Evaluating the value of concentrated solar power in electricity systems with fluctuating energy sources

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Outline

- What is residual load and how big will it be in Germany 2050?
- What technology can cover the residual load?
- How to find the lowest cost technology mix?
- Can import of CSP electricity contribute to this mix?

Principle of electric power supply: Supply and Demand need to match

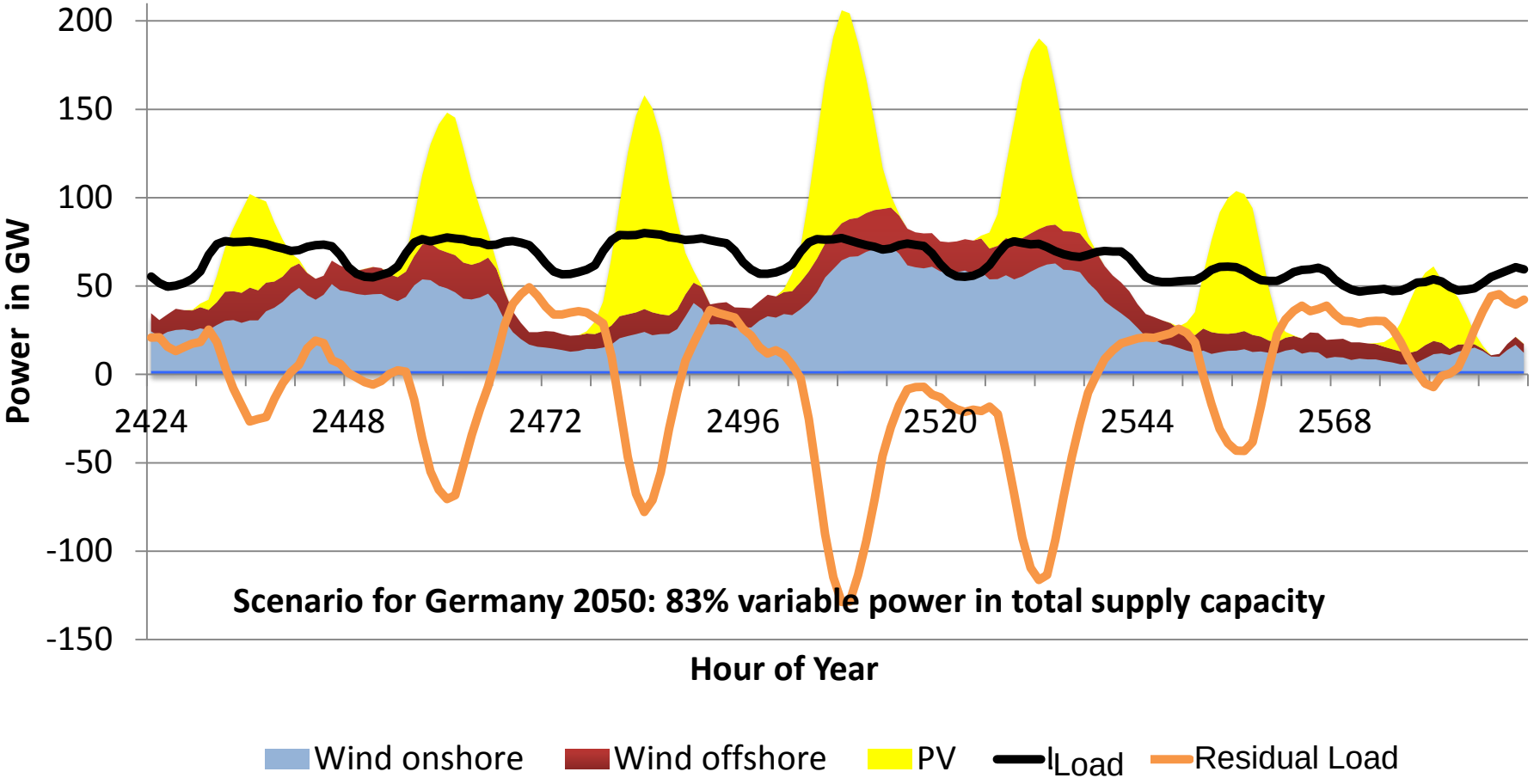

Figure: Wuppertal Institut

PV: 151 GW, Wind onshore: 82 GW, Wind offshore: 20 GW, Load deman: 602 TWh, FRES share: 83 %

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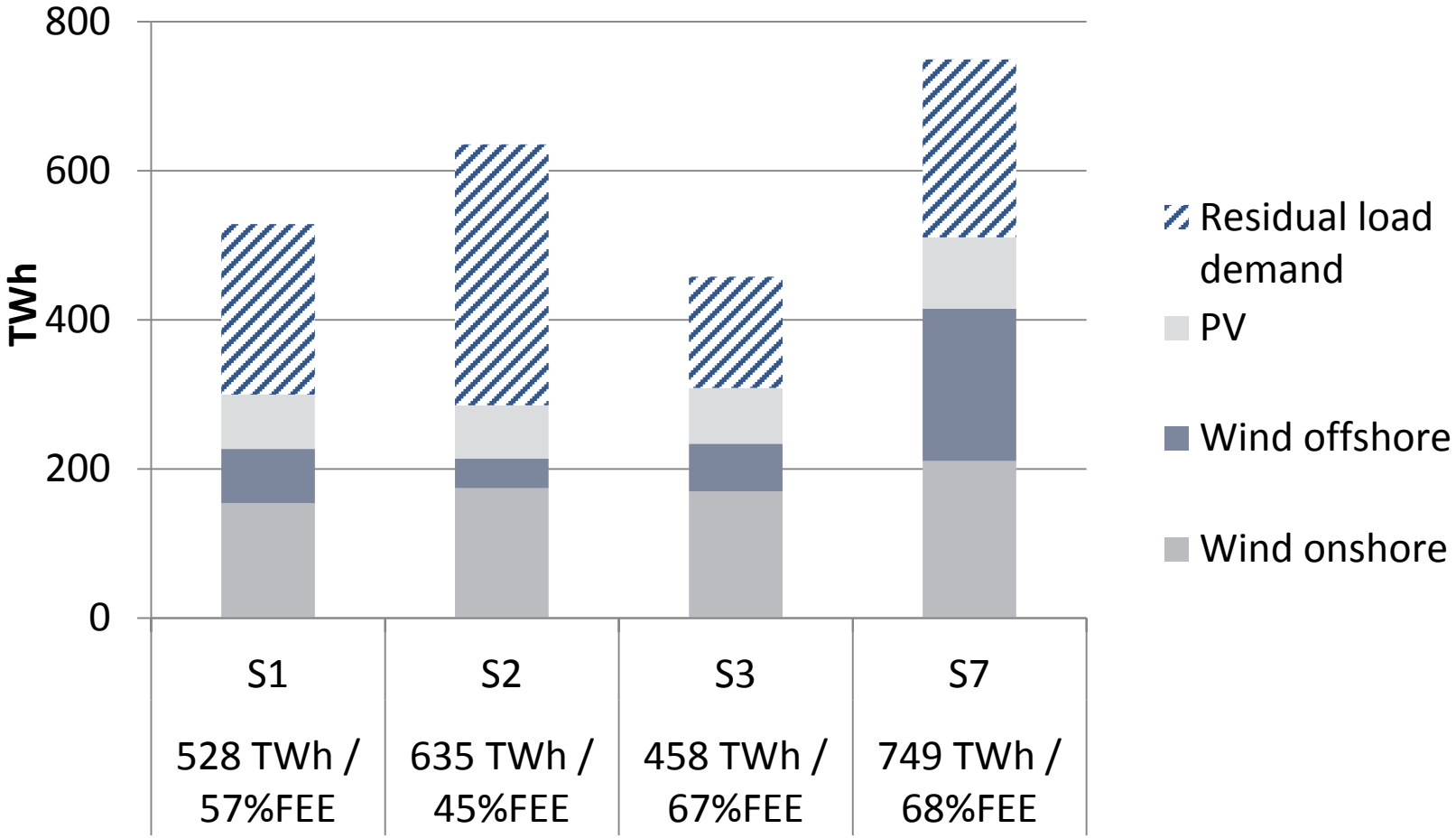
Energy Scenarios for Germany 2050:

The future may look very different….



How to cover the residual load (1/2):

Load following Biogas power plants

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Flexible fossil fuel power plant

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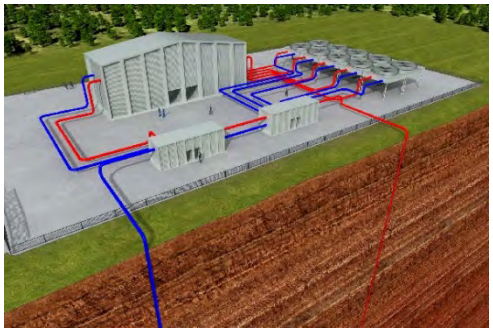
Load-following Combined heat and power



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Geothermal power plants with stoarge

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Concentrated Solar Power with storage (+.hybridisation)

Flexible generation capacity (net - producers)

How to cover the residual load (2/2):

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Demand Side Management (domestic)

© Andrei Merkulov / Fotolia

Demand Side Management (industry)

© Petair / Fotolia

Dual-use storage

Hanno Böck / https://hboeck.de/

Power-to-Gas (Chemicals)

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Grid extension

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Power-to-Heat

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Electric storage

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„smart grid“

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Curtailment of variable supply

Flexibility technologies to shift the supply in time or space

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Basic Idea

- Characterization of available technologies
  - Technical: efficiency, ramp up time, etc.
  - Economical: investment, O&M costs, fuel costs etc.
  - Basic dataset for important technologies is already available

- Determination of residual load to be covered
  - Fluctuating renewable infeed minus load
  - Hourly resolution for one year

- Cost-minimal selection of technologies (software tool)
  - Result: power system which is able to cover the residual load at all times
  - Selection based on full costs
  - Installed power, generated electricity and other data of used technologies

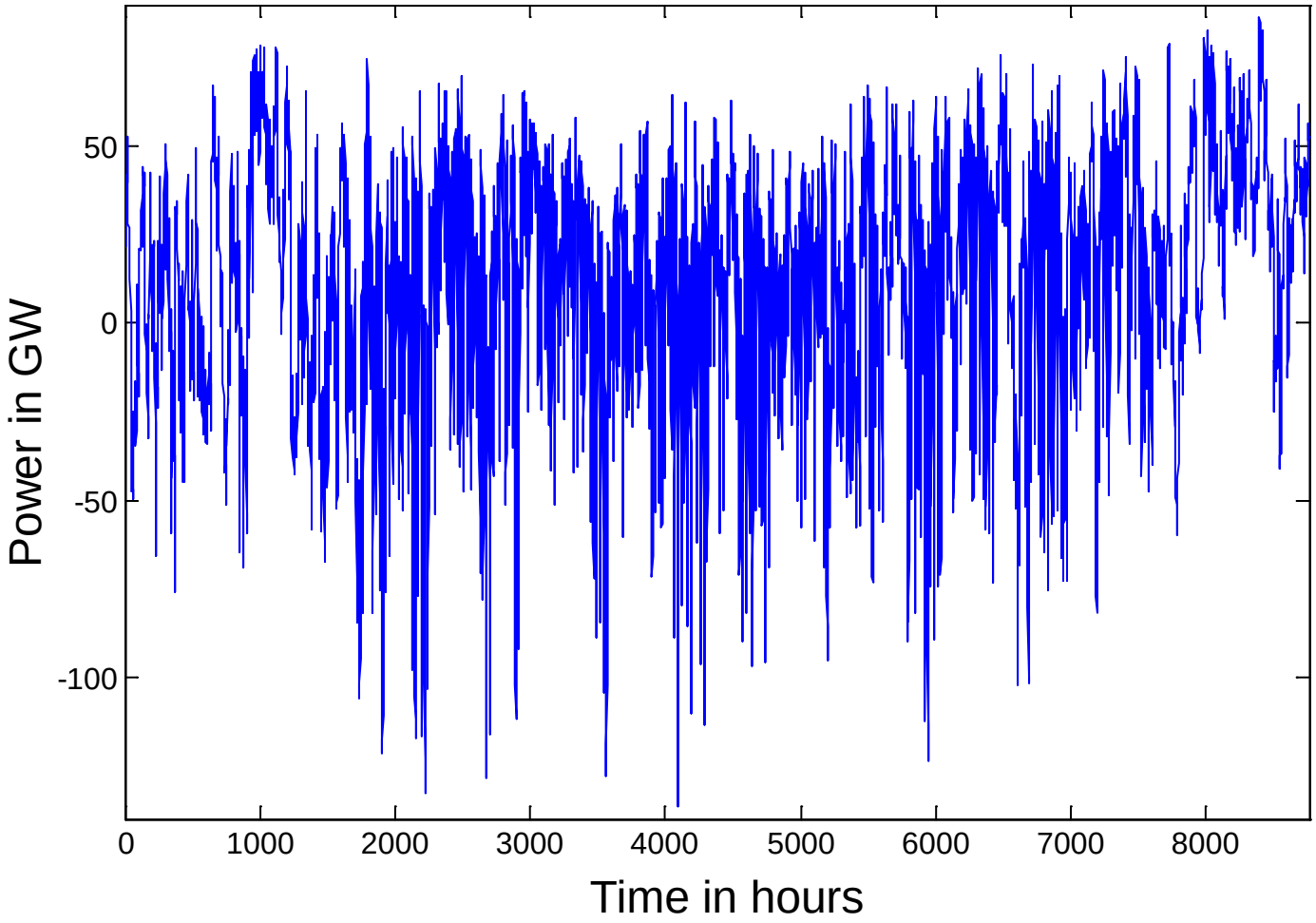
Simplified methodology: how optimizing the technology mix covering the residual load?

Cut residual load in individual load bands

Characterize the different load bands

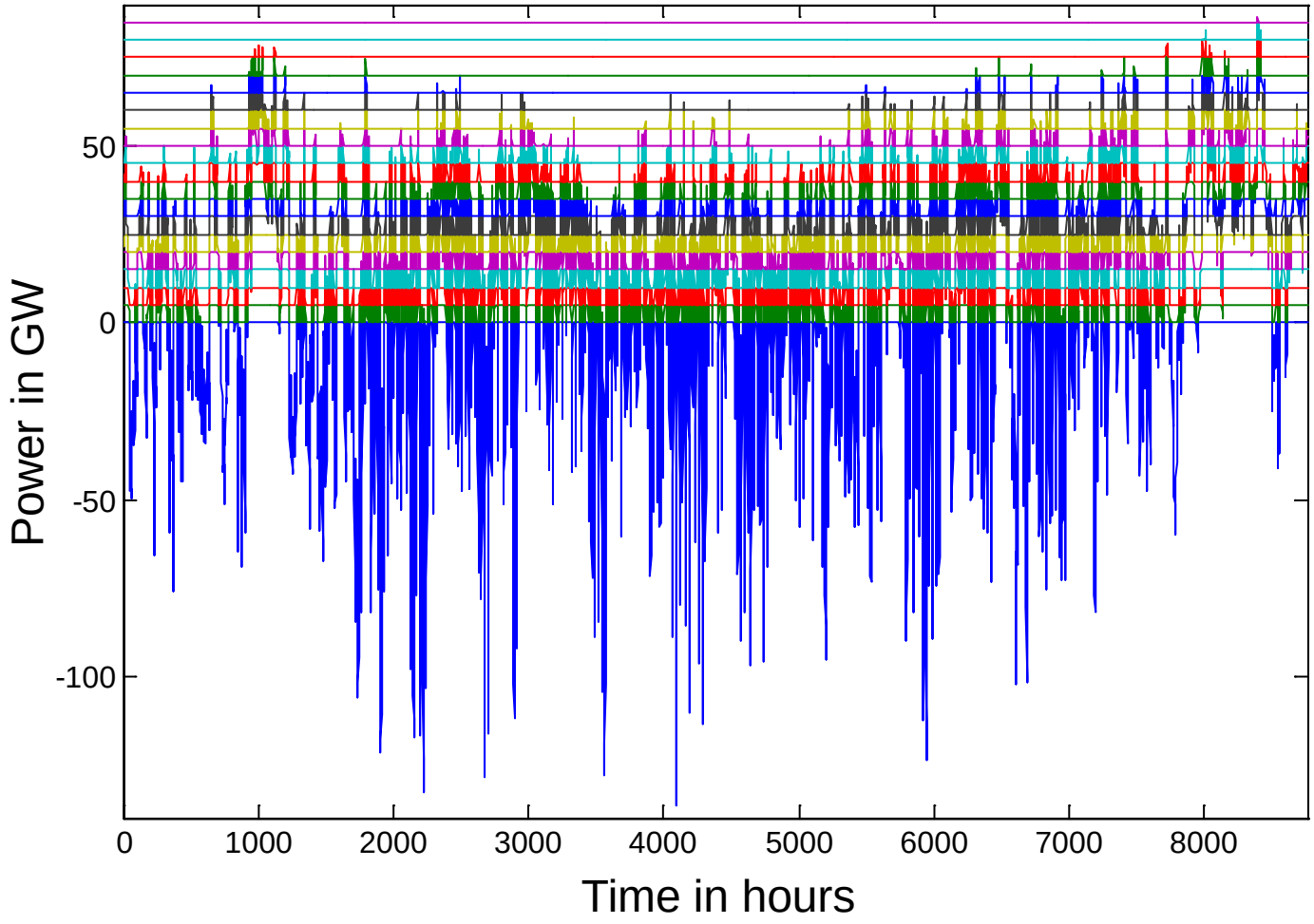
Identify for each load band the technology that covers the load at lowest cost

Residual load – for one year in hourly resolution

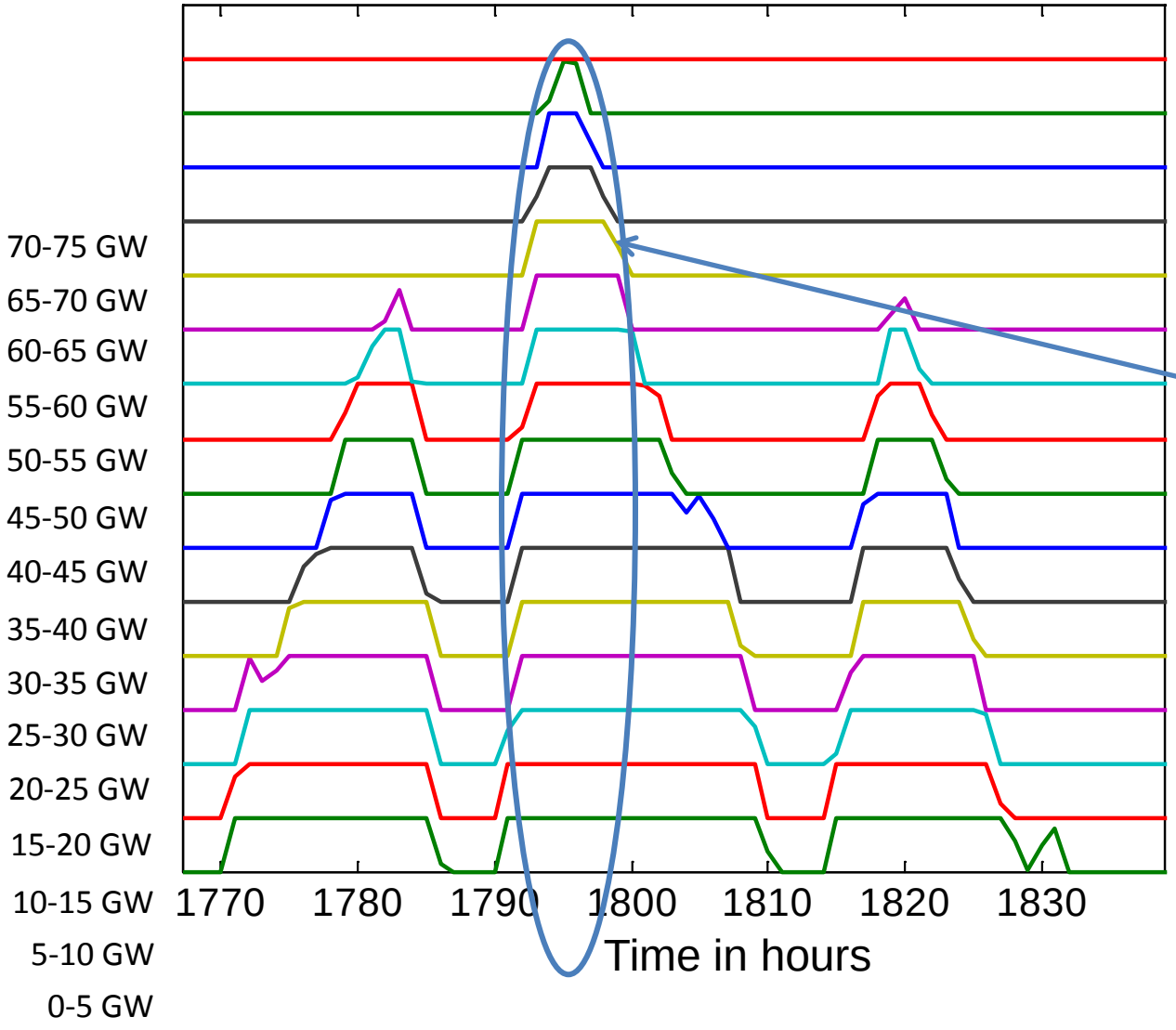


FRES-share 76%

Positive residual load is cut into load bands



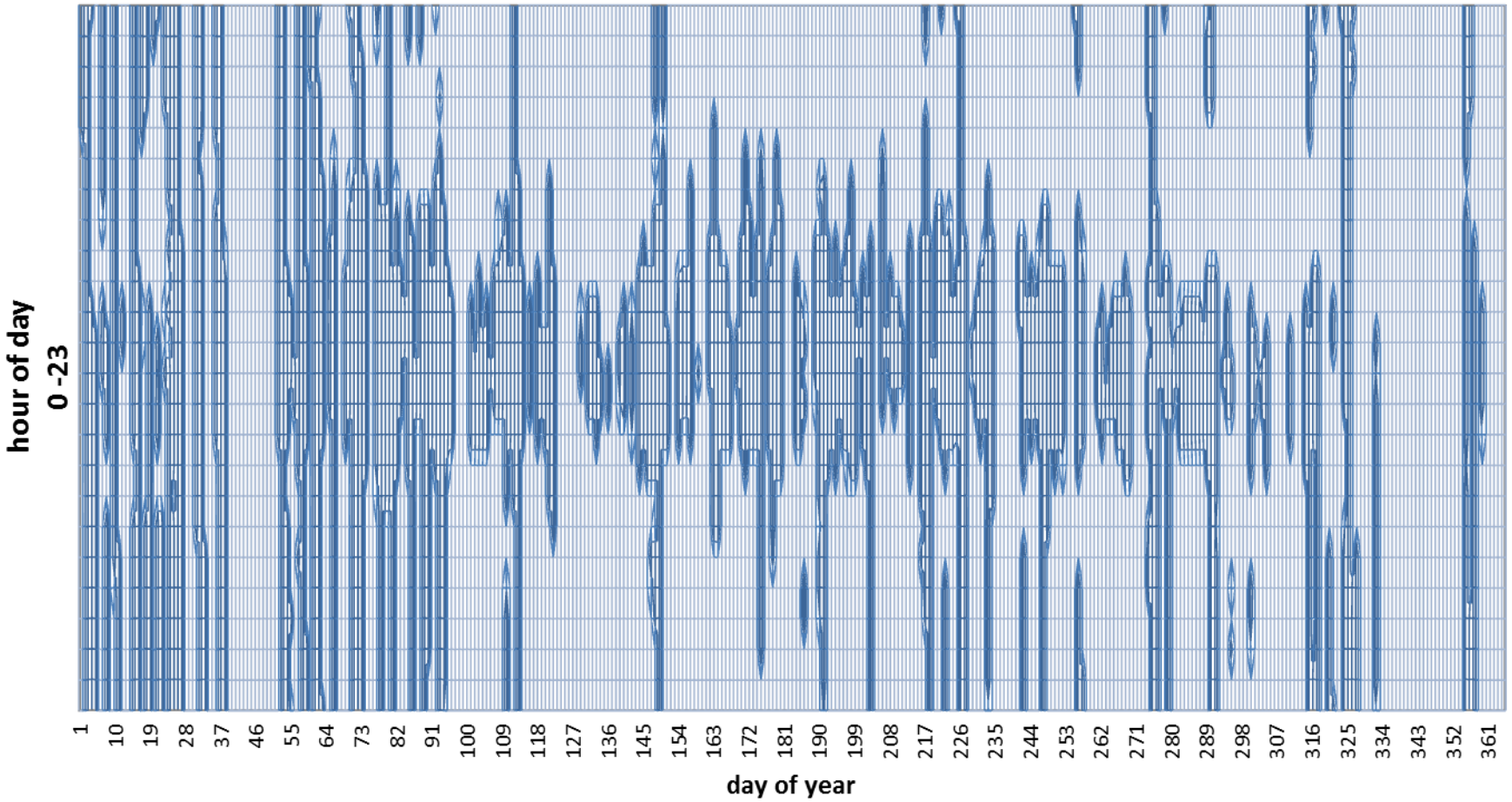
FRES-share 76%



A positive load in the top band indicates a positive load in all lower bands:
i.e. no system designed to cover the load in a lower band can provide additional energy to the upper band

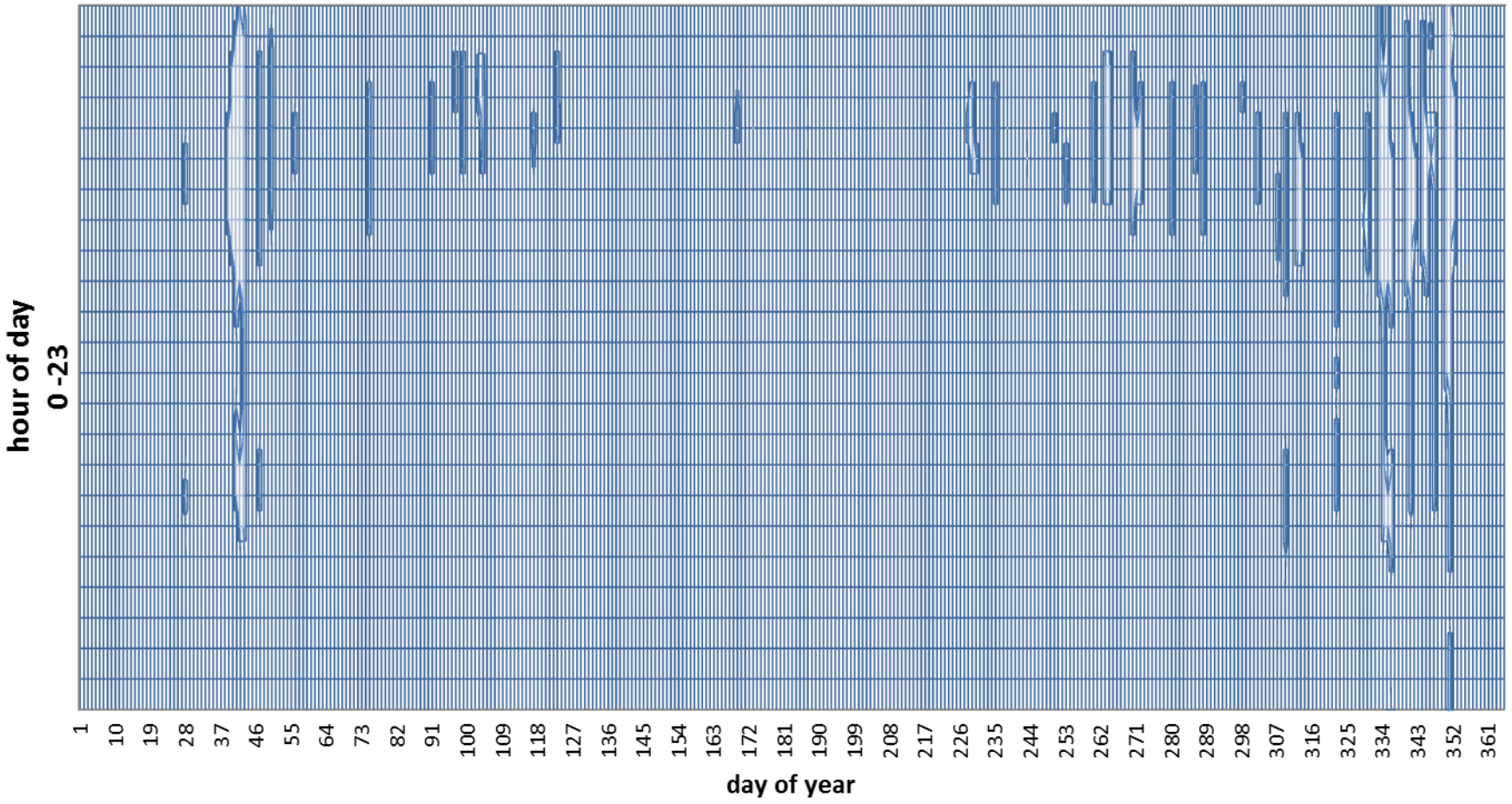
Example of the annual load curve of the lowest band

Band 1, 6596 full load hours



Example of the annual load curve of the highest band

Band 50, 346 full load hours



Example: Technologies compete in a load band

Technology (Cost in Mio. €/GW)	Lignite CCS	Gas Turbine	Combined Cycle
Full load hours in load band	**5970**	**5970**	**5970**
Annuity	221,0	32,7	61,0
Operation & Maintenance	89,1	13,1	21,0
Fuel cost	21,3	430,0	311,0
Start-up cost	6,0	5,3	18,6
CO_2-Cost	35,5	199,0	144,0
Total annual cost	373,0	680,0	556,0
Specific generation cost in €ct/kWh	**6,2**	**11,4**	**9,3**

WKA & PV 76%, Band 1 (1 GW)

Example: Technology competition in a different load band

Technology (Cost in Mio. €/GW)	Lignite CCS	Gas Turbine	Combined Cycle
Full load hours in Load band	**2520**	**2520**	**2520**
Annuity	221,0	32,7	61,0
Operation & Maintenance	89,1	13,1	21,0
Fuel cost	9,0	181,0	131,0
Start-up cost	6,3	5,4	20,9
CO_2-Cost	15,0	83,9	60,7
Total annual cost	340,0	316,0	295,0
Specific generation cost in €ct/kWh	**13,5**	**12,5**	**11,7**

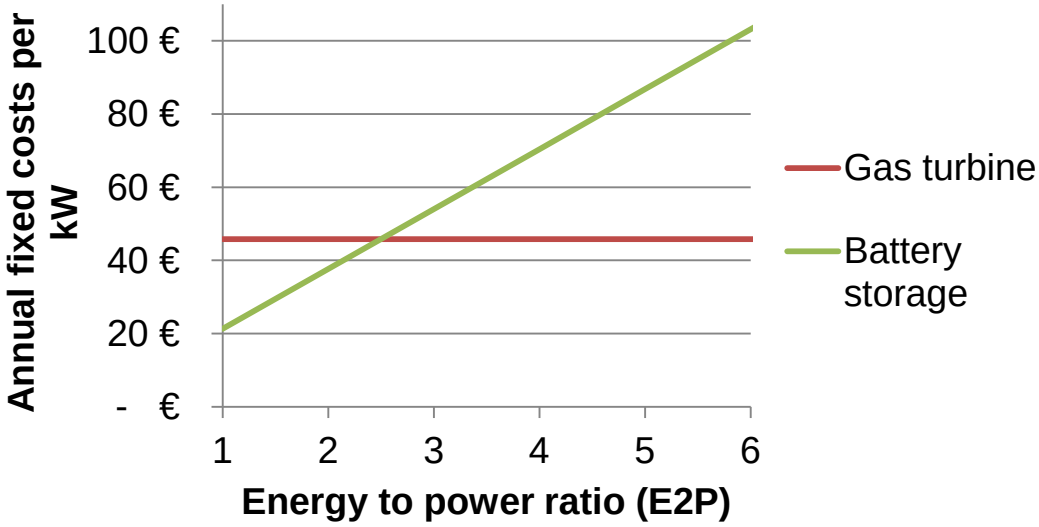
WKA & PV 76%, Band 36 (1 GW)

Example: Storage technology use negative residual to be charged

Technology (Cost in Mio. €/GW)	Hydrogen Storage	Methan-Storage	Gas-Turbine	Lignite CCS
Full load hours (Discharge)	3110	3110	3110	3110
Charging Power	4,5 GW	8,8 GW	-	-
Capacity	796 GWh_{th}	964 GWh_{th}	-	-
Total annual cost	323 Mio. €	1061 Mio. €	338 Mio. €	345 Mio. €
Specific storage/ generation cost	**10,4 €ct/kWh**	**34,1 €ct/kWh**	**10,9 €ct/kWh**	**11,1 €ct/kWh**

FRES-share 76%, Band 36 (1 GW)

Batteries vs. power plants

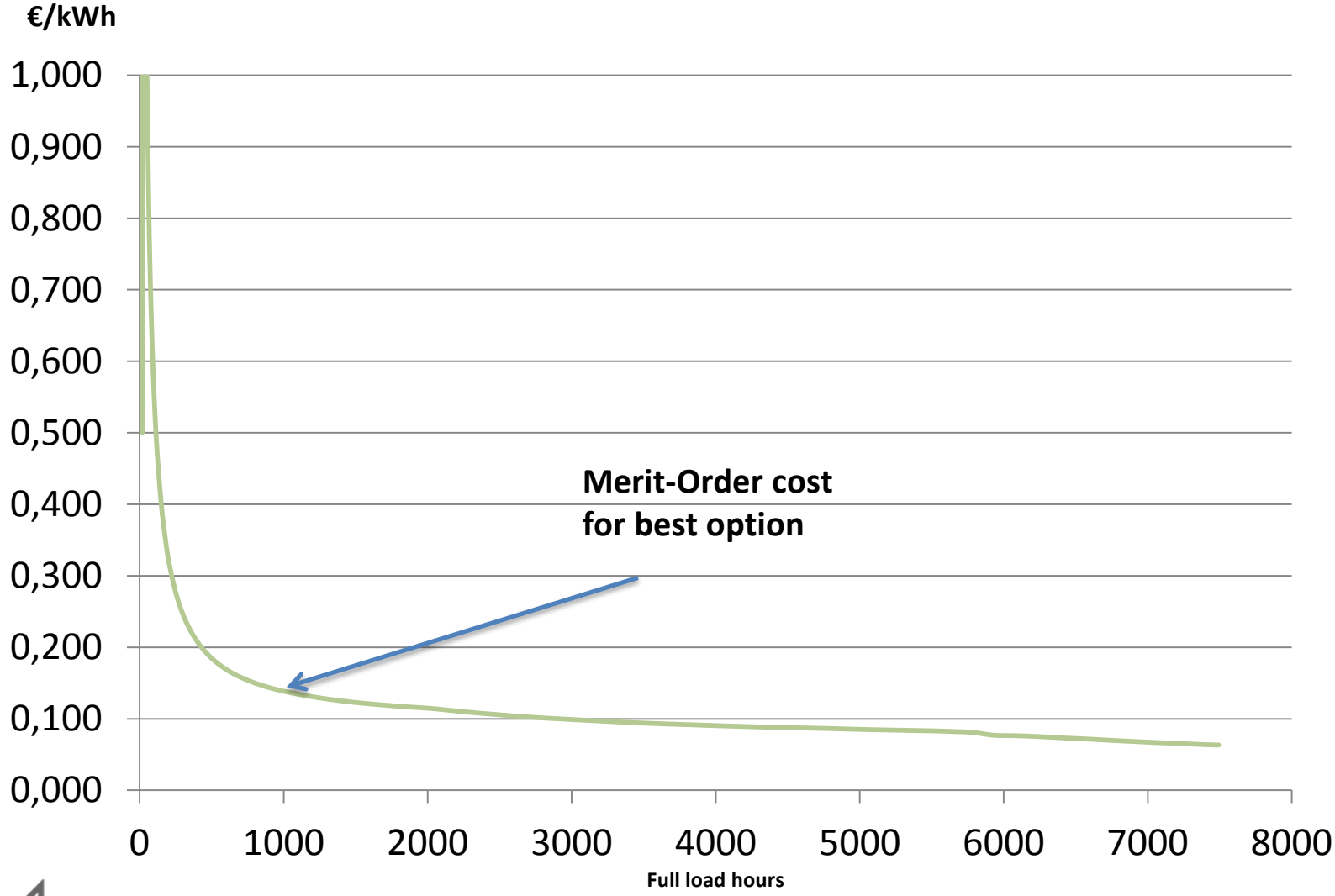


Gas turbine
- 375 €/kW
- Lifetime >30a

Battery storage
- 45 €/kW **plus** 150 €/kWh
- Lifetime <30a

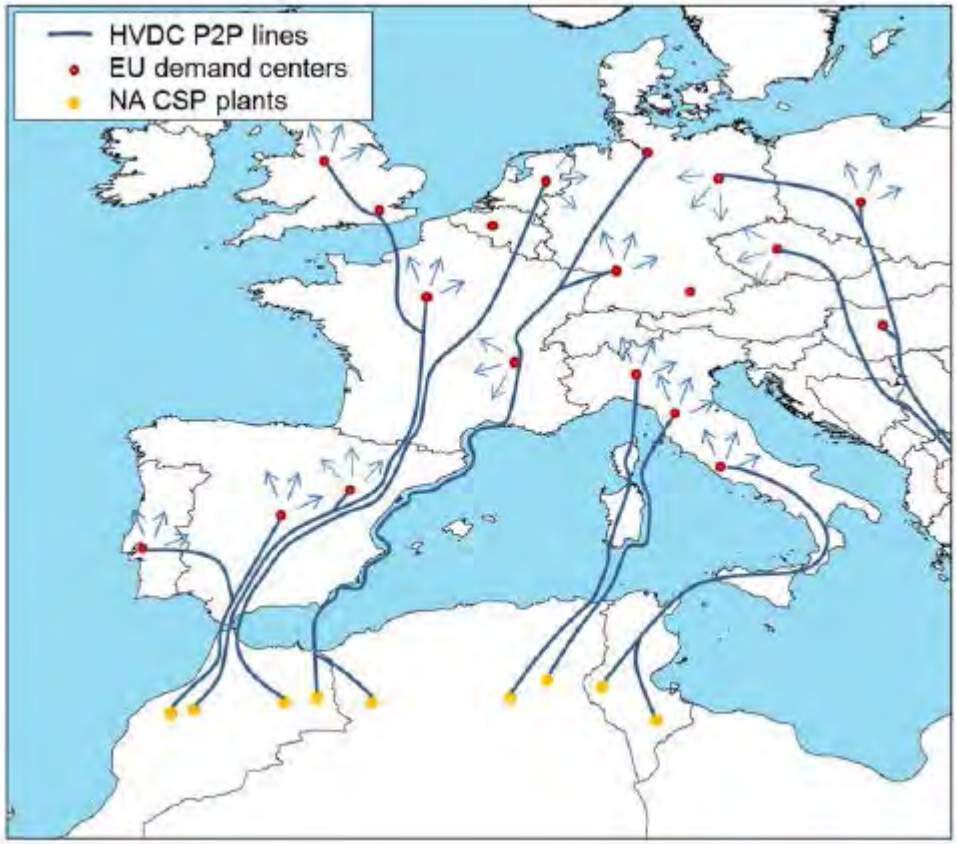
- Certain E2P necessary for delivering power to a load band
- In comparison to gas turbines battery storage is not economic for supplying power to a load band, if E2P > 2,5h is necessary (1GW and > 2,5 GWh)
- Battery storage rather used for optimizing operation of conventional power plants or for supplying peak loads.

The electricity cost of the „winning technologies“ as a function of the full load hours



Datenquelle: Prof. Pitz-Paal

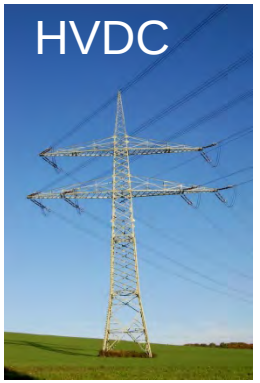
Is CSP import an economic option for Germany to cover a part of the residual load?



CSP + HVDC cost assumptions for 2050

	2050 (min)	2050 (max)
System parameters		
Annual System efficiency sol- > electr	19%	22%
Annual system effciency fossil -> electr.	45%	50%
CO2 Emission factor (natural gas) [t/MWht	0,247	0,247
specific CSP cost		
Solar field [€/m²]	55	80
Themal storage	11	16
Power block	590	750
Engineering, Development, EPC, Continge	25%	29%
Annual O&M % of invest	2%	2%
specific fuel cost[€/MWhth]	33,1	33,1
CO2 penalty [€/t CO2]	76,0	76,0
Financial parameters		
life time	30	30
interest rate	8%	8%

	2050 (min)	2050 (max)
Cost HVDC		
Earth cable €/kM-MW	700	720
Sea cable €/kM-MW	825	850
Overhead line €/kM-MW	120	125
Cost per DC/AC Station €/MW	90.000	95.000
Losses earth cable %/1000kM	3,50%	3,50%
Losses sea cable %/1000kM	2,70%	2,70%
Losses overhead cable %/1000kM	4,5%	4,5%
Losses AC/DC conversion	0,7%	0,7%
Annual O&M % of Invest	2%	2%
Lifetime HVDC	40	40
interest rate	8%	8%



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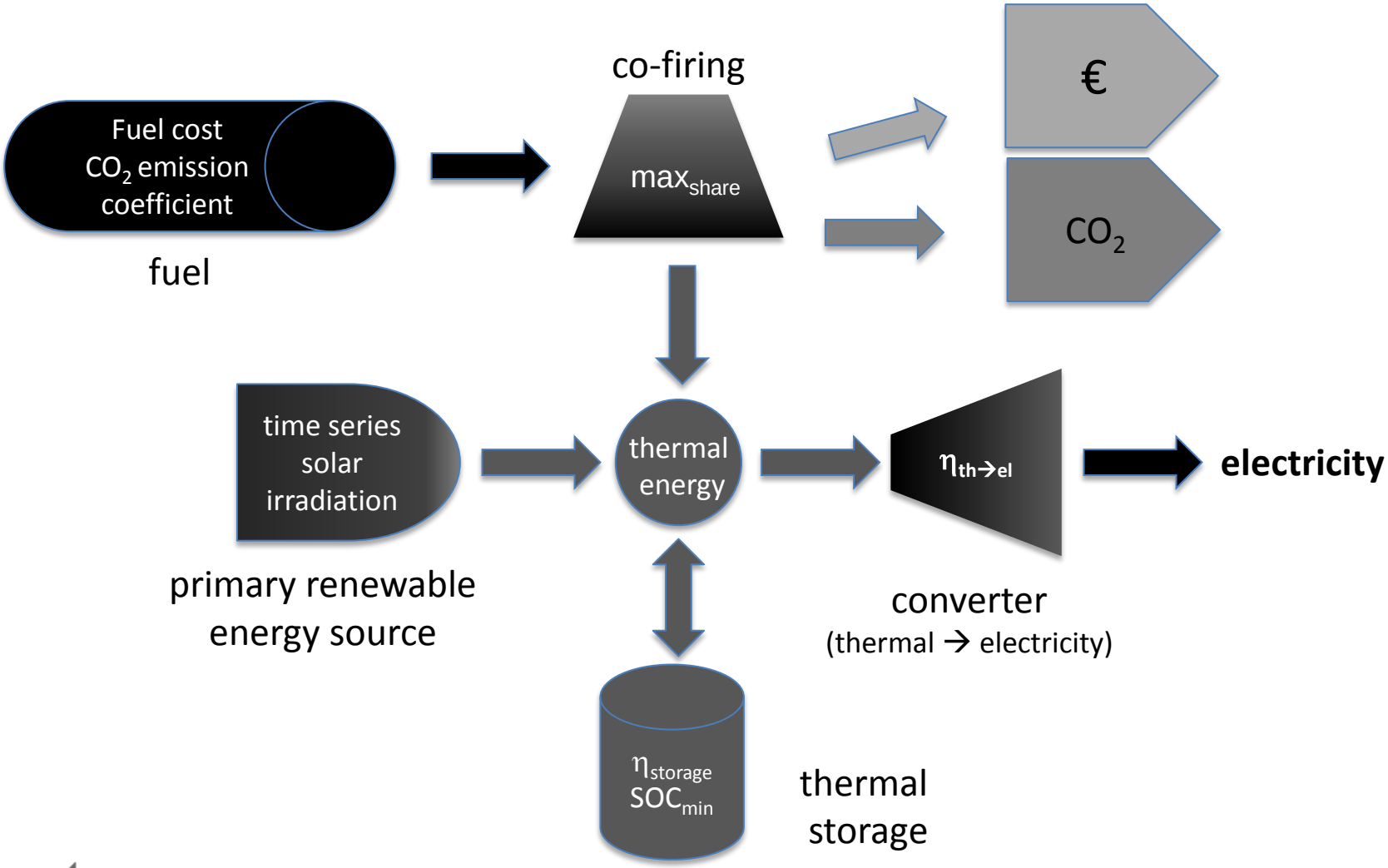
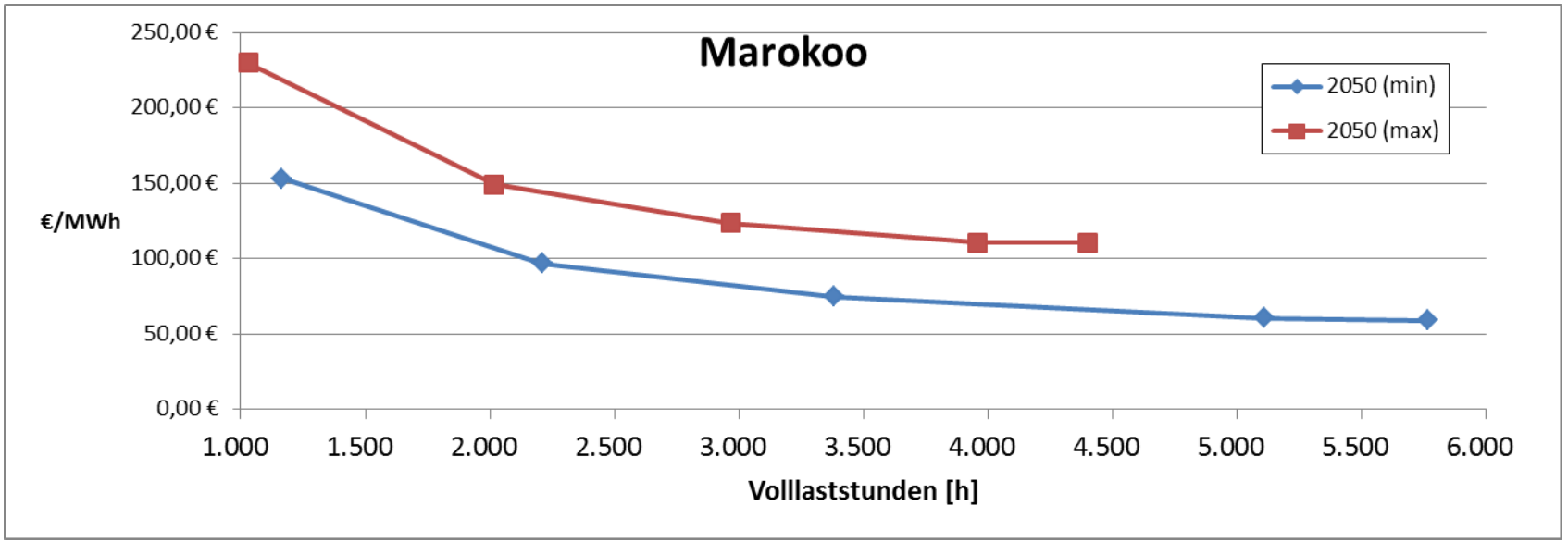
CSP plant optimization for each load-band

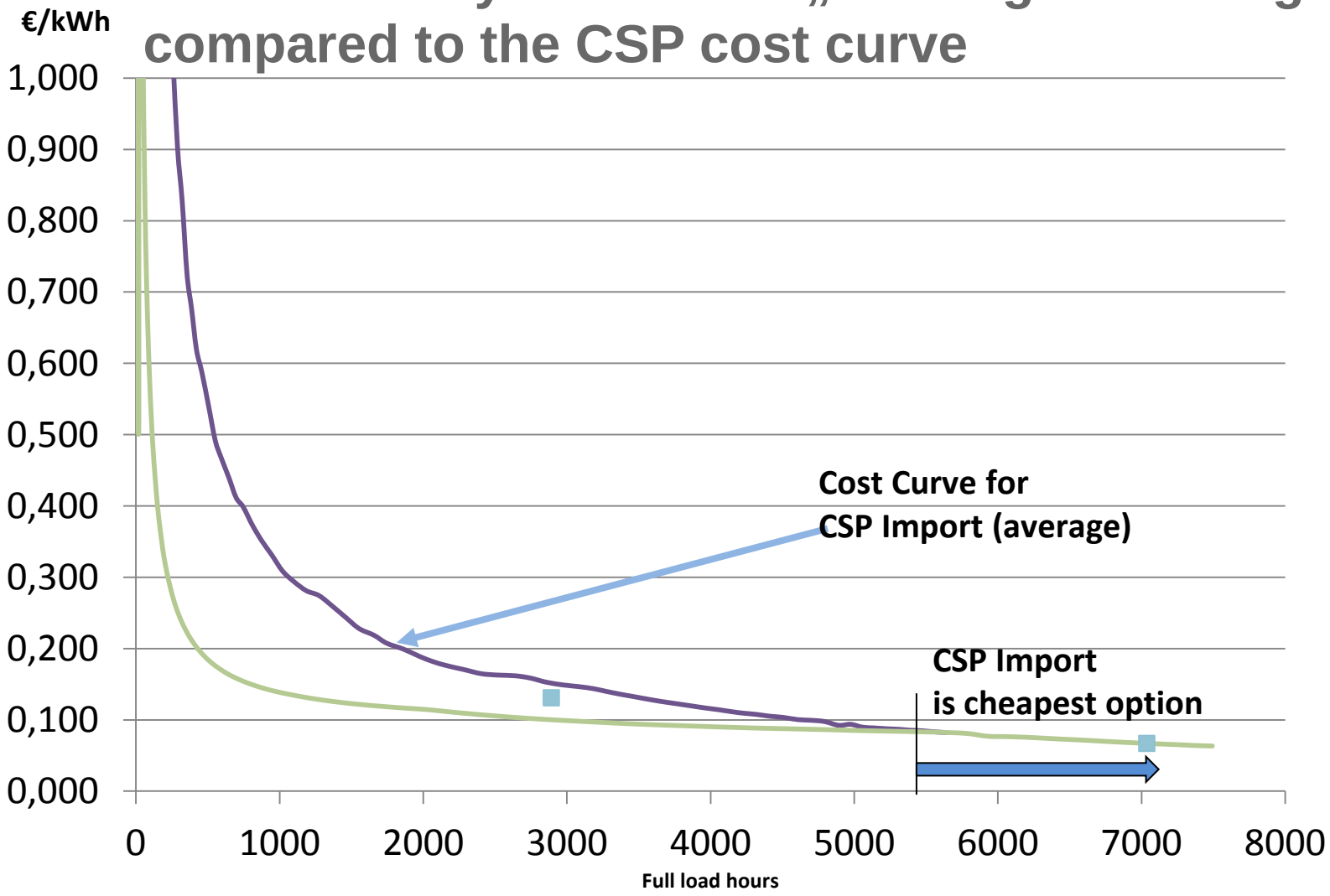


Generation cost to cover different load bands: CSP Generation + HVDC + Fuel + CO_2 Penalty



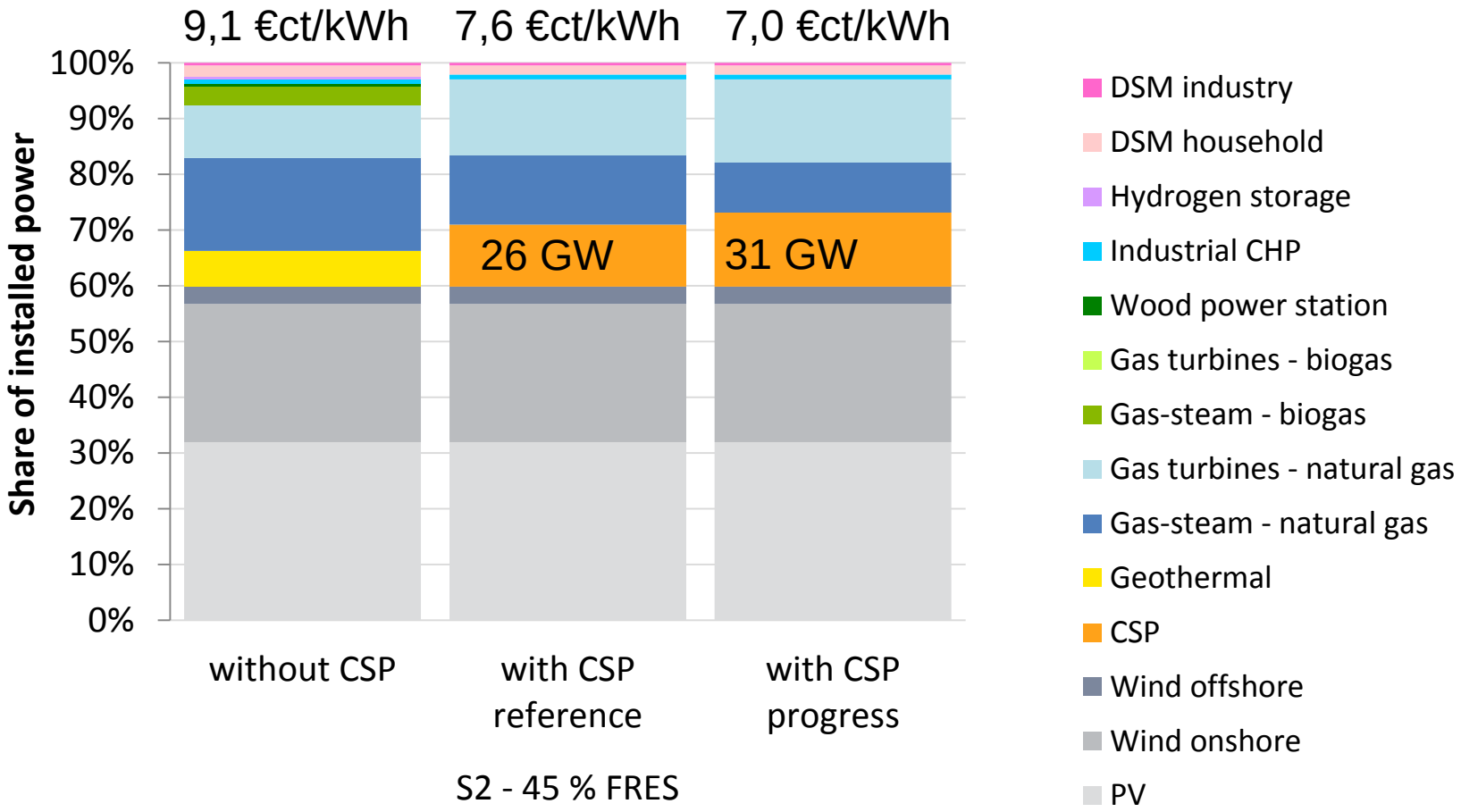
- Reference case is average between 2050 min and max
- Progress case is equal to 2050 max

The electricity cost of the „winning technologies“ compared to the CSP cost curve



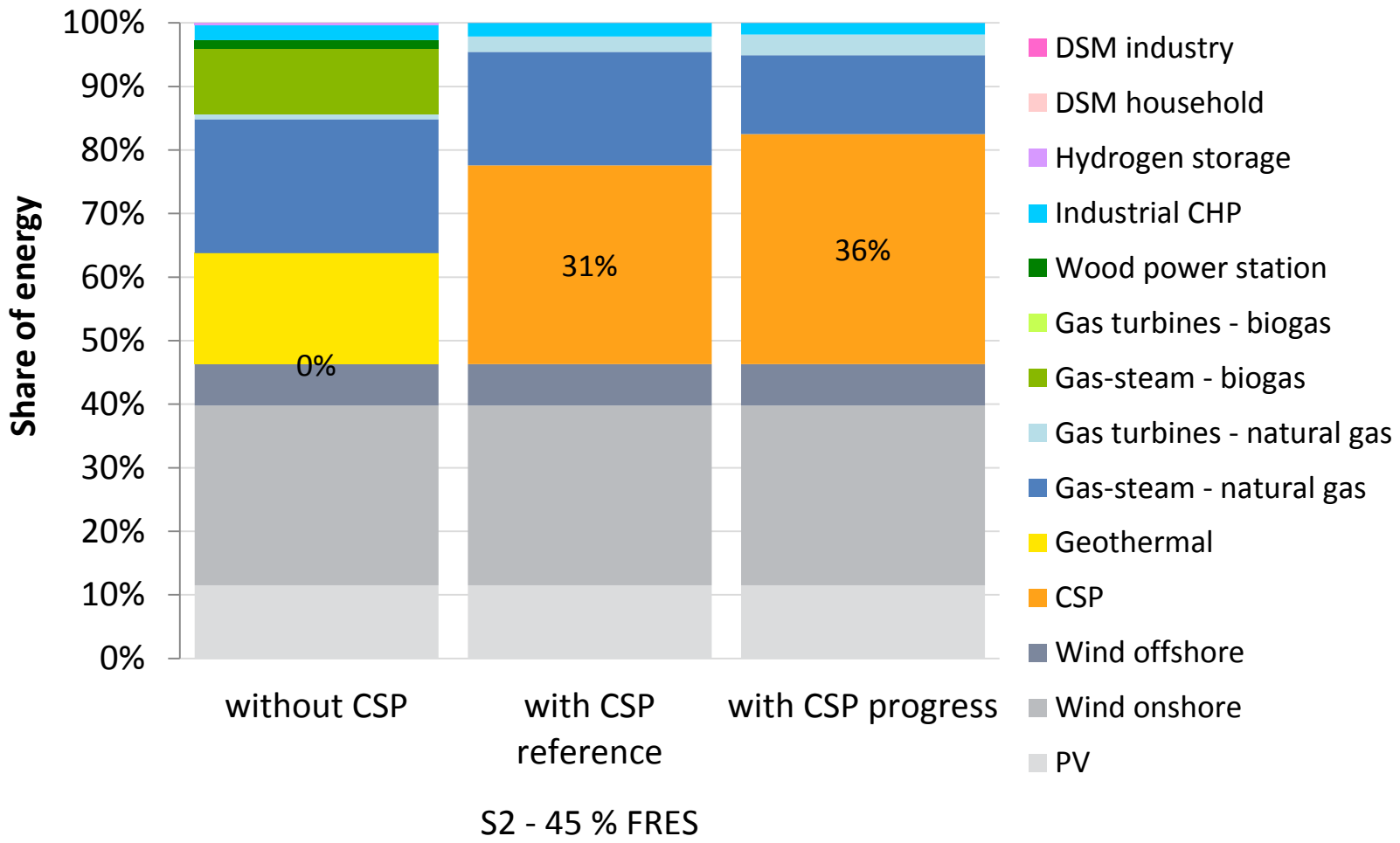
1. Example Results for 90% CO_2 Reduction Target

Fraction of Wind an PV 45%; 100% = 234 GW



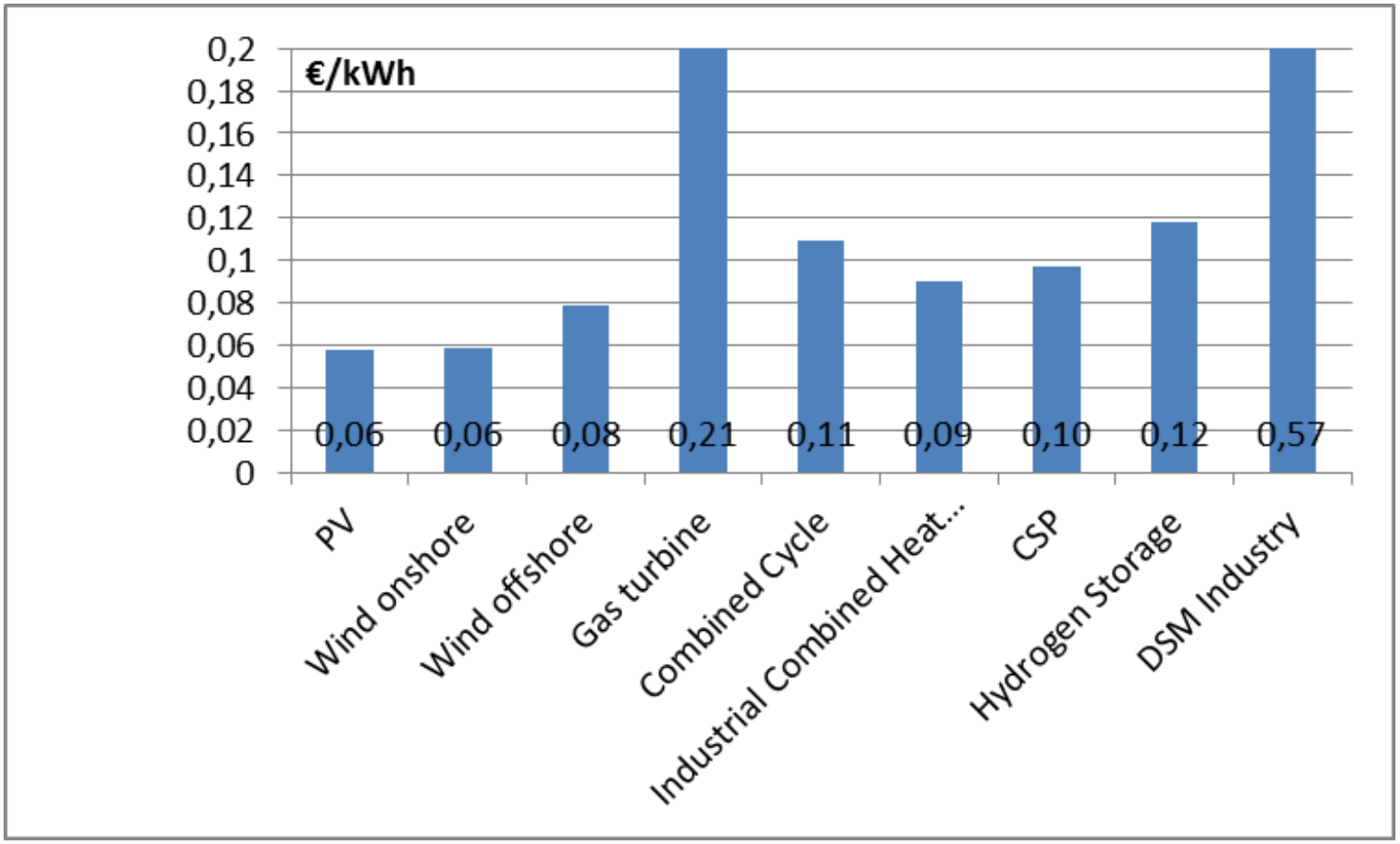
1. Example Results for 90% CO_2 Reduction Target

Fraction of Wind an PV 45% 100% = 635 TWh



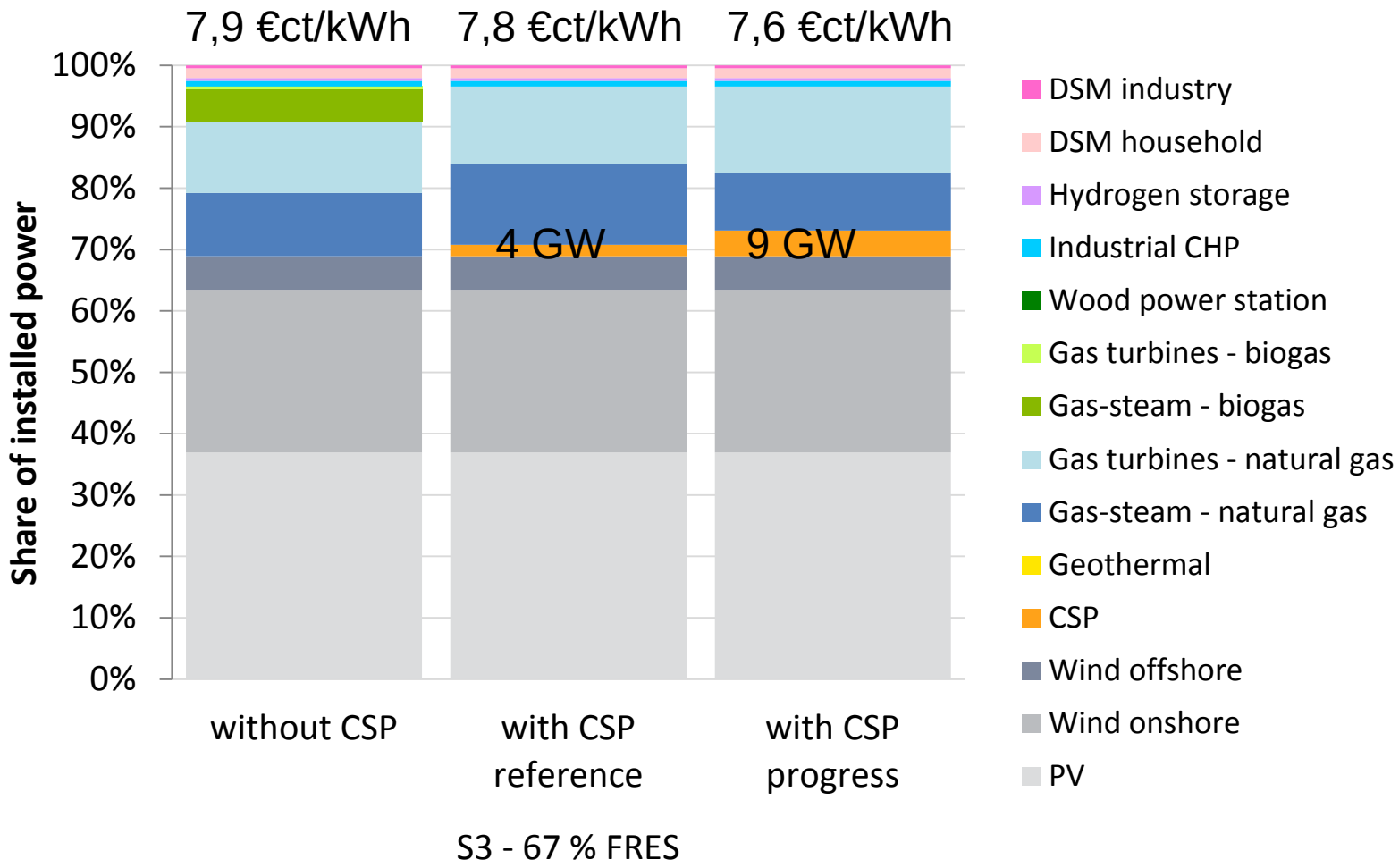
S2 - 45 % FRES

Mix of energy cost in CSP reference scenario



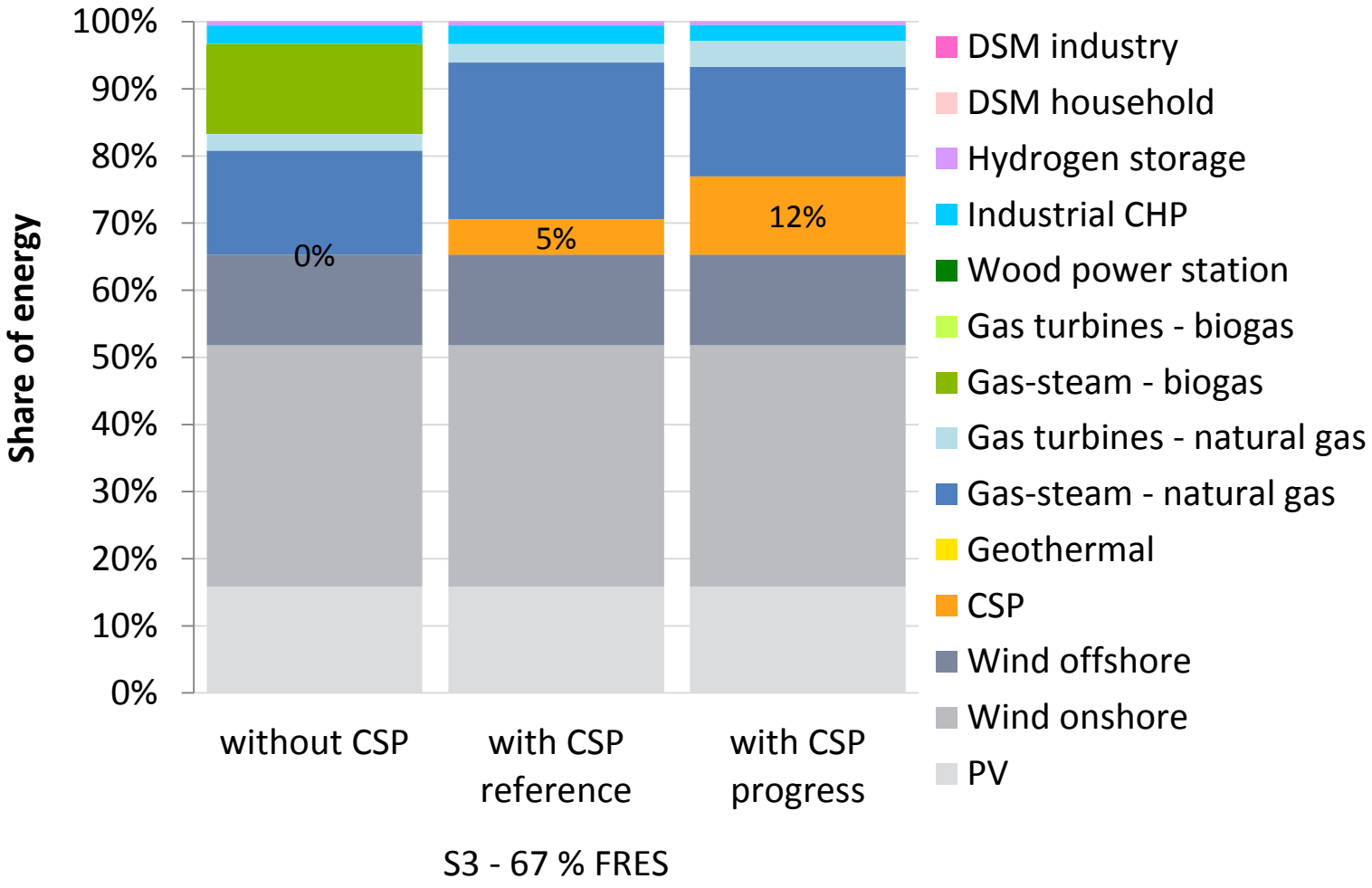
2. Example: Results for 90% CO_2 Target

Fraction of Wind an PV 67%; 100% = 213 GW

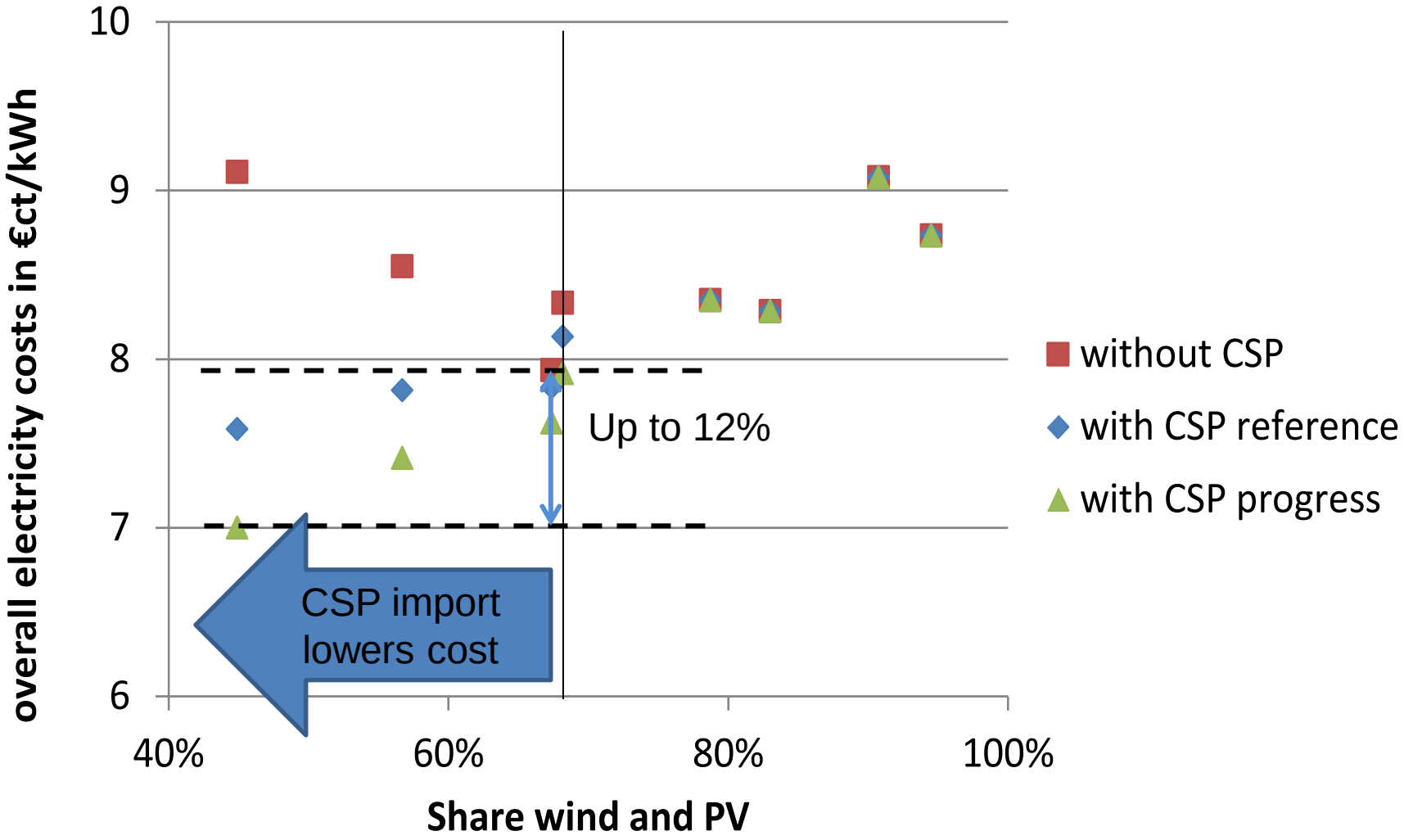


1. Example: Results for 90% CO_2 Target

Fraction of Wind an PV 67%: 100% = 458 TWh



CSP import lowers electricity cost to cover residual load



Summary

- In energy systems with high shares of fluctuating renewables a mix of technology options is required to balance the residual load
- A simplified methodology is presented, that can cost-optimize the technology mix to cover the residual load for different energy scenarios
- Import of hybrid CSP by HVDC is considered as one reasonable option in Germany in this context to achieve a 90% CO_2 reduction goal until 2050
- Import of CSP allows for up to 12,5% lower overall electricity cost compared to reference case and would require less PV and wind power in Germany
- CSP is required for mid-load power and replaces mainly biomass power plants
- This analysis can be considered as a first step. Issues that are not considered are grid limitations, role of existing depreciated facilities, integration of European capacity and other aspects.

New SolarPACES Grid Integration Working Group under preparation using this Methodology

- Which role can CSP play in national power systems?
- What are the key factors which influence the use of CSP?
- How are CSP systems dimensioned in a power system context?
  - Size of storage, collector field, co-firing unit, turbine
- What is the mix of generation, storage and other flexibility technologies?
- What are the electricity generation costs?

If you are an expert and have access to country specific data, you are invited to join.