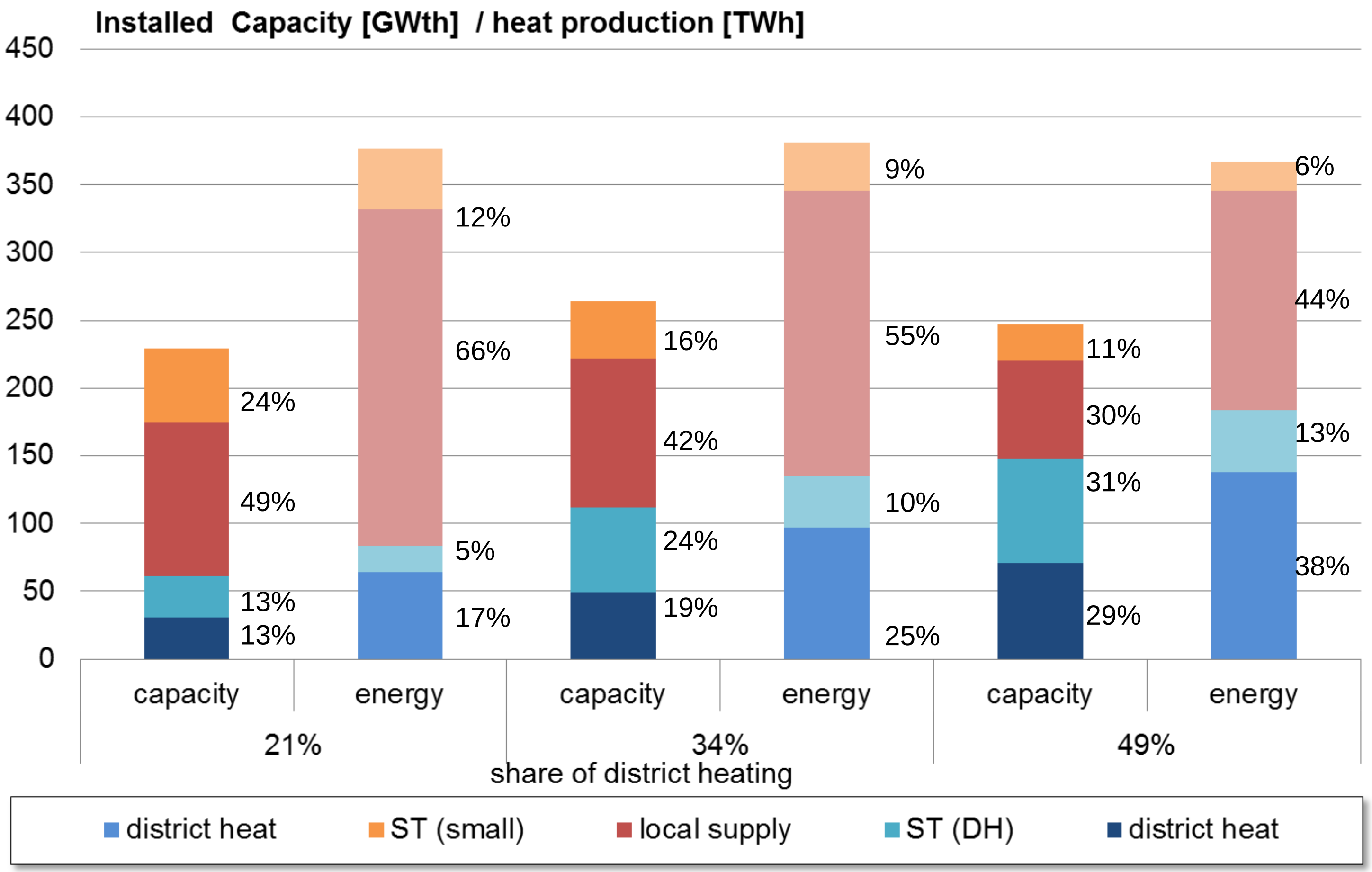
Szenarios Solar Thermal heat supply

Germany 80% CO2 Reduction



Task 52
Solar Heat and Energy Economics in Urban Environments

Szenarios Solar Thermal heat supply
Germany 80% CO2 Reduction



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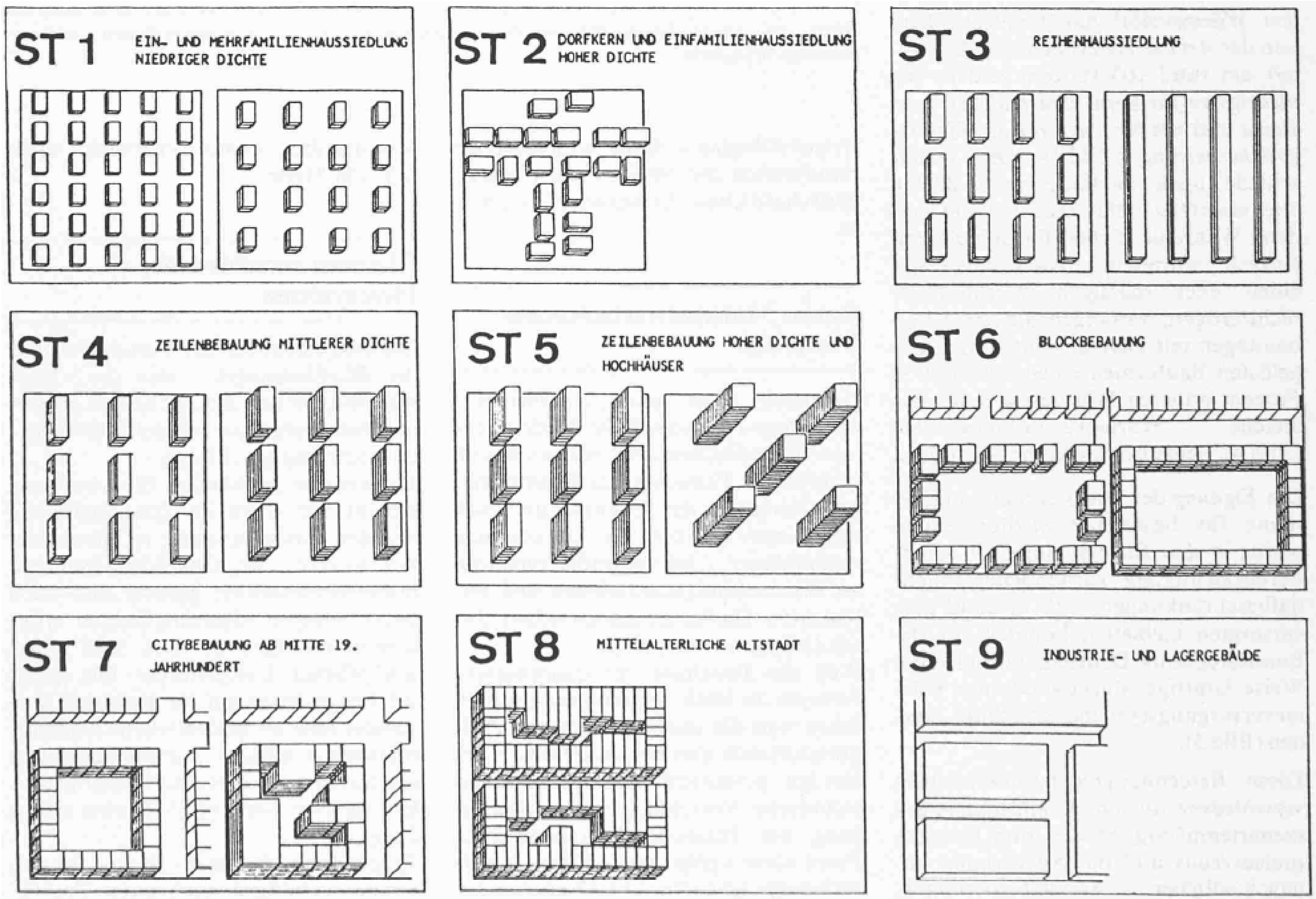
Urban Structure Types

Urban Morphology



Urban Structure Types

Urban Morphology -> Simplified urban structure

9 different types of urban structures from Roth	
ST 1	One family houses/ duplex houses with low concentration
ST 2	Village center and one family houses with high concentration
ST 3	Row housing
ST 4	Multi family houses with medium concentration
ST 5	Multi family houses with high concentation, multi-story buildings
ST 6	Blockhouses
ST 7	City structure after mid. 19th century
ST 8	Medieval town
ST 9	Industrial buildings and warehouses

Simplified urban structures for REMod_D	
ST II	Village- and City Suburban areas
ST IIIa	Medium building density
ST IIIb	(Very) high building density and multi-story buildings
ST IV	Industrial and commercial buildings

A further differentiation is not possible from a technical point of view

Covers 92% of build environment

//Roth // UBA_Nahwärme

Building Typology

Types

4 different building types
- One/two family houses
- Small/medium multi story houses
- large multi story houses
- Industrial/commercial buildings

3 different construction ages
- Up till 1948
- 1949-1994
- After 1995

Building retrofit
- Renovated houses
- Not renovated houses

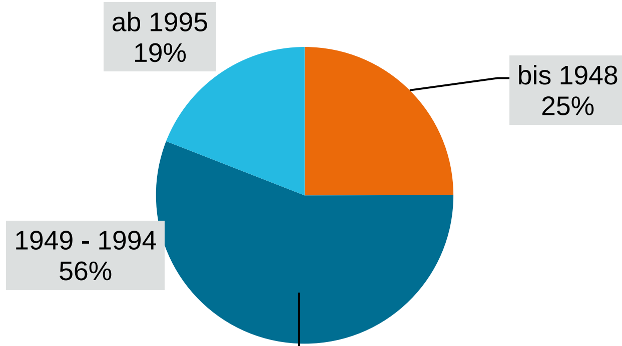
Example

	One/two family houses		
Building age	<1948	1949-1994	>1995
Quantity	3,777	8,463	2,884
Renovated	806	2,909	1,849
Not renovated	2,971	5,554	1,035
	Heat load in kW		
Renovated	6.99	7.24	7.62
Not renovated	20.89	17.01	11.50
Average	17.9	13.7	9.0
Average	**13.8**		

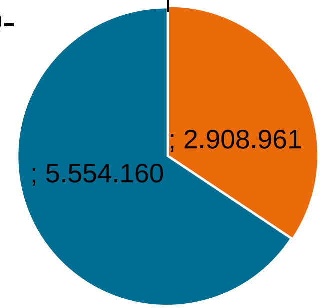
Building Typology

e.g.:

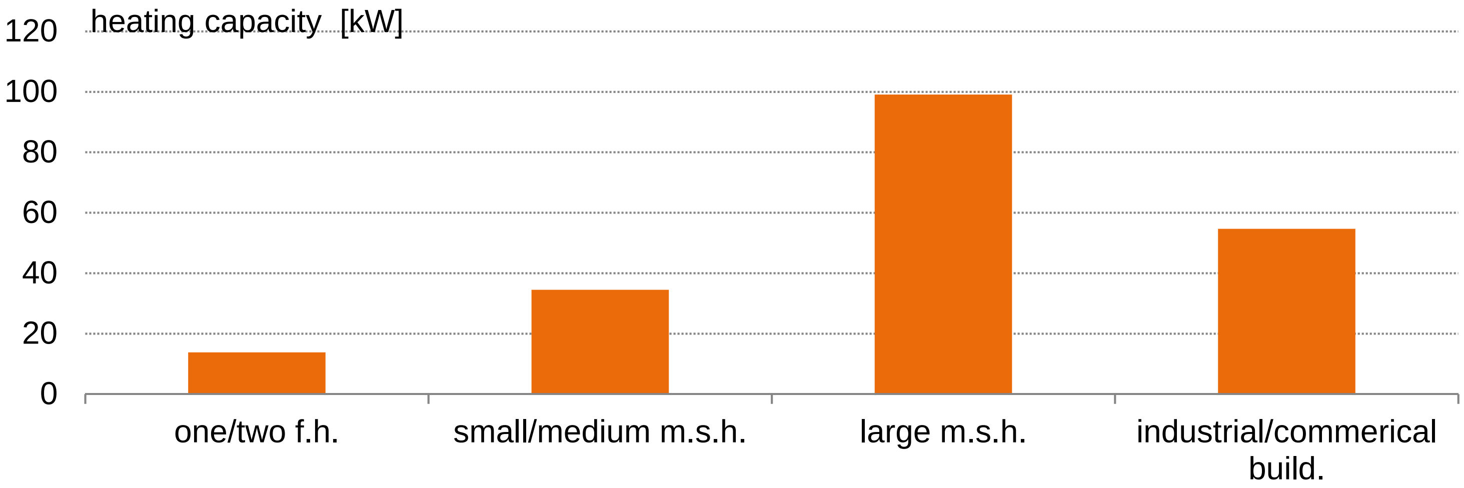
Construction age of single/double family houses:



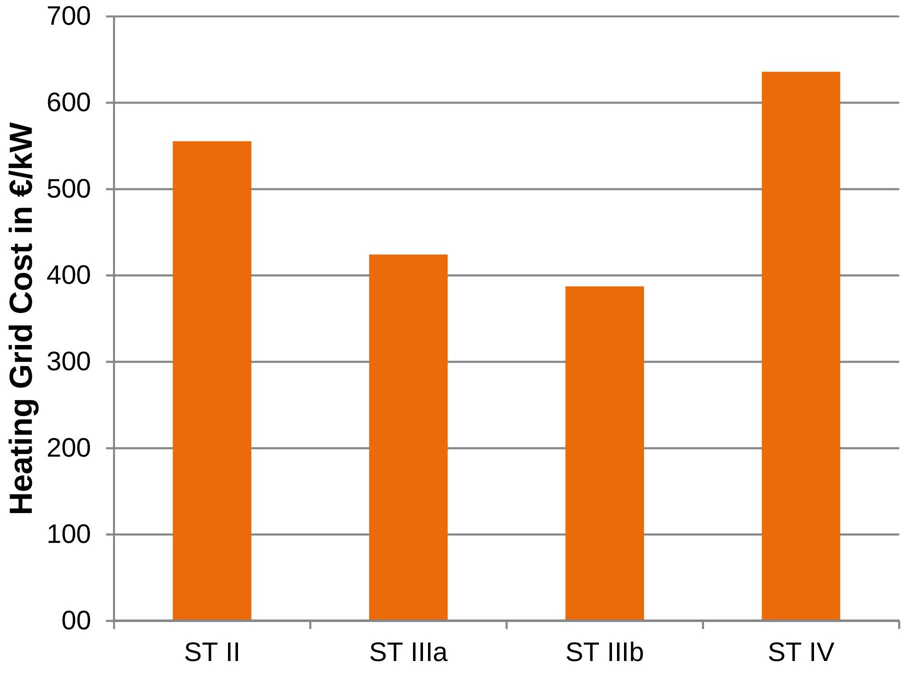
Retrofitted houses 1949-1948:



Average installed heating capacity in building types



Investment cost for district heating in different urban structures



// DLR //Zensus //UBA

Distribution of urban structures in Germany

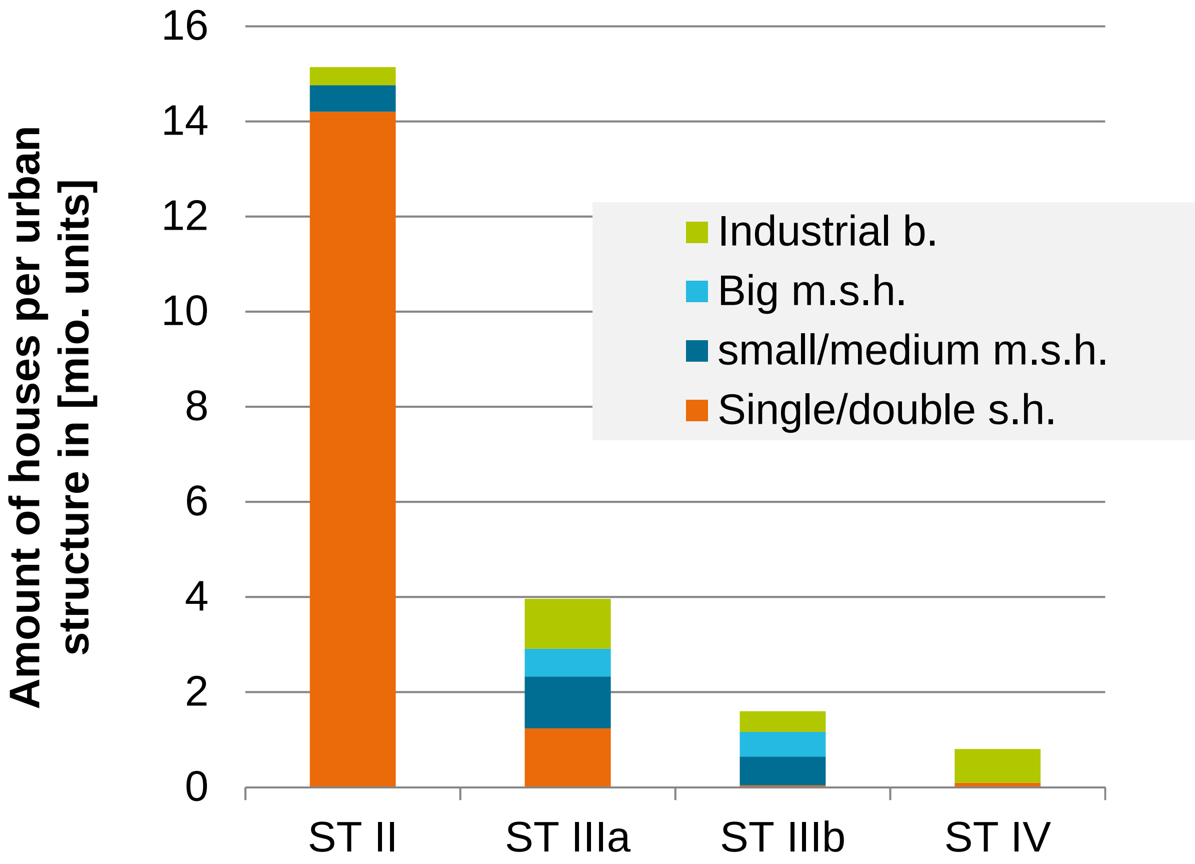
	Urban area
Urban Structure	in [1000 ha]
ST II	1656
ST IIIa	401
ST IIIb	93
ST IV	308
Sum	**2458**

ST II – Village/Suburban area

ST IIIa – medium building density

ST IIIb – high density; big multi-s.-h.

ST IV – industrial area



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// DLR //Zensus //UBA

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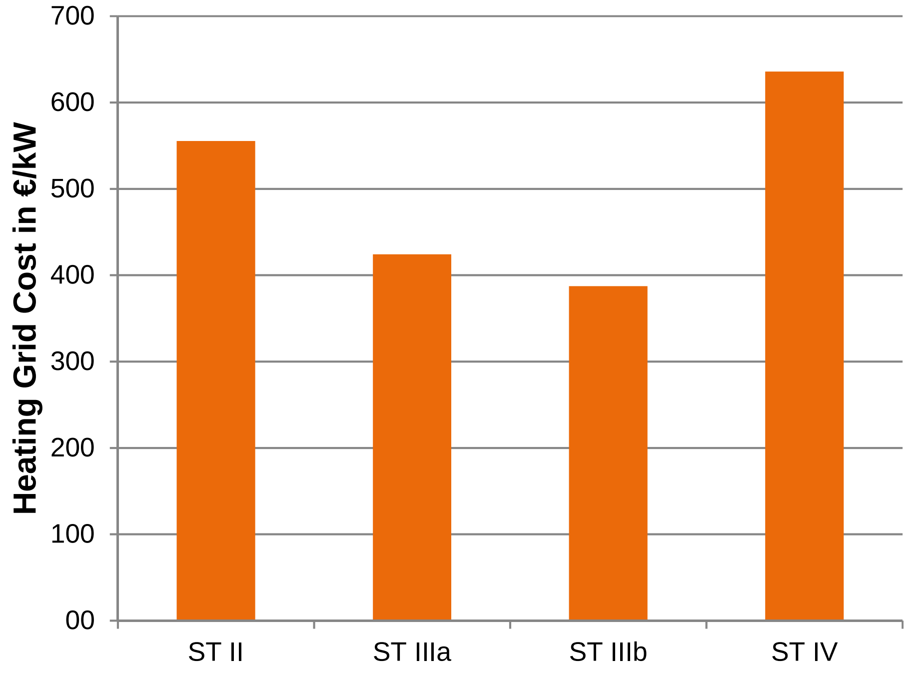
Investment cost for district heating

Urban structure	ST II	ST IIIa	ST IIIb	ST IV
Building type	build./ha	build./ha	build./ha	build./ha
One/two f.h.	8.58	3.09	0.40	0.29
Small/medium m.s.h.	0.34	2.72	6.51	0.00
Large m.s.h.	0.00	1.45	5.58	0.00
Industrial buildings	0.23	2.62	4.68	2.31
total	**9.14**	**9.88**	**17.17**	**2.60**

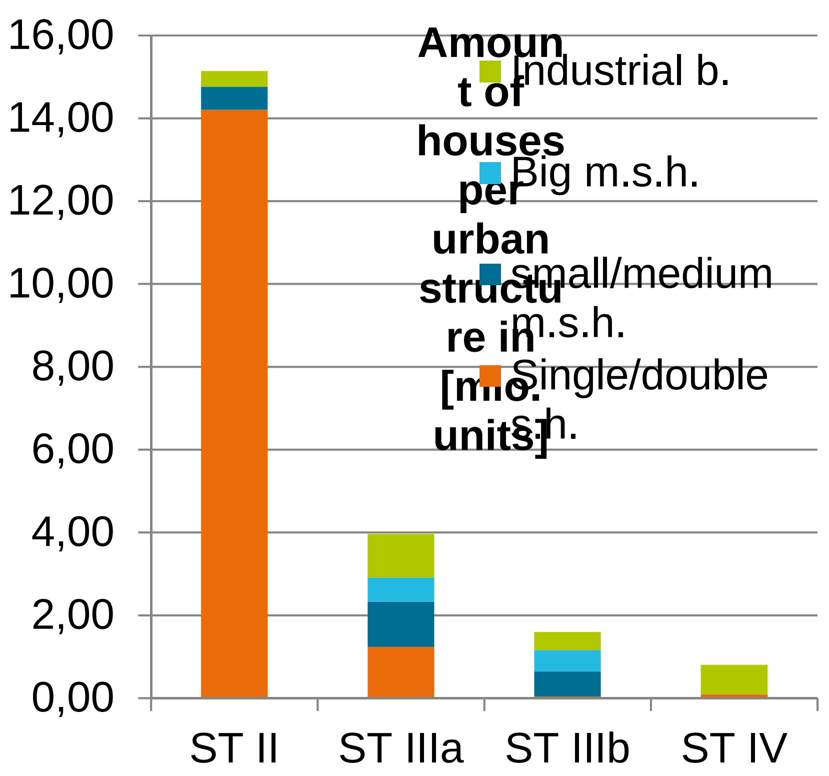
	Unit	ST II	ST IIIa	ST IIIb	ST IV
Sub-distribution grid length	m/ha	123	129	177	58
Grid lenght house connection	m/build.	8.4	9.7	9	25.7
Grid cost	€/m	220	330	440	440
Connection cost	€/build.	2602	4163	4290	4400
Heat load with coincidence factor	kW/ha	123	270.1	526	104.5
Heating grid cost	**€/kW**	**555.4**	**424.2**	**387.3**	**635.8**

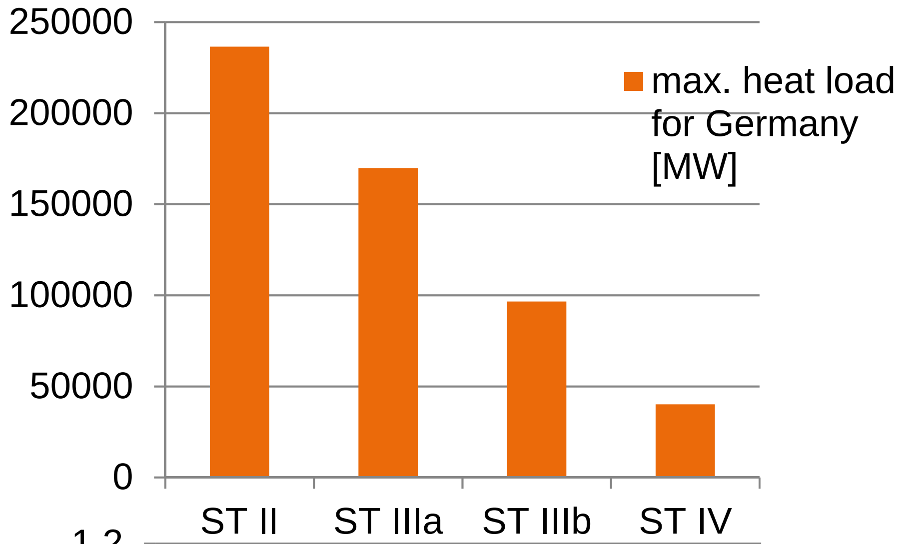


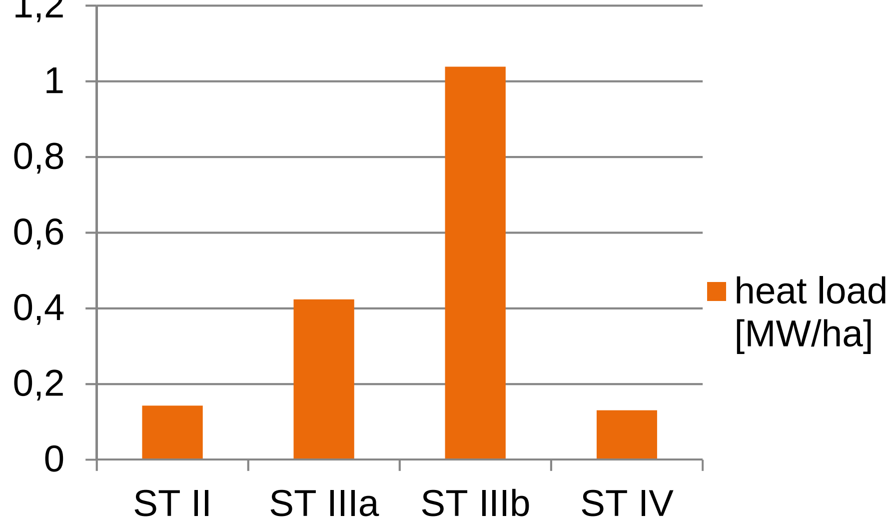
Future Tasks

- Validate crucial data, especially grid cost [€/m]
- Max. potential for solar heat for each urban structure
- Average value for REMod-D input
- Adapt parameters for ST IV
- (Maybe) differentiate further between different pipelines (avg. distance to centralized producer)

Distribution of urban structures in Germany







ST II – Village/Suburban area

ST IIIa – medium building density

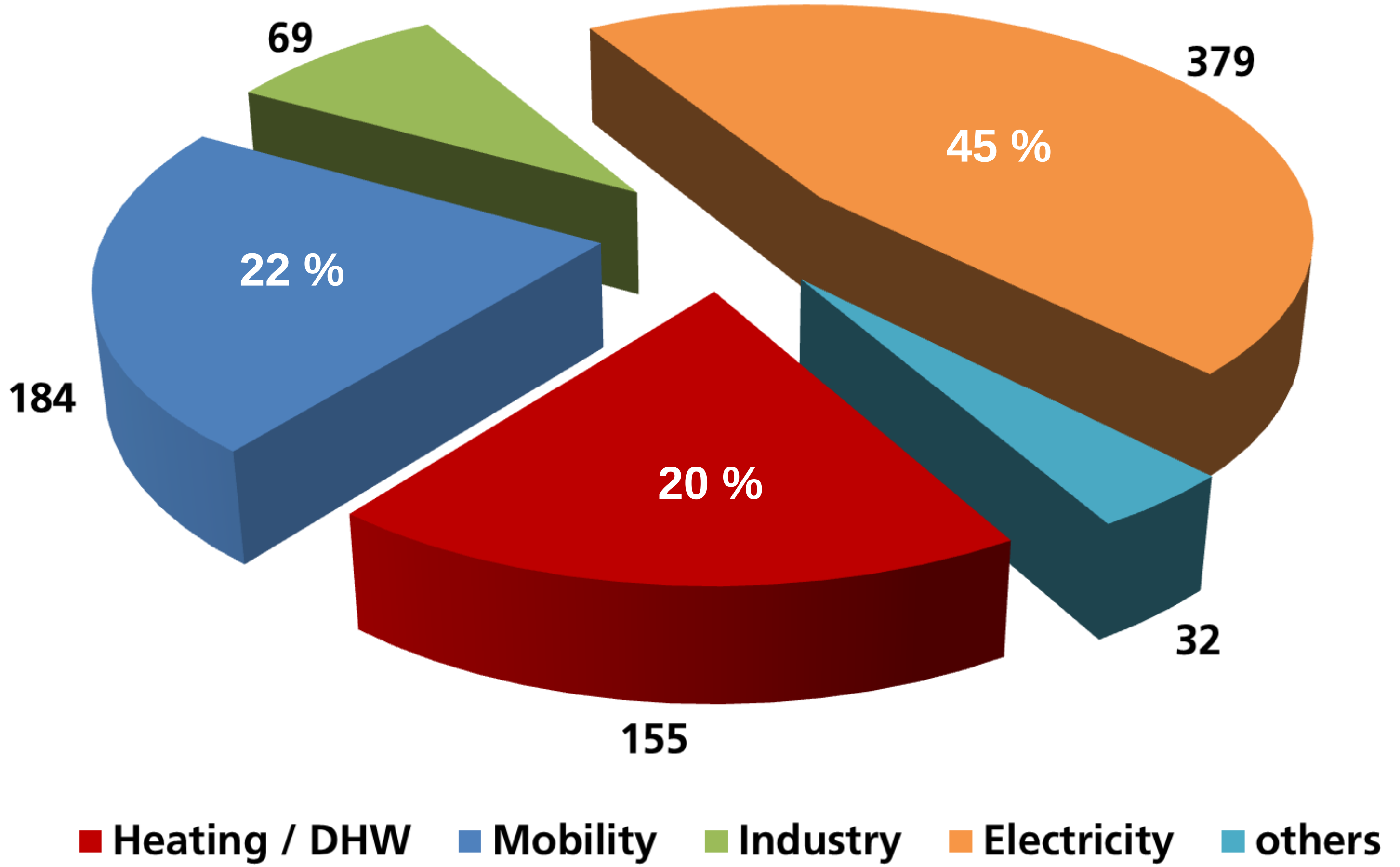
ST IIIb – high density; big multi-s.-h.

ST IV – industrial area

// DLR //Zensus //UBA

German energy-related CO_2 emissions (2008)

Distribution among sectors (Mio tons)



source: "Politikszenarien für den Klima-schutz VI - Treibhausgas-Emissions-szenarien bis zum Jahr 2030„. Öko-Institut et al. im Auftrag des Umwelt-bundesamtes (UBA), März 2013

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

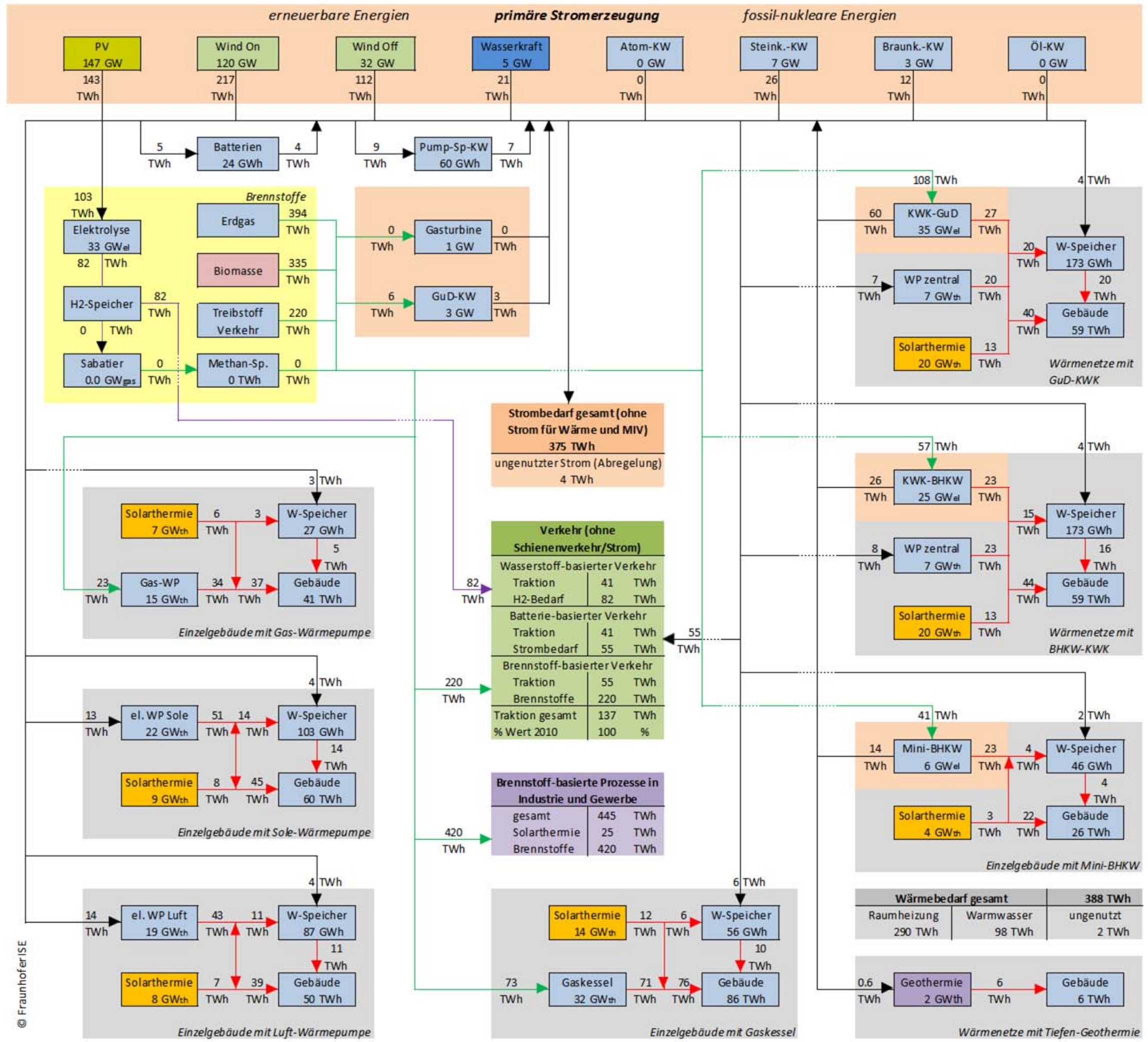
- Goal function: minimum of total annual cost (re-investment, maintenance, operation, financing)

➔ 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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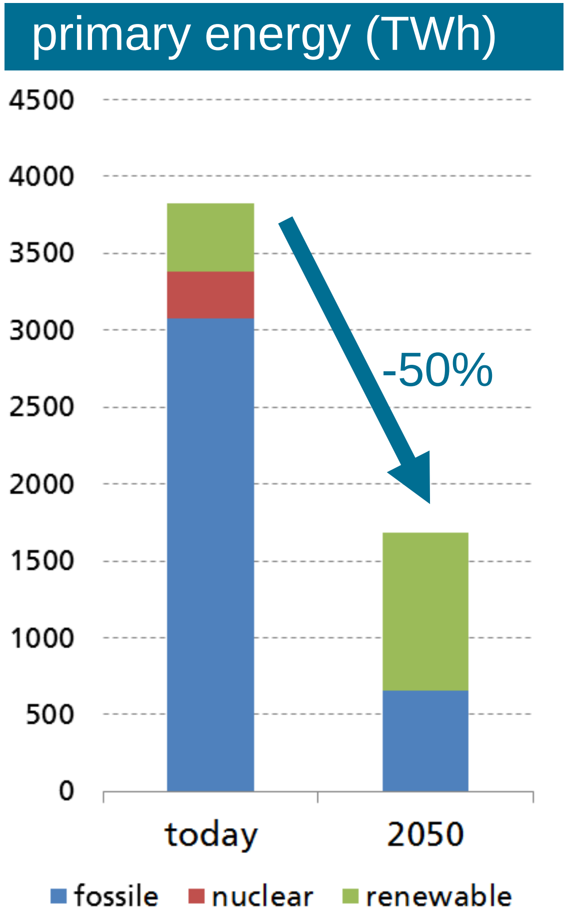
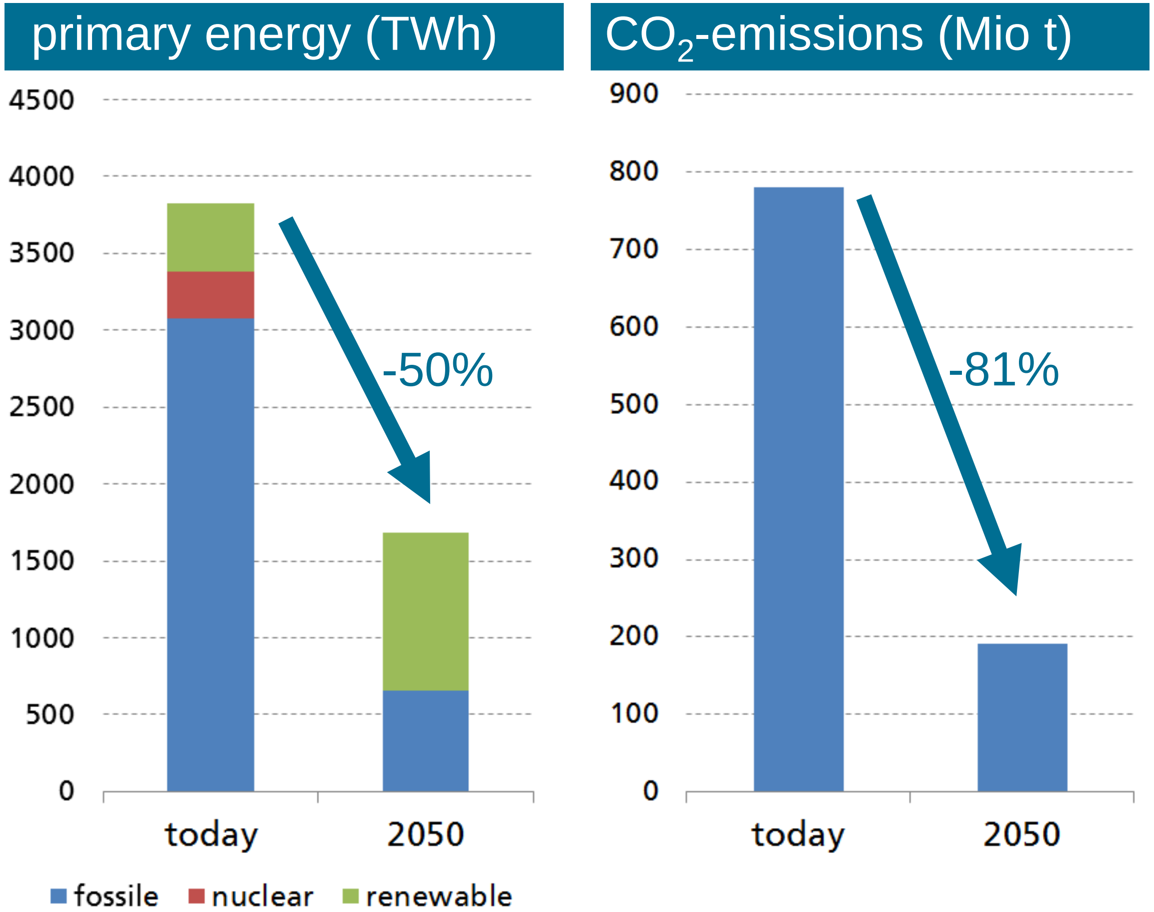
Overall comparison
Today vs. 2050 optimized system

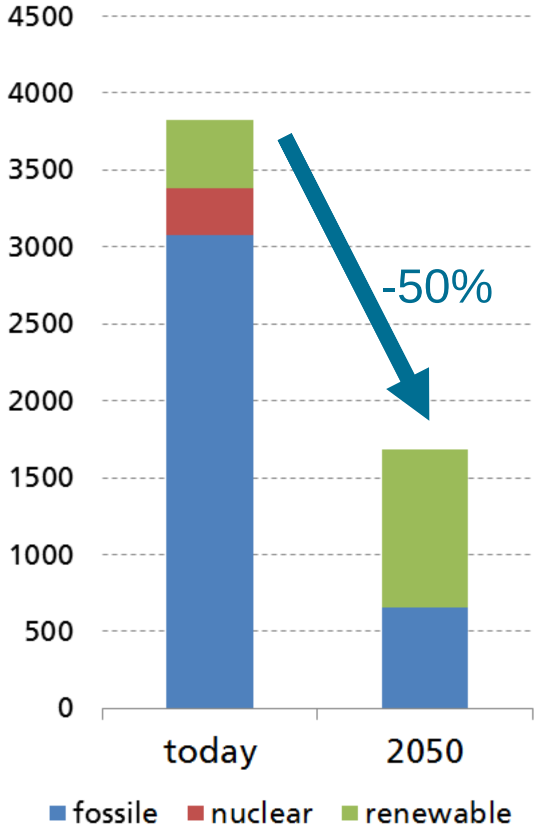


Overall comparison
Today vs. 2050 optimized system

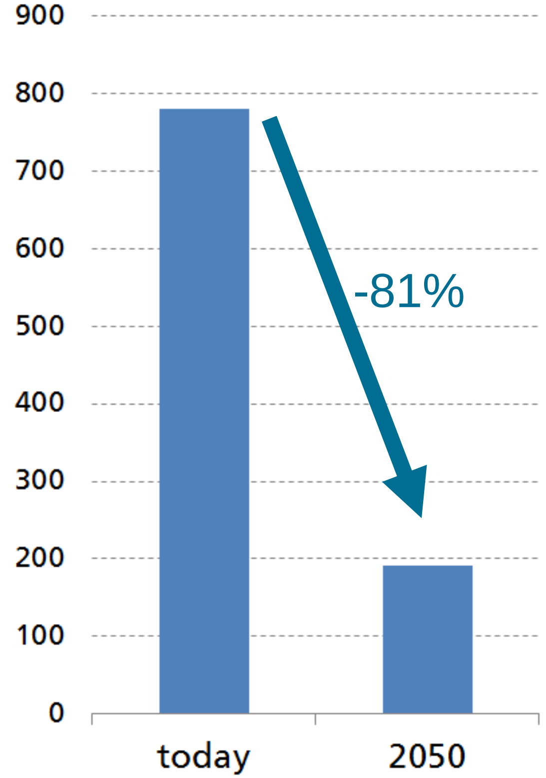


Overall comparison
Today vs. 2050 optimized system

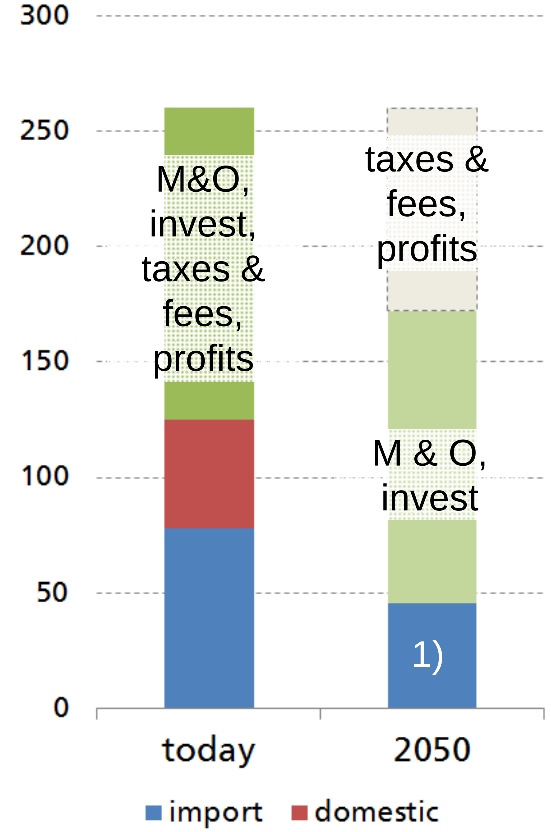
primary energy (TWh)



CO_2-emissions (Mio t)



annual cost (bill. €$_{2014}$)



1) Assumed doubling of fossil energy prices until 2050

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Solar Heat and Energy Economics
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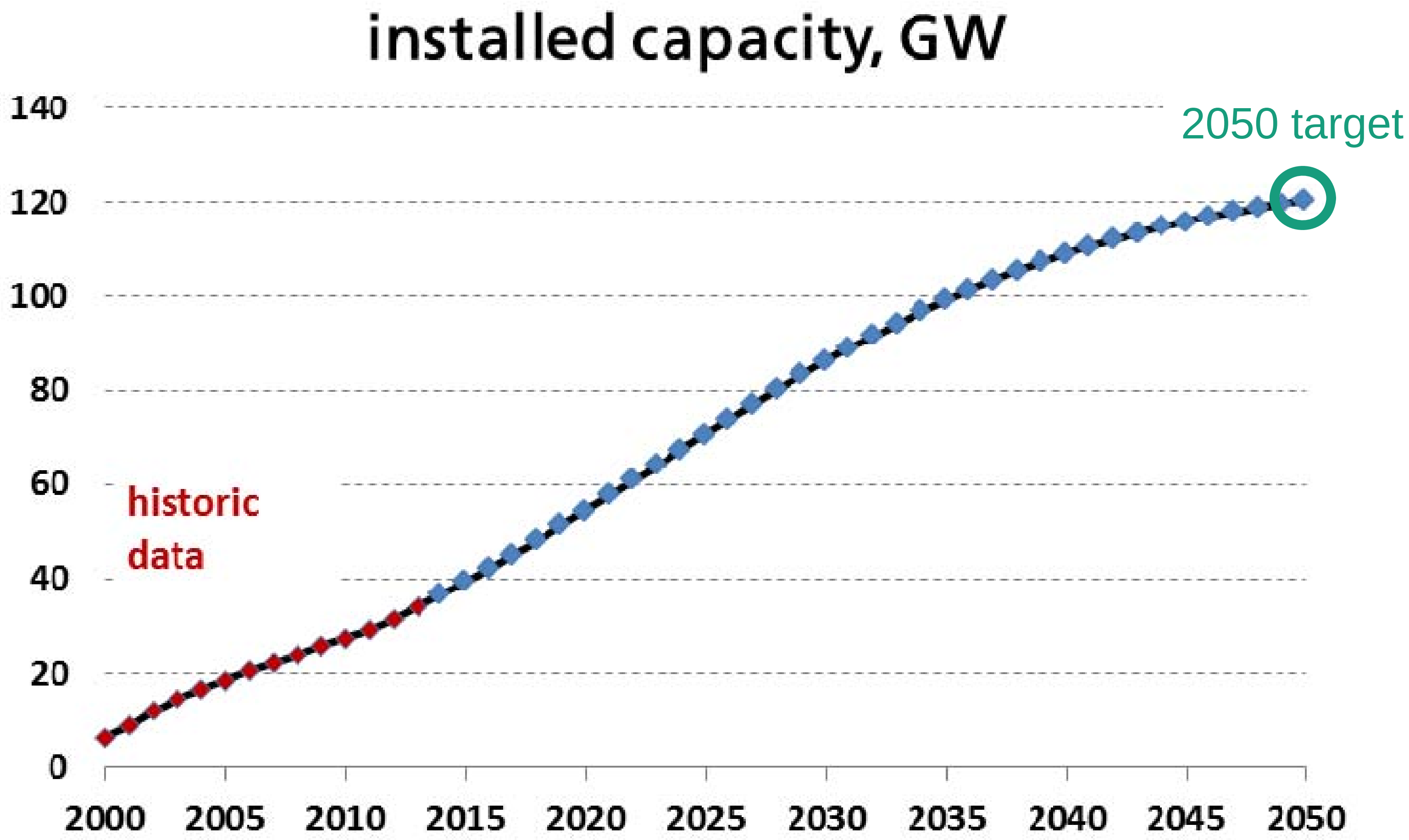
Outline

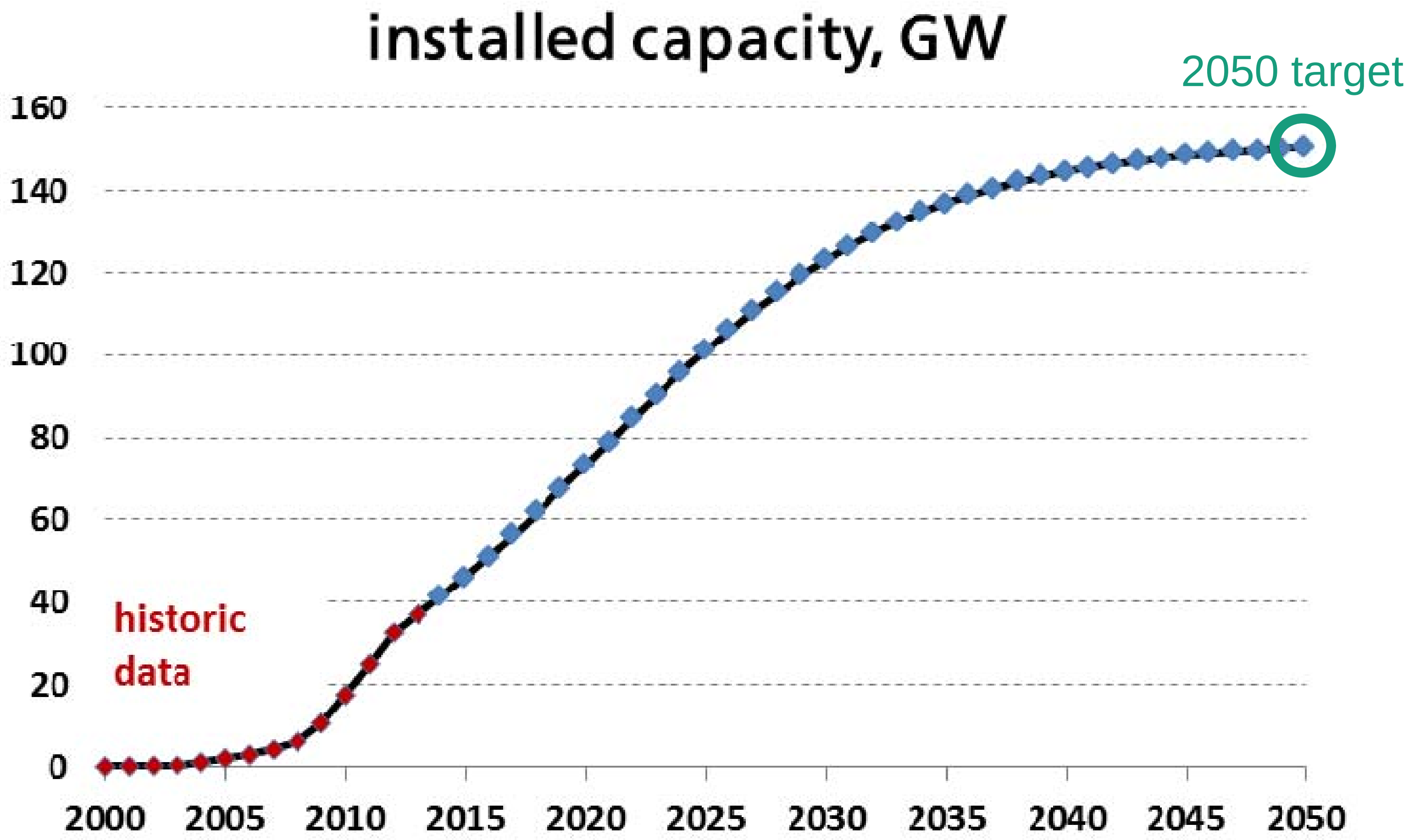
- Overall targets of the German climate protection policy
- Analysis of a renewable German energy system in 2050
  - Methodology
  - Results
  - Investments
- Conclusions & outlook

Analysis of investments from today until 2050
Onshore wind

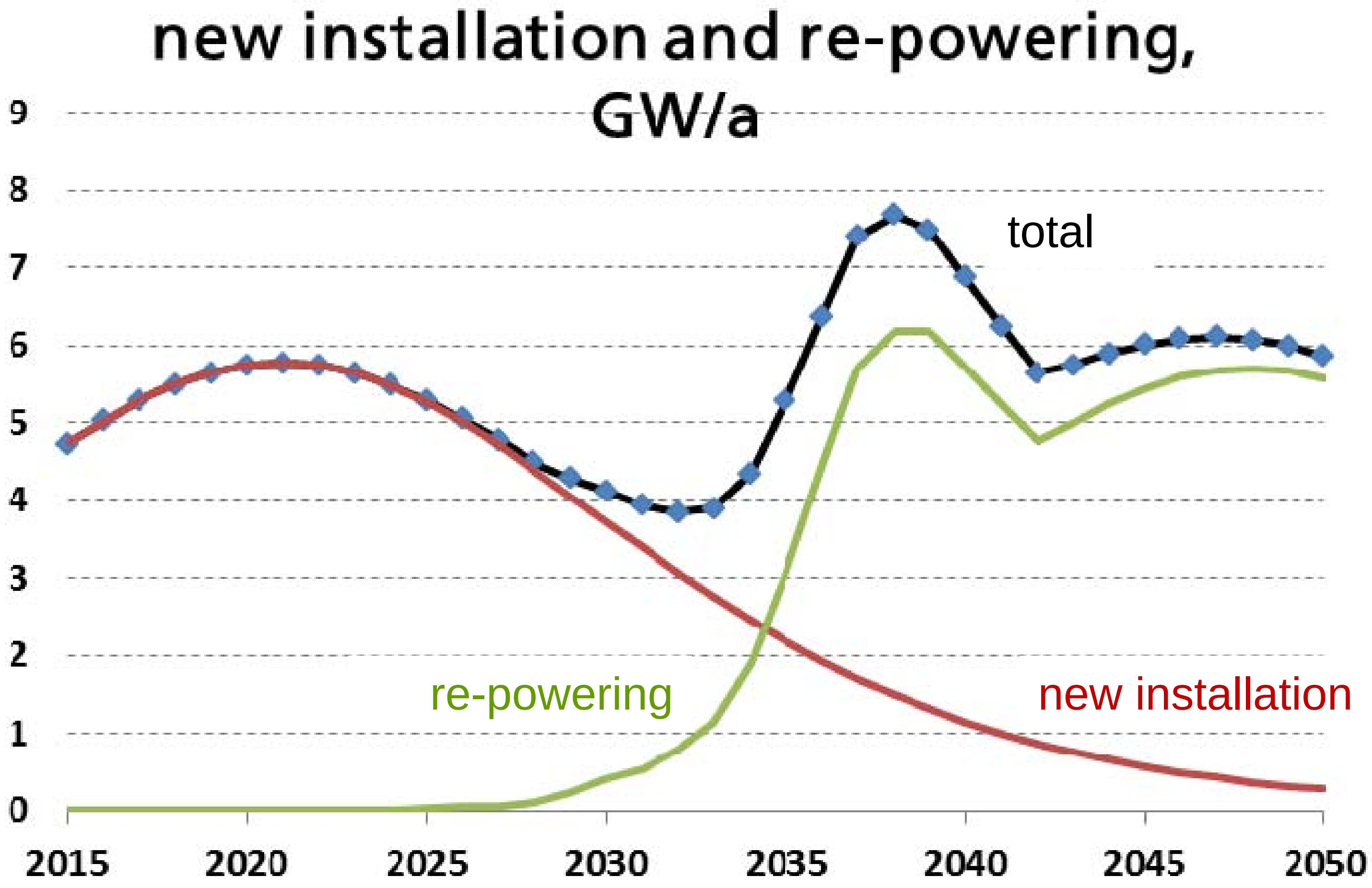


Analysis of investments from today until 2050

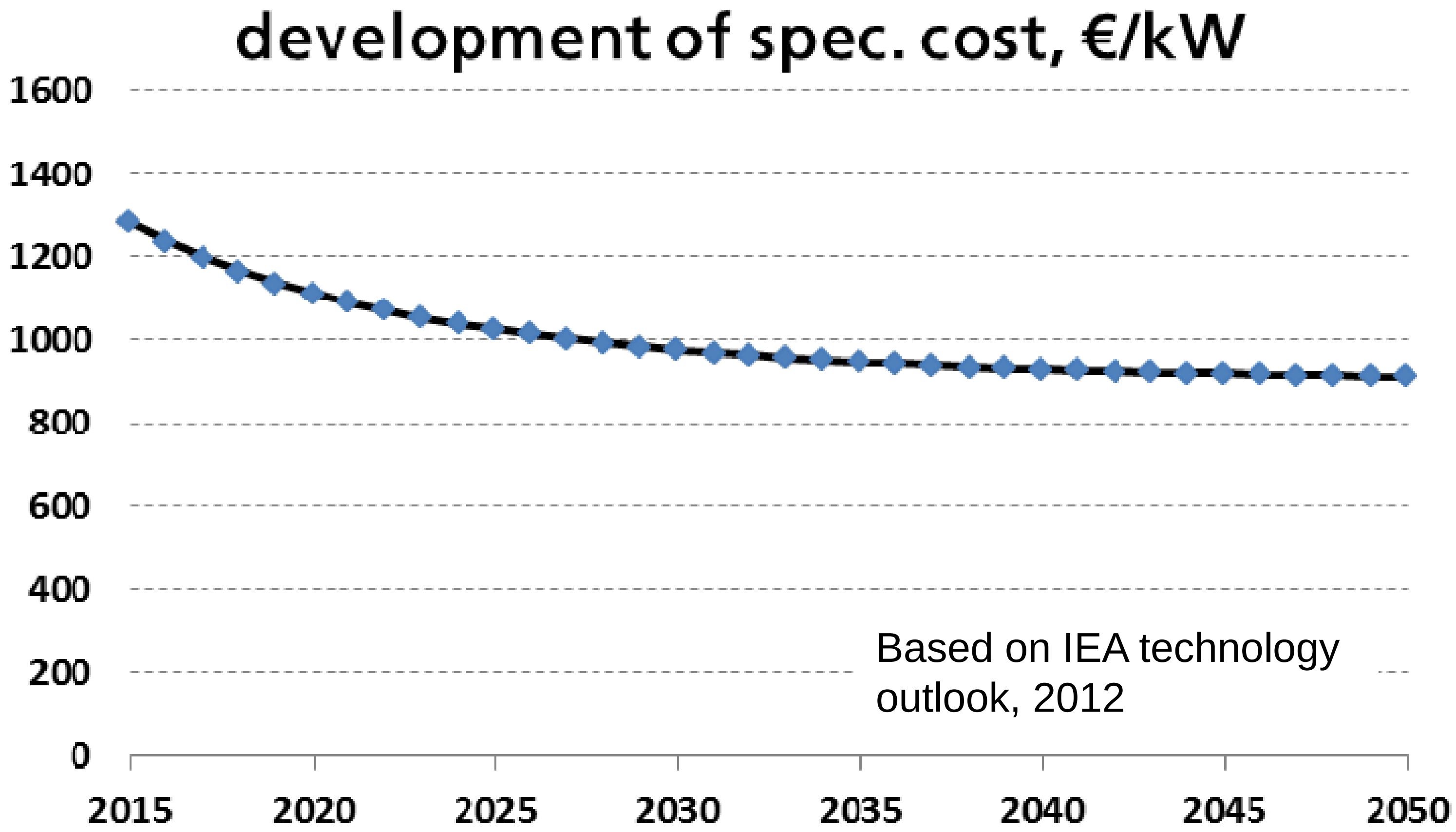
Photovoltaics



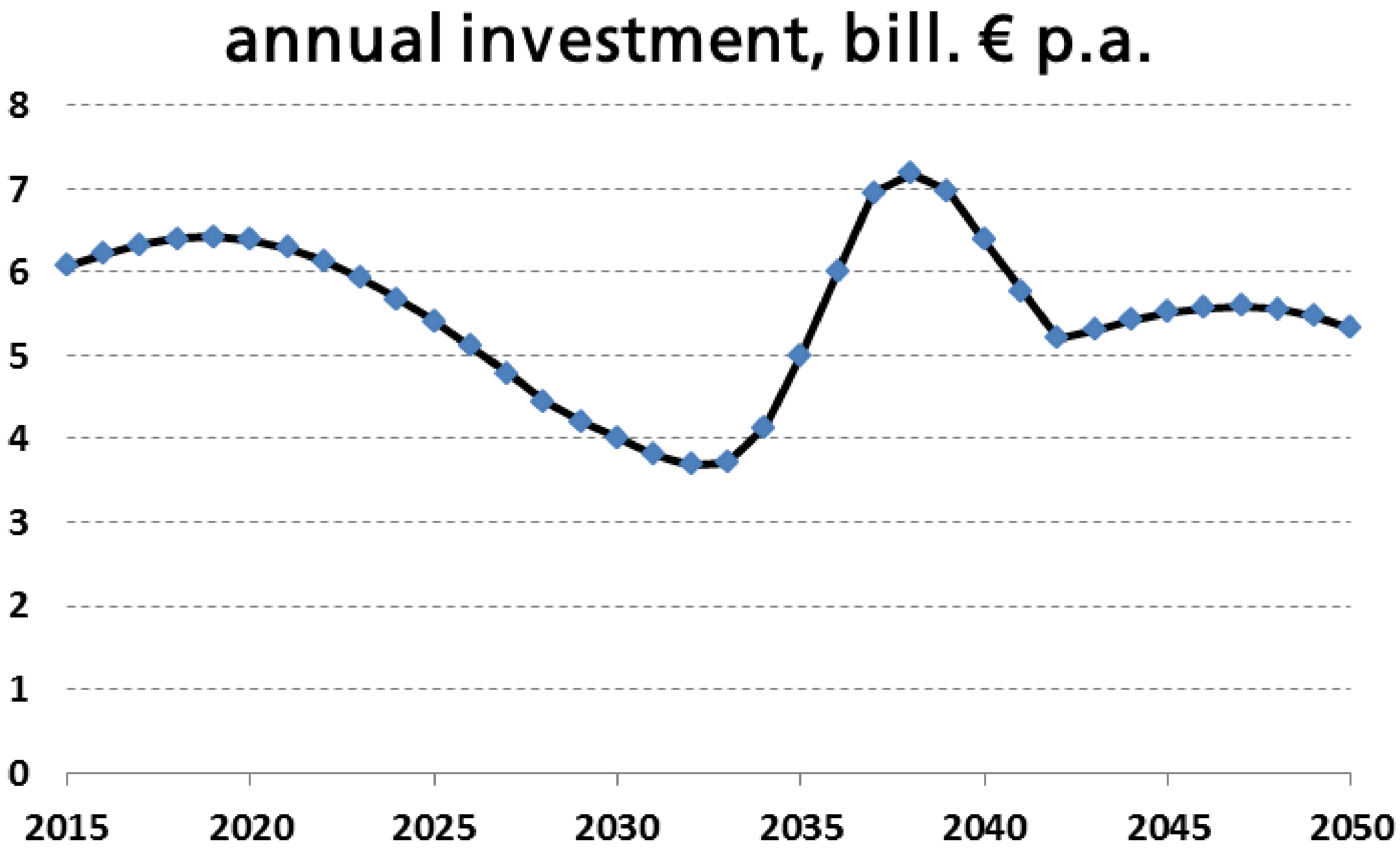
Analysis of investments from today until 2050
Example photovoltaics



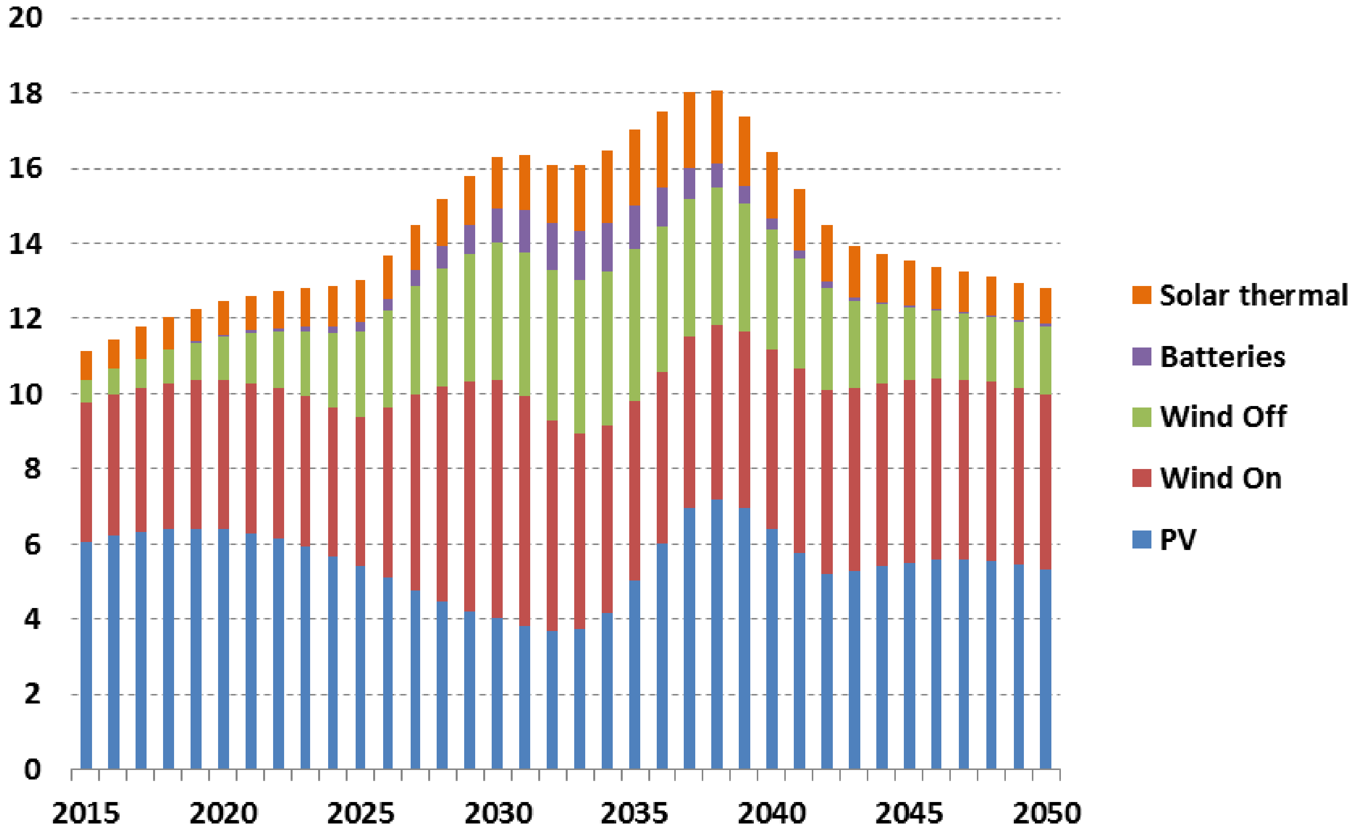
Analysis of investments from today until 2050
Example photovoltaics



Analysis of investments from today until 2050
Example photovoltaics

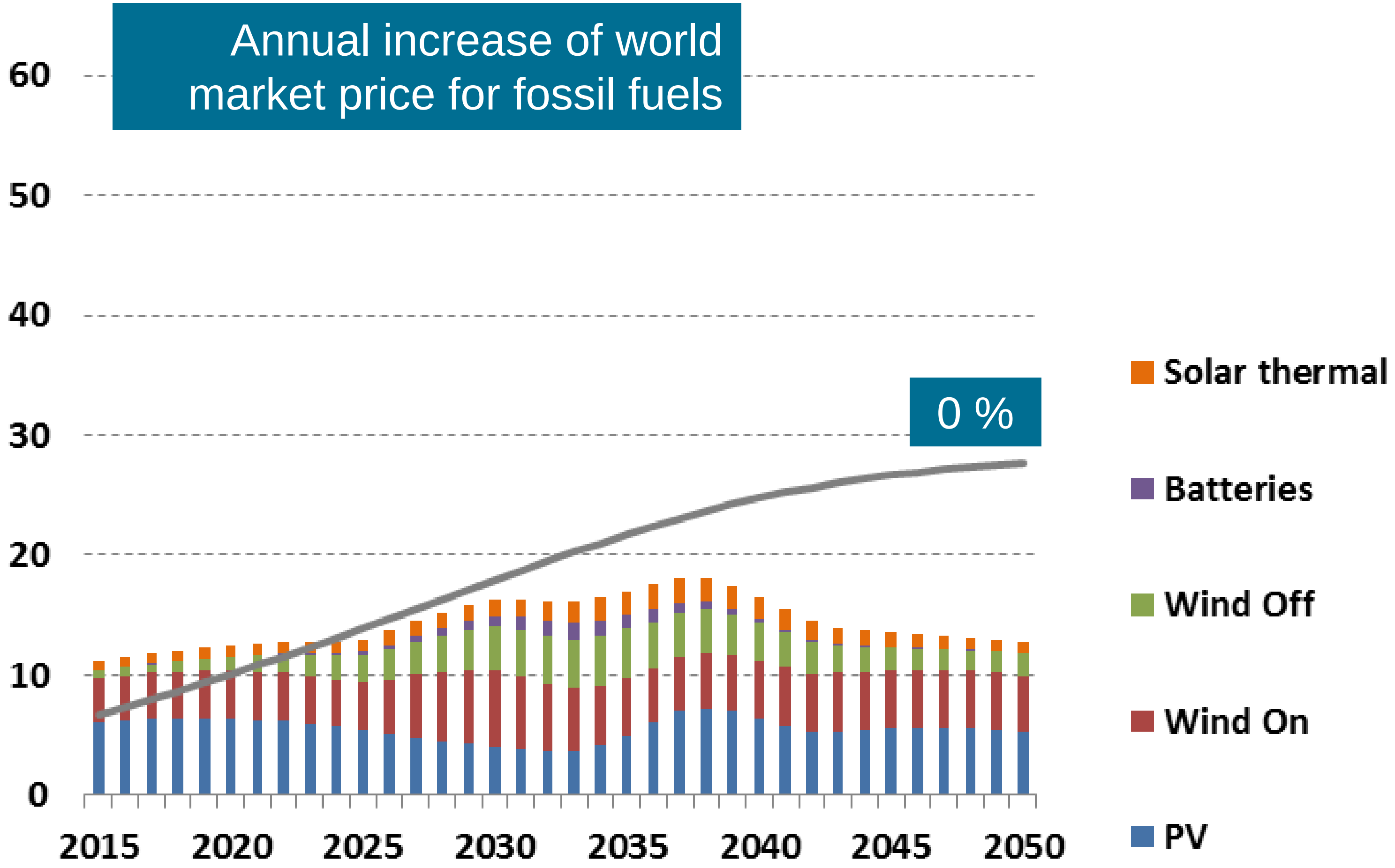


Investments for RE (wind, solar) and stationary batteries
Bill € p.a.

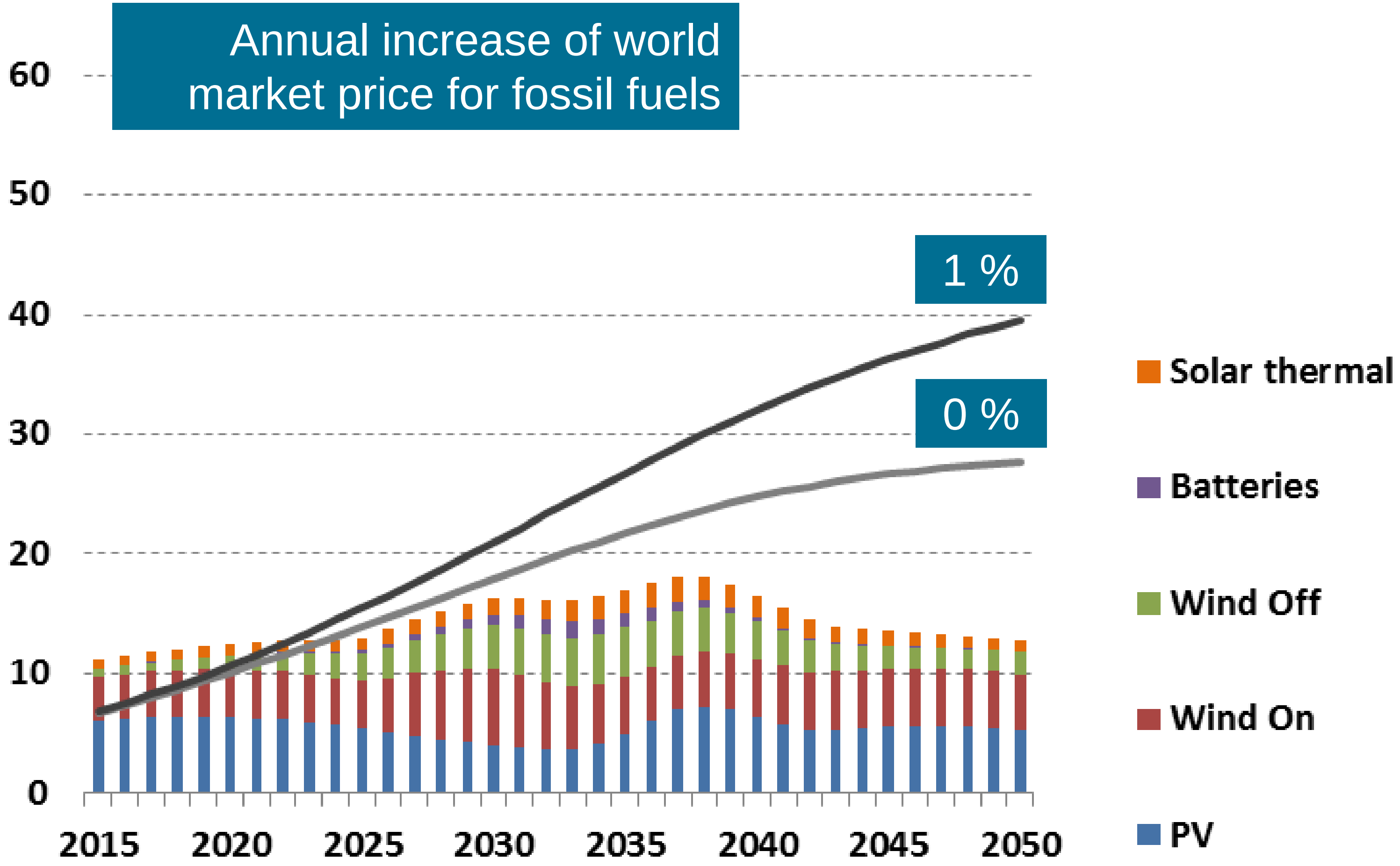


- Total investments (w/o capital cost, incl. re-powering) from 2015 to 2050: 515 bill. $€_{2014}$

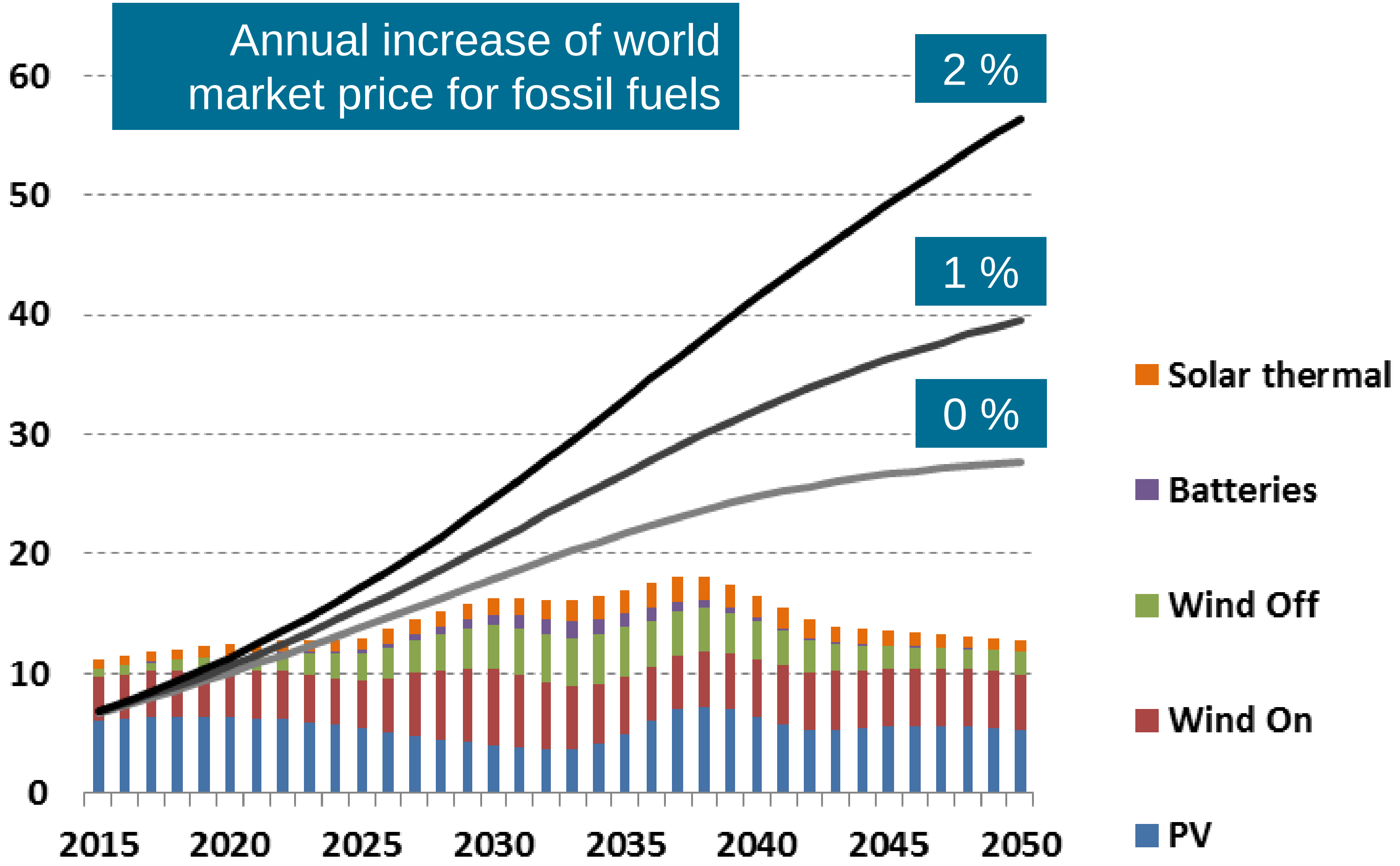
Investments vs. saved fuel cost in bill. € p.a.



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



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

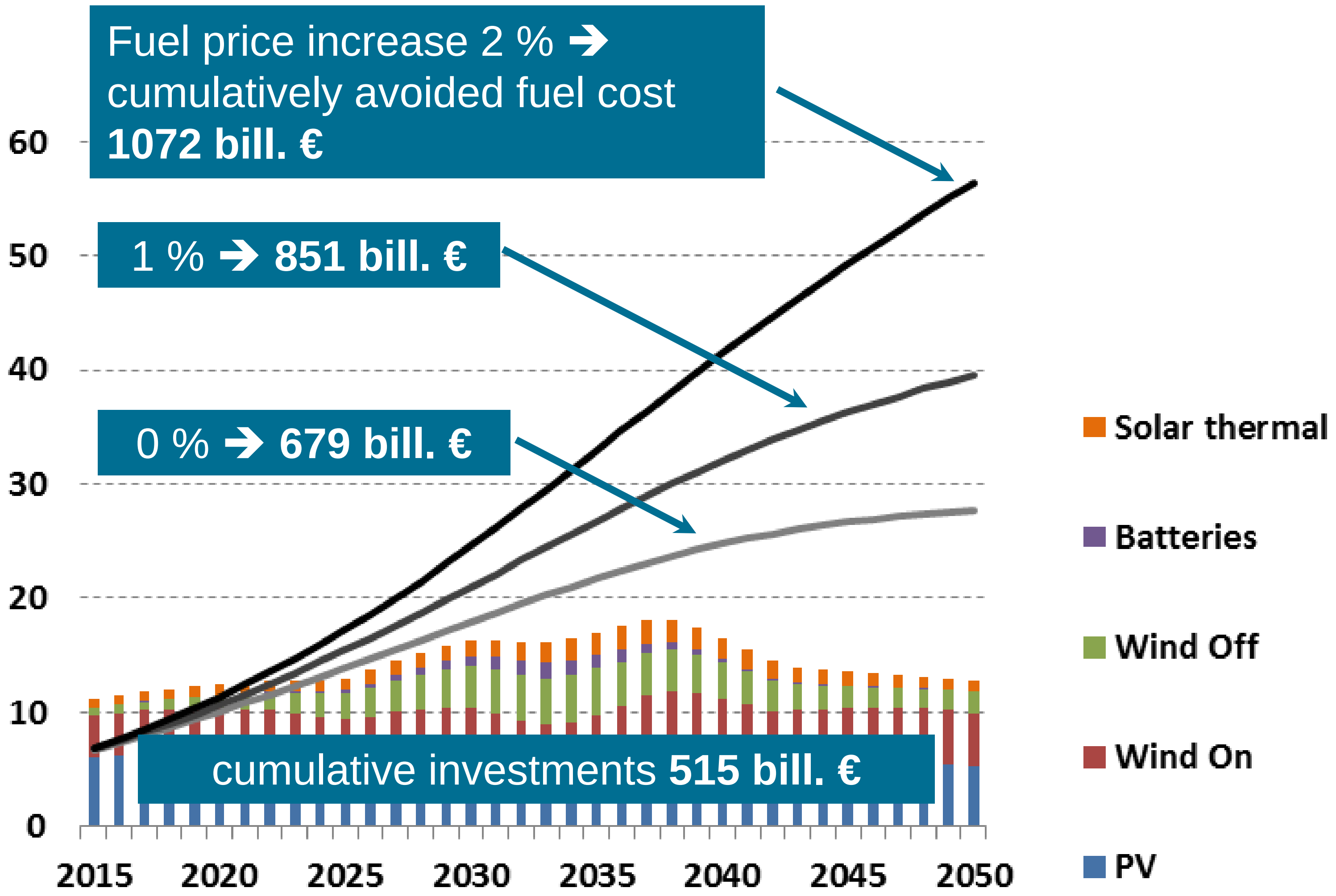


Task 52
Solar Heat and Energy Economics in Urban Environments

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Fraunhofer ISE

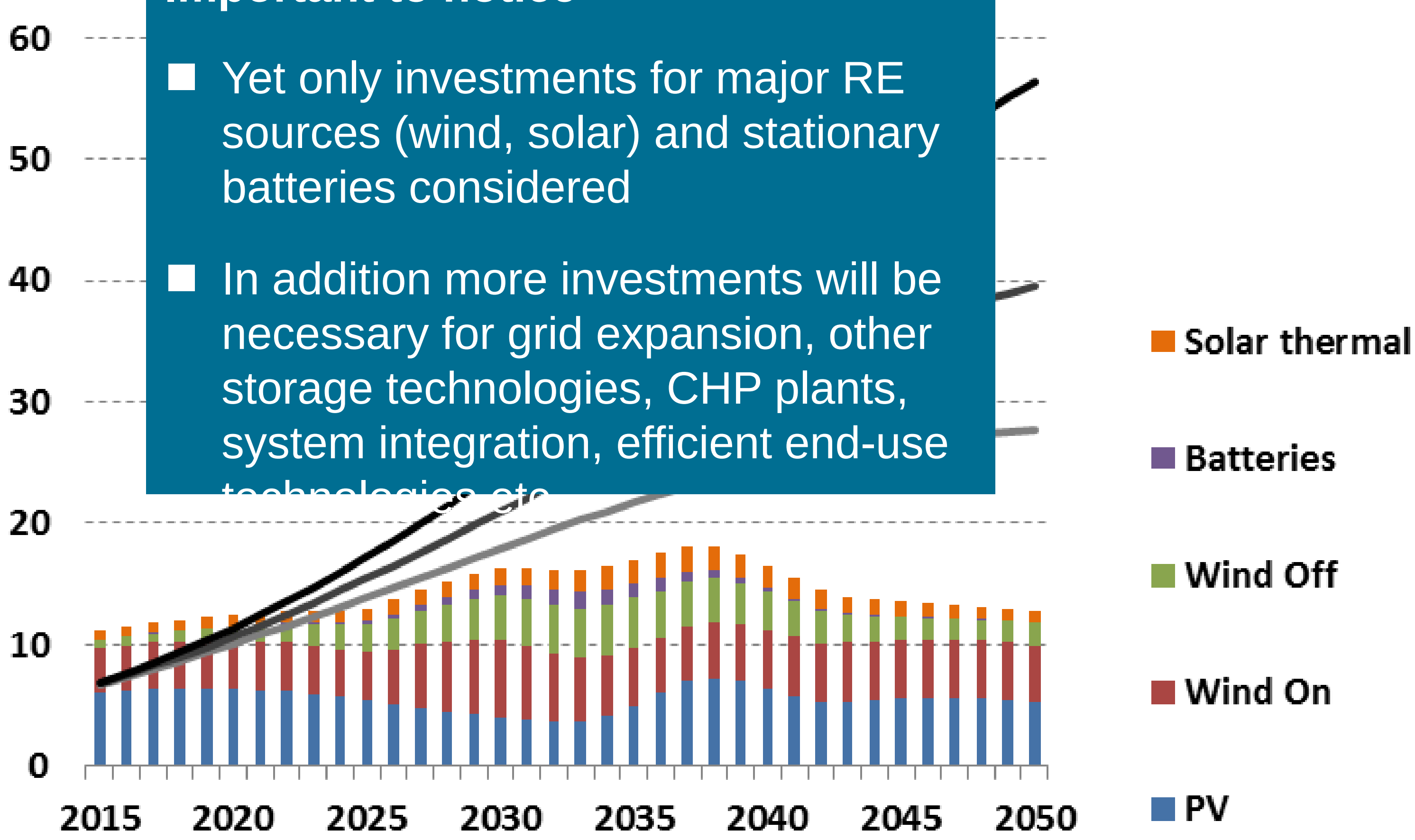
Investments vs. saved fuel cost in bill. € p.a.



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

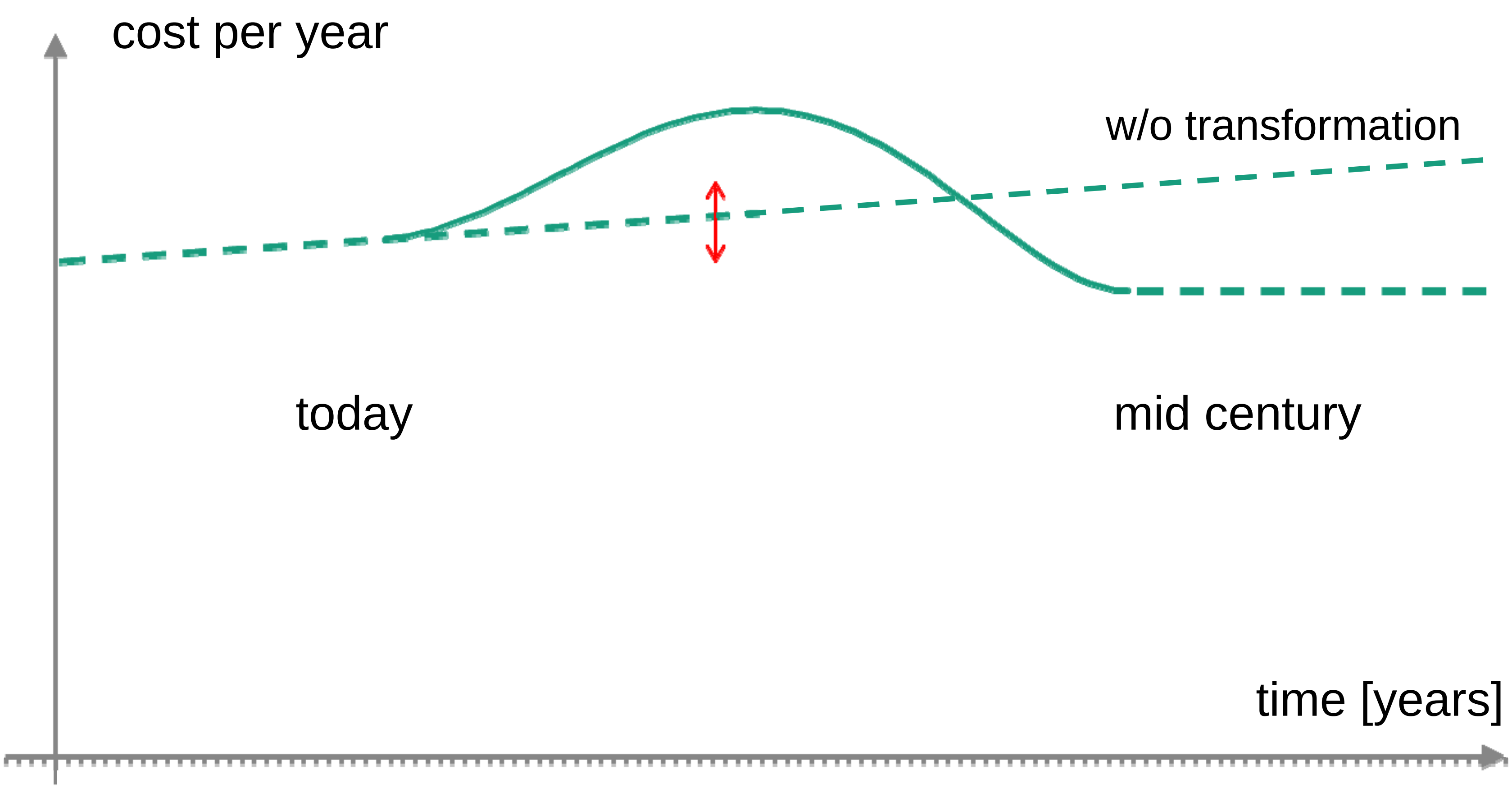
Important to notice

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



Transformation of the energy system

Qualitative trend of total annual cost



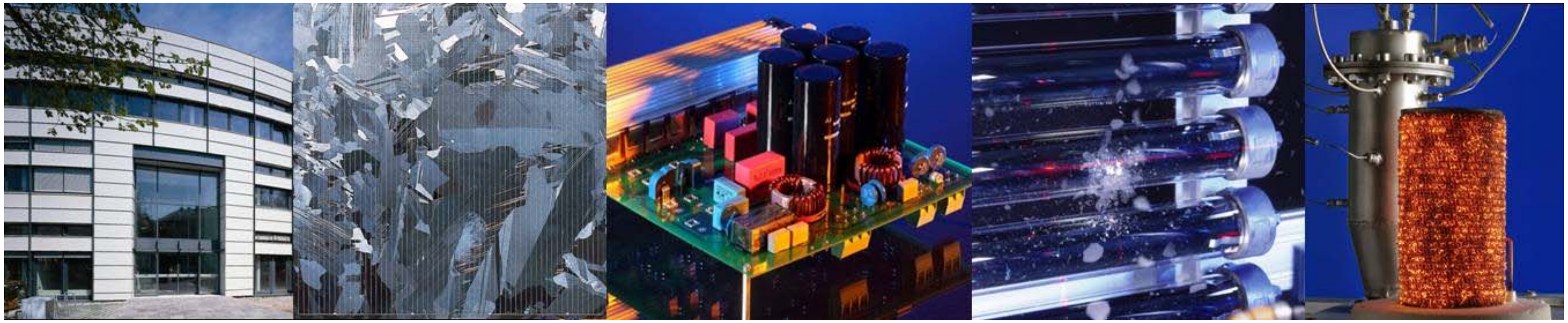
Summary 1/2

- 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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