energy
scenarios
school

Requirements for electrical energy storage

State of research and results from the energy system model REMix

2nd German-Japanese Workshop on Renewable Energies

Stuttgart, 07/05/2017

Dipl. Wi.-Ing. Felix Cebulla

German Aerospace Center (DLR)

Systems Analysis and Technology Assessment

DLR

Agenda

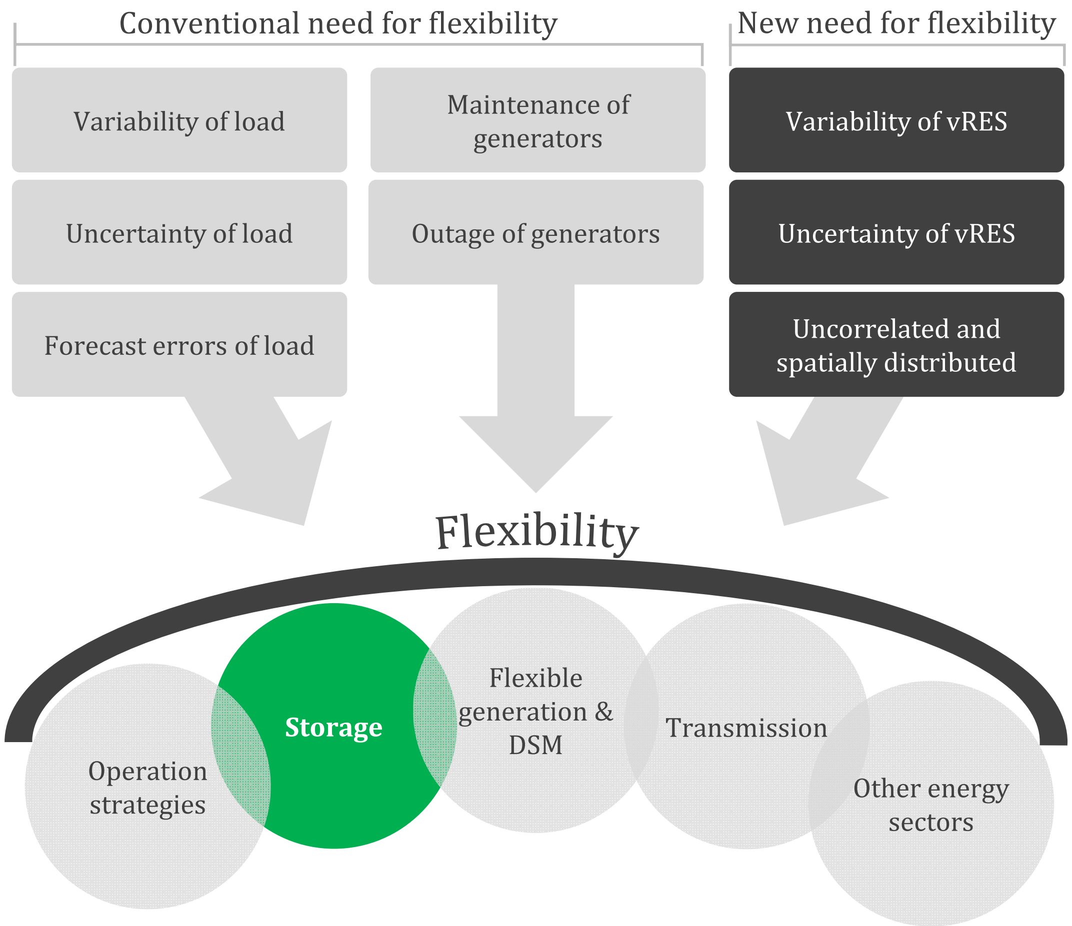
I. The need for system flexibility

II. Status quo: storage capacity requirements

III. Storage demand in highly renewable European energy scenarios

IV. Conclusions

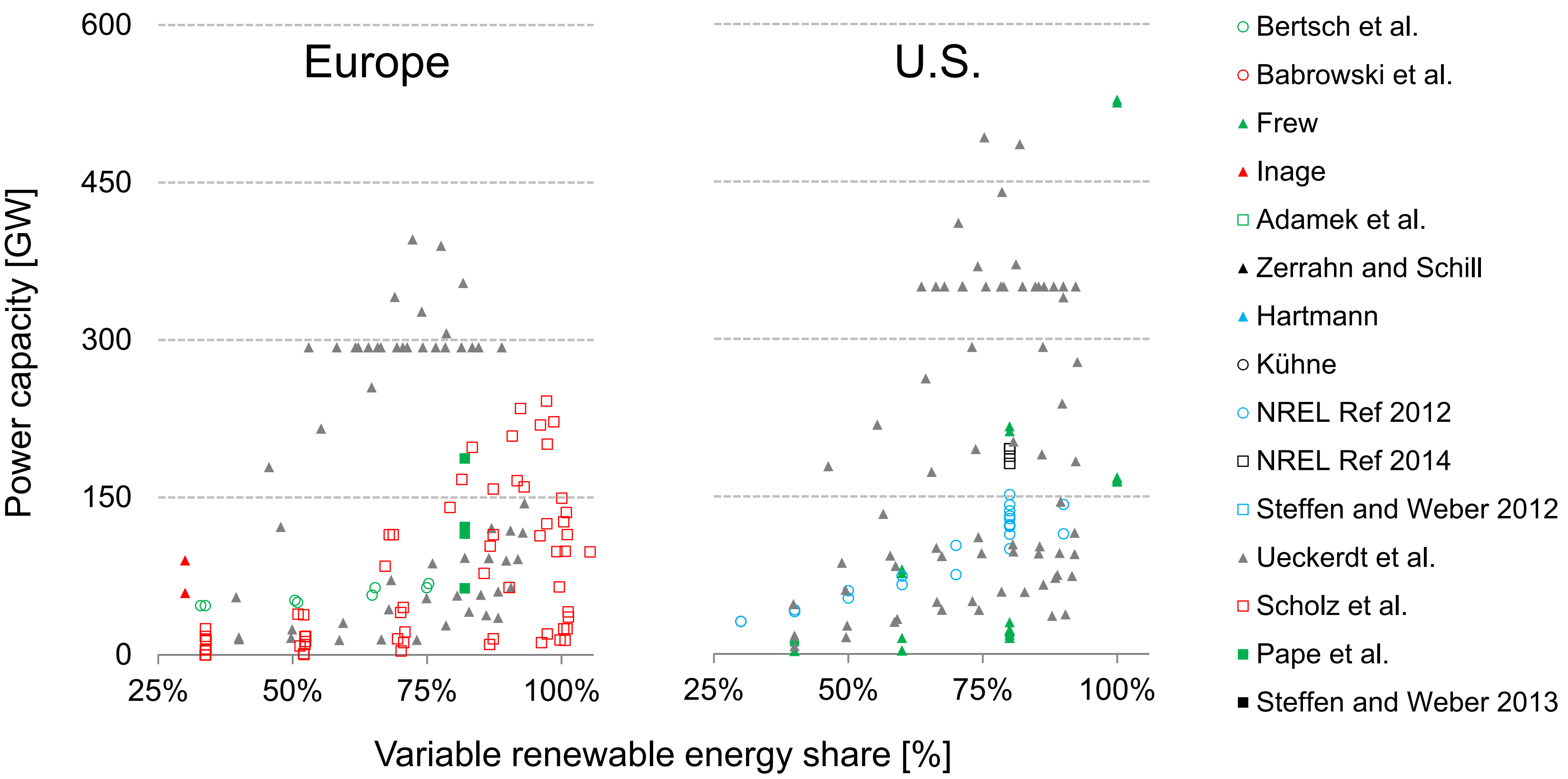
The need for flexibility*



* J. Haas, F. Cebulla, K. Cao, W. Nowak, R. Palma-Behnke, C. Rahmann, and P. Mancarella, "Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review," *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 603–619, 2017.

Broad ranges of storage requirements* (I)

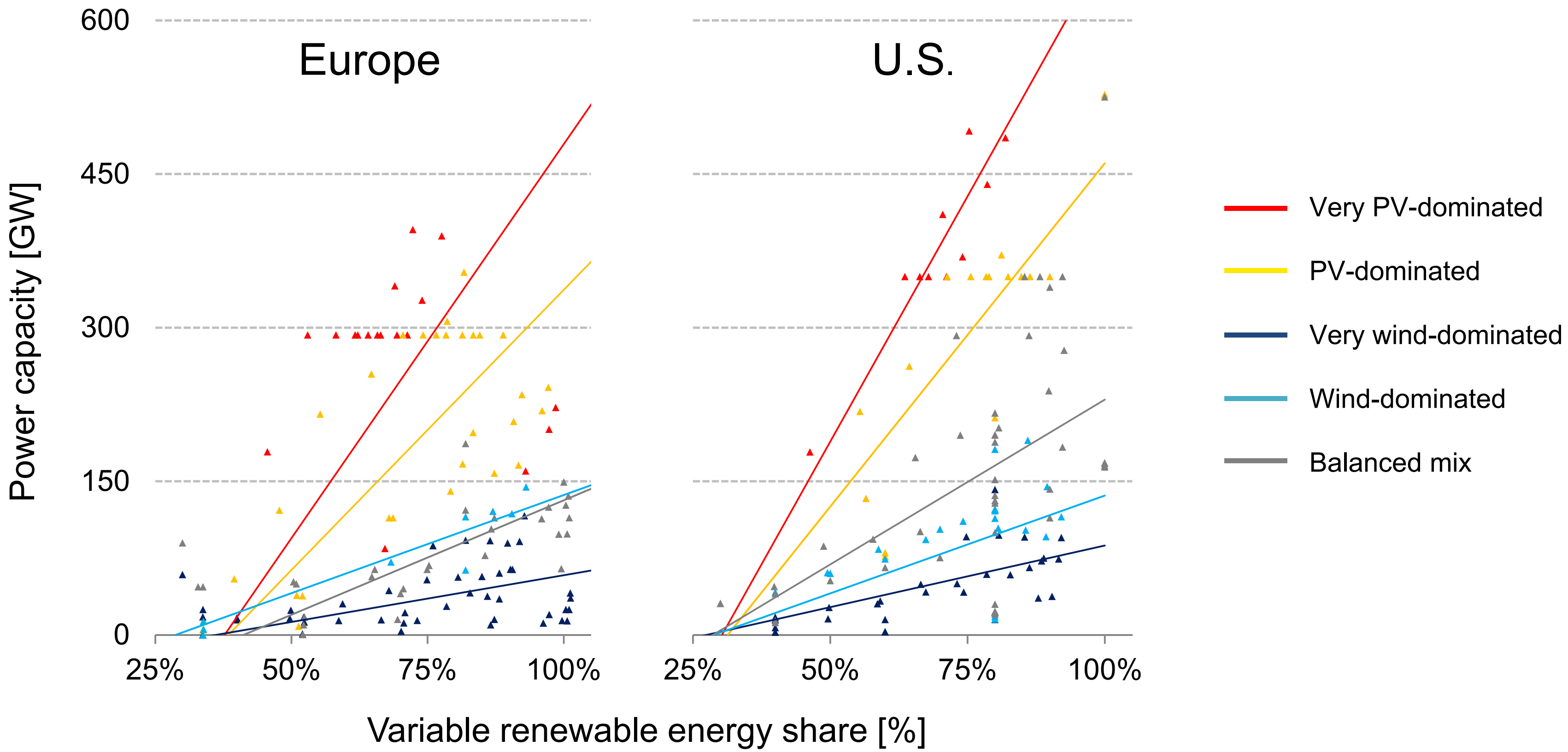
Review of model-based assessments



* F. Cebulla, J. Haas, J. Eichman, W. Nowak, and P. Mancarella, "How much energy storage do we need? A review and synthesis for the U.S., Europe, and Germany".

Broad ranges of storage requirements (II)

Review of model-based assessments



… What other main drivers are there?

Energy system model REMix*

- **R**enewable **E**nergy **Mix**
- Linear (mixed-integer) optimization model, written in GAMS, solved with CPLEX
- Minimize overall system costs
- Decision variables: capacity invest (single year, myopic, or path optimization) and hourly dispatch of all assets

- Sectors: power, heat, transportation, hydrogen infrastructure
- Renewables: wind (onshore, offshore), photovoltaic, hydro (pumped, run-of-river, reservoir), biomass, geothermal, concentrated solar power (CSP)
- Fossil and nuclear thermal power plants (incl. CHP)
- Flexibility options: electricity storage, transmission grid expansion (AC,DC), flexible CHP with thermal storage, demand response, controlled charging of BEV

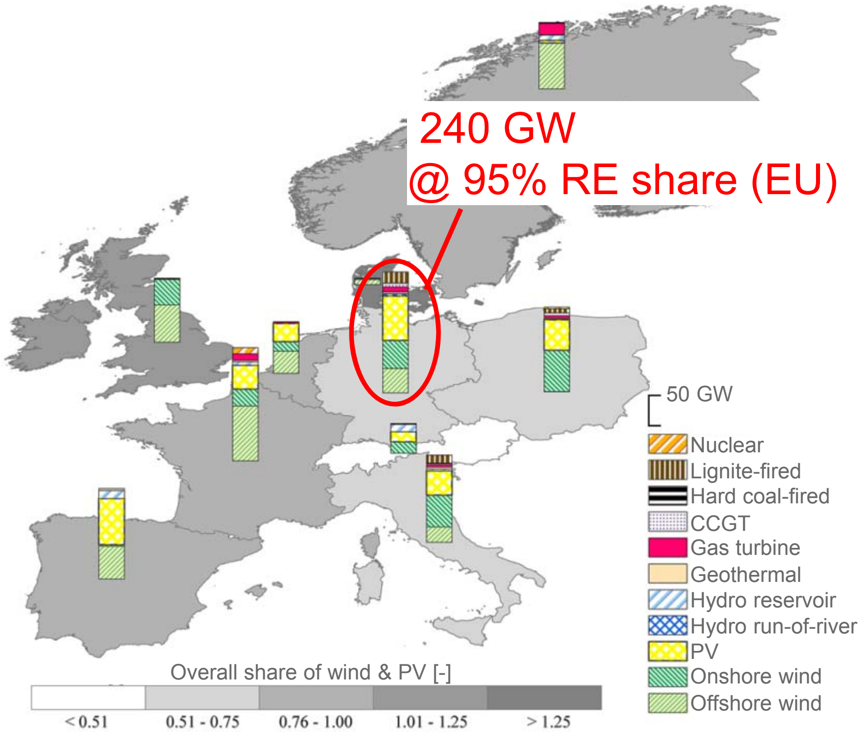
- Typical constraints: renewable shares or ratios, CO_2 cap, minimum firm capacity, secondary or tertiary reserve, domestic generation shares

* H. C. Gils, Y. Scholz, T. Pregger, D. L. de Tena, and D. Heide, “Integrated modelling of variable renewable energy-based power supply in Europe,” *Energy*, vol. 123, pp. 173–188, 2017.

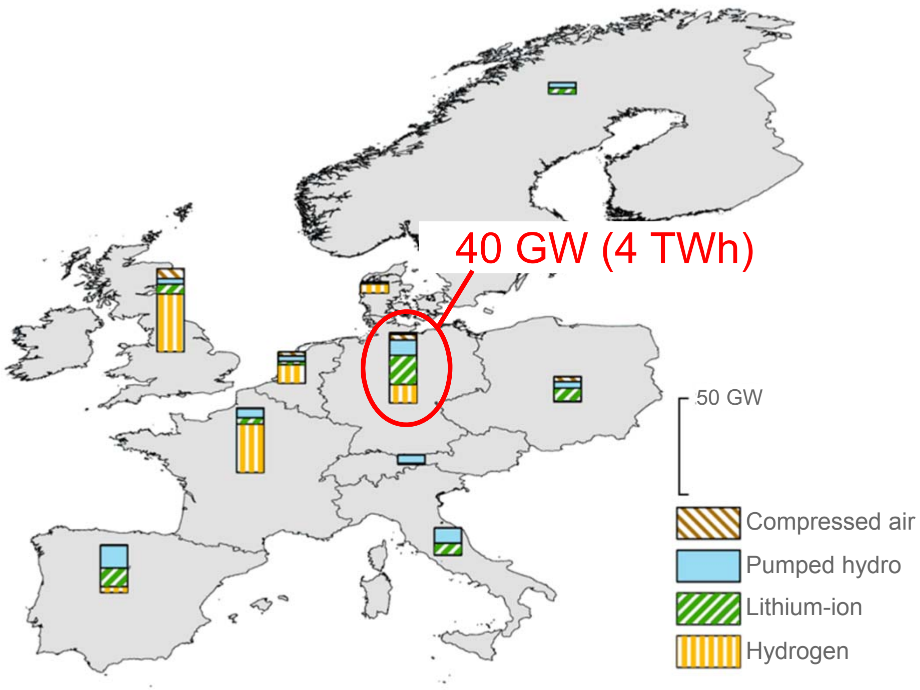
Storage requirements in Europe (I)

Renewable and storage capacity

Generation



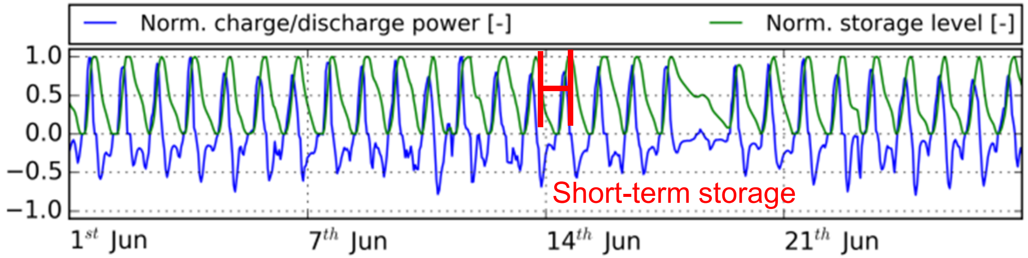
Storage



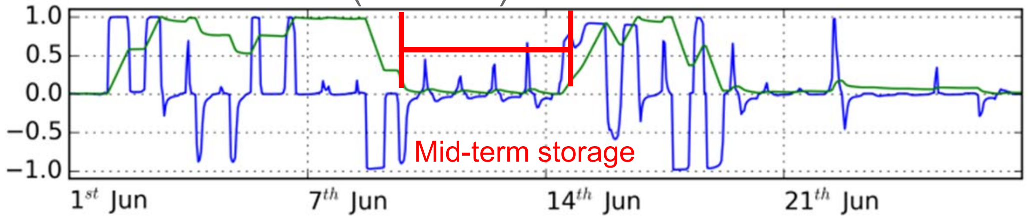
Storage requirements in Europe (II)

Storage utilization

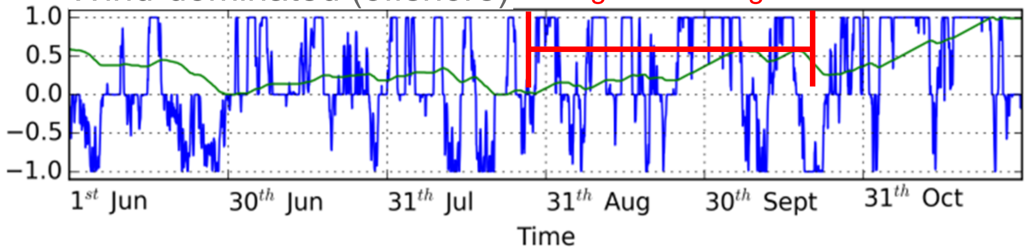
PV-dominated



Wind-dominated (onshore)



Wind-dominated (offshore)



… But how robust are these results?

Robustness of storage capacity requirements*

Influence of data assumptions and methodology

Data

- Investment costs for renewables, storage, and grid
- Operational costs: fuel cost, CO_2 certificates
- Variations of weather year for PV and wind generation

Methodology

- Detailed unit-commitment vs. simple LP power plant modeling
- Unlimited vs. restricted curtailments
- 20 node model vs. single node representation (“copper plate”)
- Influence of temporal resolution

Further possible drivers

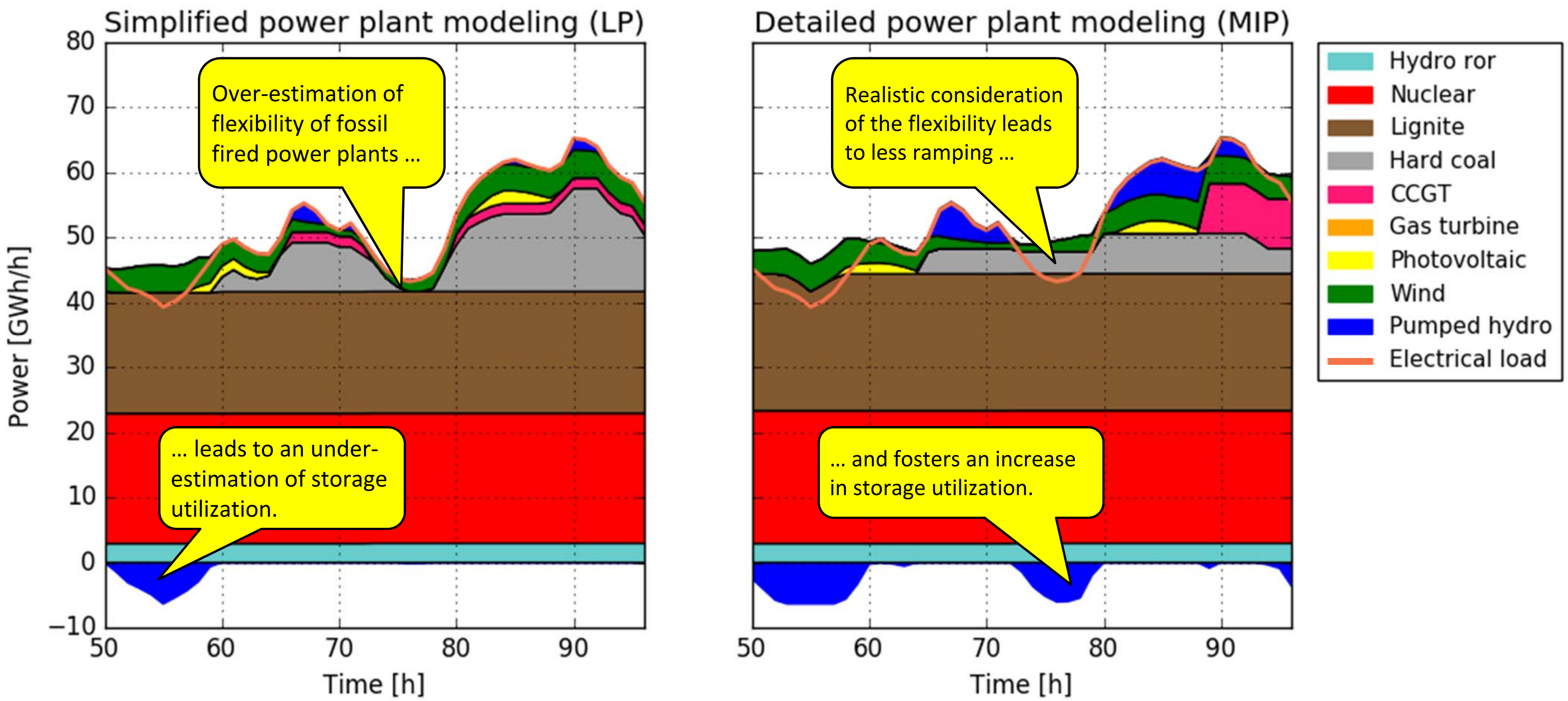
- Modeling approach: optimizations vs. simulation
- Model-inherent foresight, e.g. for investment and dispatch decisions (myopic, path, or rolling horizon)
- Consideration of other technological details, e.g. DC approximation versus load-flow
- Multi criteria optimization (not solely system costs) and sector coupling

DLR

* F. Cebulla, “Storage demand in highly renewable energy scenarios for Europe: The influence of methodology and data assumptions in model-based assessments,” University of Stuttgart, 2017, submitted.

Influence of power plant modeling approach* (I)

LP versus MIP



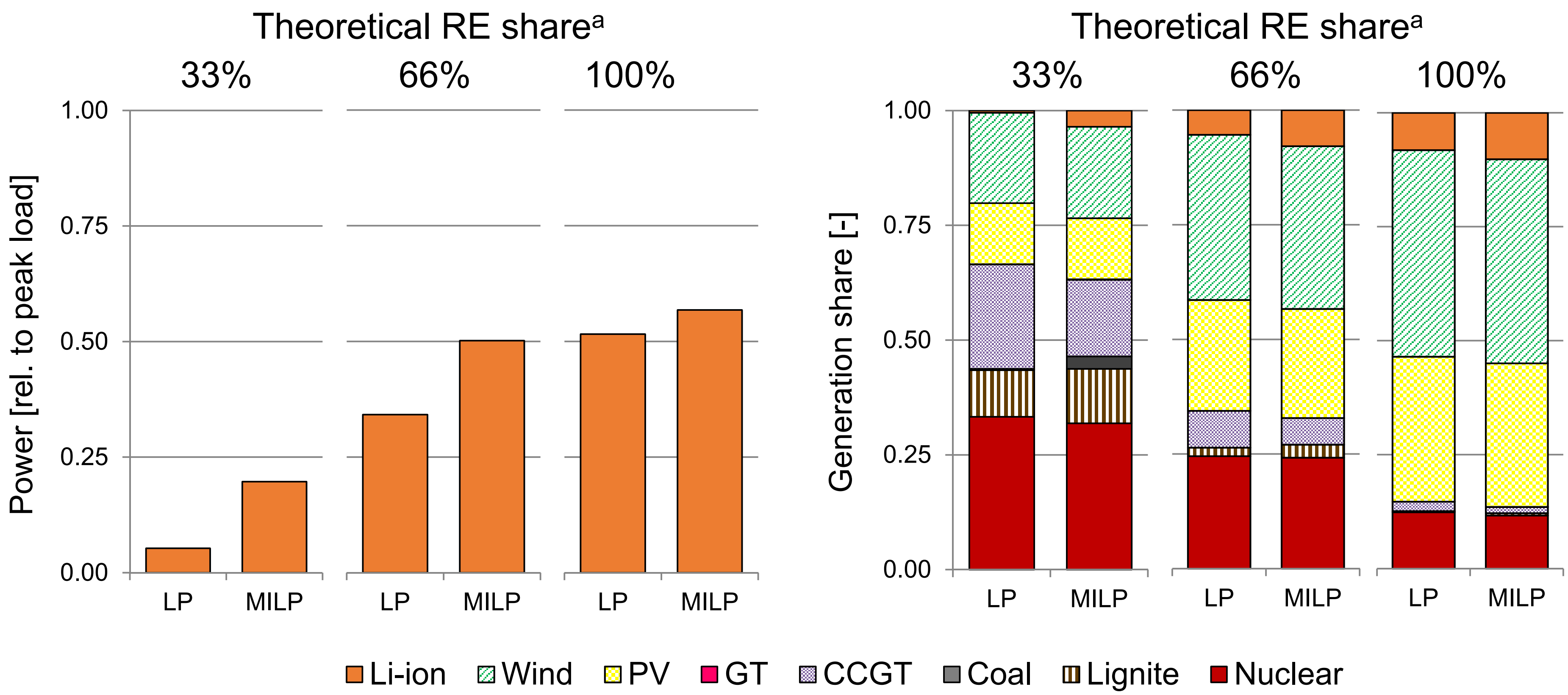
* F. Cebulla and T. Fichter, “Merit order or unit-commitment: How does thermal power plant modeling affect storage demand in energy system models?,” Renewable Energy, vol. 105, pp. 117–132, 2017.

Influence of power plant modeling approach (II)

Effect on storage capacity expansion and utilization

Storage expansion

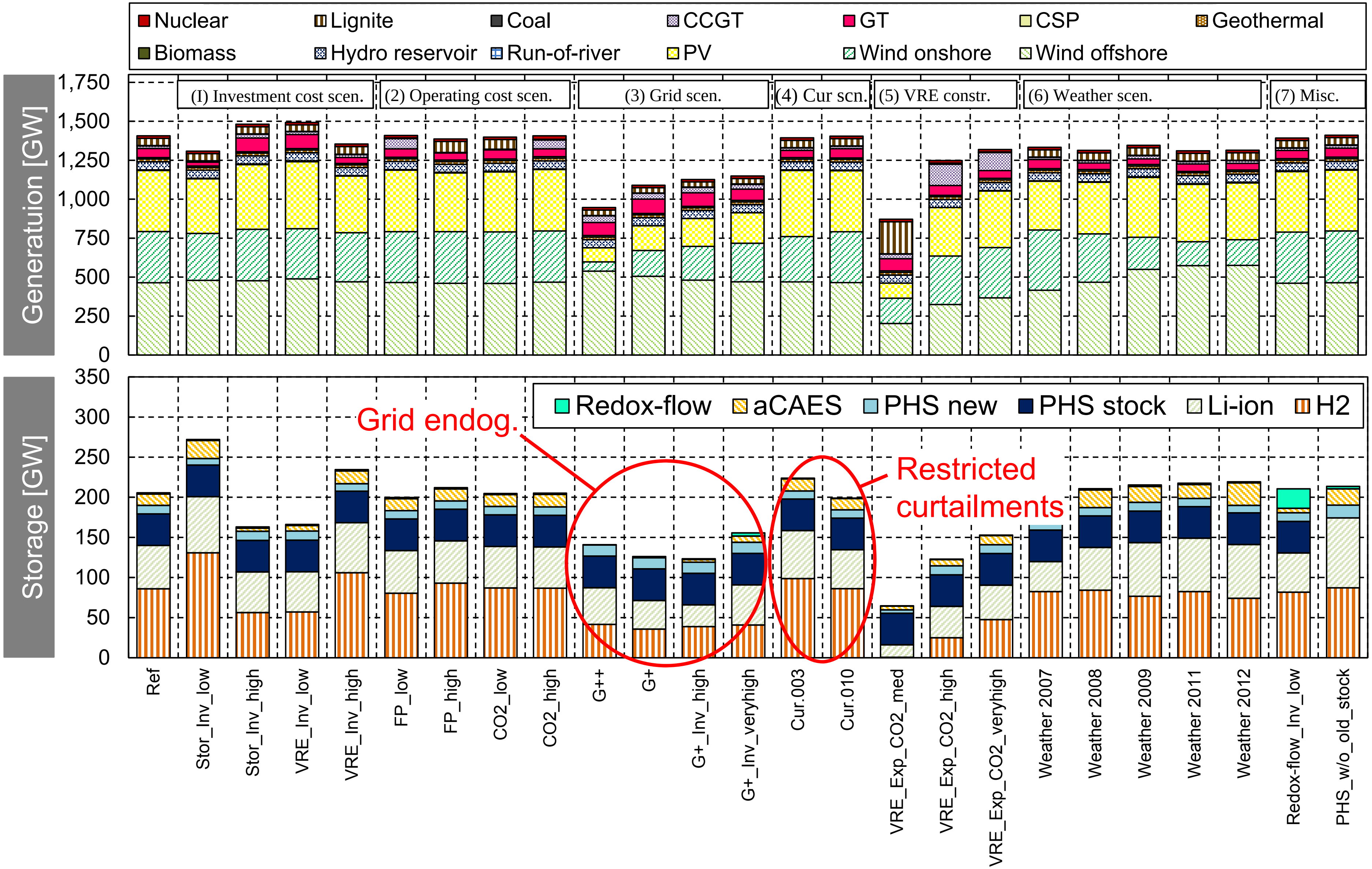
Utilization



[a] Before curtailments, storage- and transmission losses

Influence of further assumptions (I)

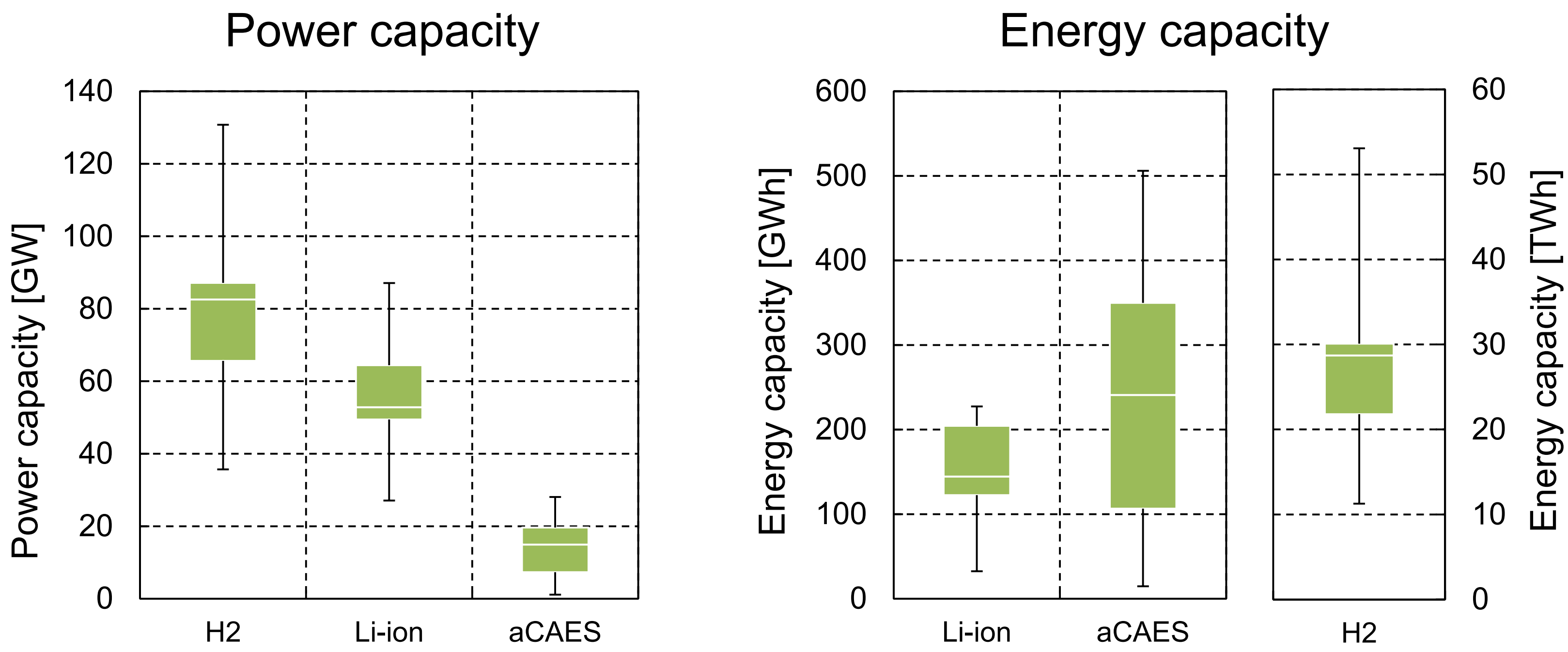
Renewable and storage capacities



Influence of further assumptions (II)

Technology-specific ranges of storage capacity

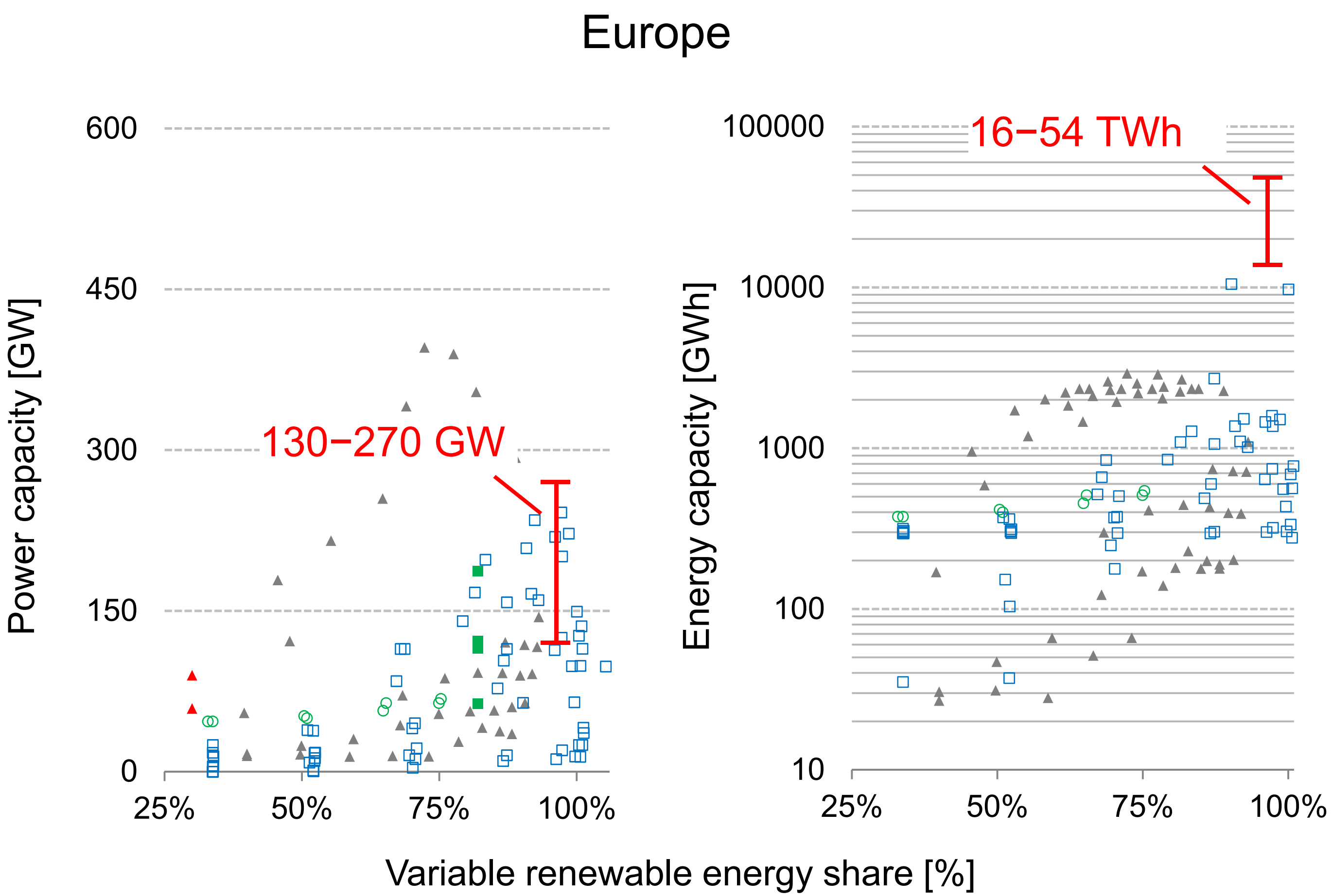
- Spreads for EU scenarios with a RE share ≥ 90%[a]
- 1st and 3rd quartile, median, min, and max
- Technology-specific capacities in large parts robust, however, some outliers exist



[a] Pumped hydro & redox-flow excluded due to marginal bandwidths and insignificant capacities

Conclusions (I)

Can we narrow down the range of storage requirements?



DLR

Conclusions (II)

State of research

- Current studies result in broad ranges for storage requirements
- PV-dominated scenarios tend to foster higher storage capacities, compared to wind-dominated or balanced mixes

Storage requirements in Europe

- Storage sensitive to scenario and methodological assumptions:
  - EU: 130–270 GW, 16–54TWh
- Power plant modeling affects storage requirements only in small systems with low shares of variable renewable energies
- Large parts of storage capacity can be substituted by transmission grid expansion
- However, grid and storage are complement options and temporal decoupling of load and supply is still necessary, even under perfect grid assumptions („copper plate”)
- Technology-diverse storage portfolio essential; each storage fills a certain niche
- Spatial storage capacity distribution mainly influenced by the shape of the net load

energy
scenarios
school

Thank you!

Questions?

Dipl. Wi.-Ing. Felix Cebulla

German Aerospace Center

Systems Analysis and Technology Assessment

DLR

References

[1] J. Haas, F. Cebulla, K. Cao, W. Nowak, R. Palma-Behnke, C. Rahmann, and P. Mancarella,“ Challenges and trends of energy storage expansion planning for flexibility provision in low-carbon power systems – a review,” *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 603–619, 2017.

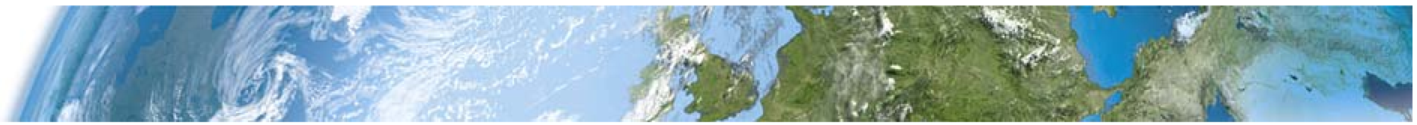
[2] F. Cebulla, J. Haas, J. Eichman, W. Nowak, and P. Mancarella, “How much energy storage do we need? A review and synthesis for the U.S., Europe, and Germany”.

[3] H. C. Gils, Y. Scholz, T. Pregger, D. L. de Tena, and D. Heide, “Integrated modelling of variable renewable energy-based power supply in Europe,” *Energy*, vol. 123, pp. 173–188, 2017.

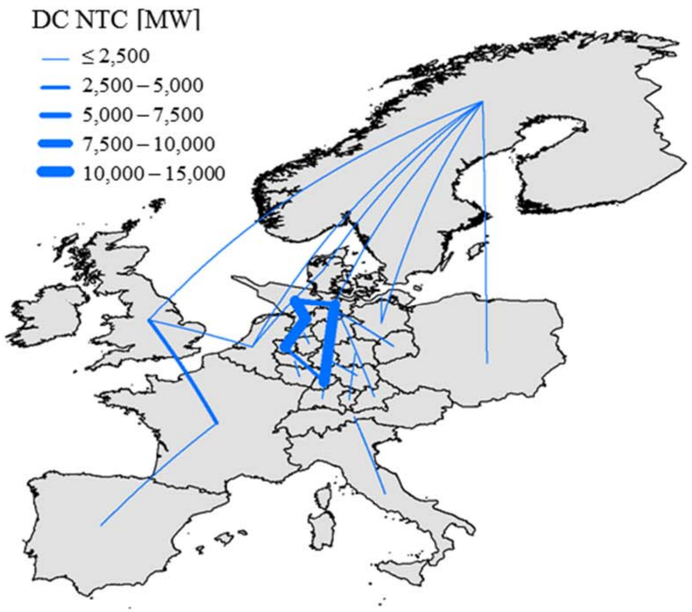
[4] F. Cebulla, T. Naegler, and M. Pohl, “Storage demand, spatial distribution, and storage dispatch in a European power supply system with 80% variable renewable energies,” 2017.

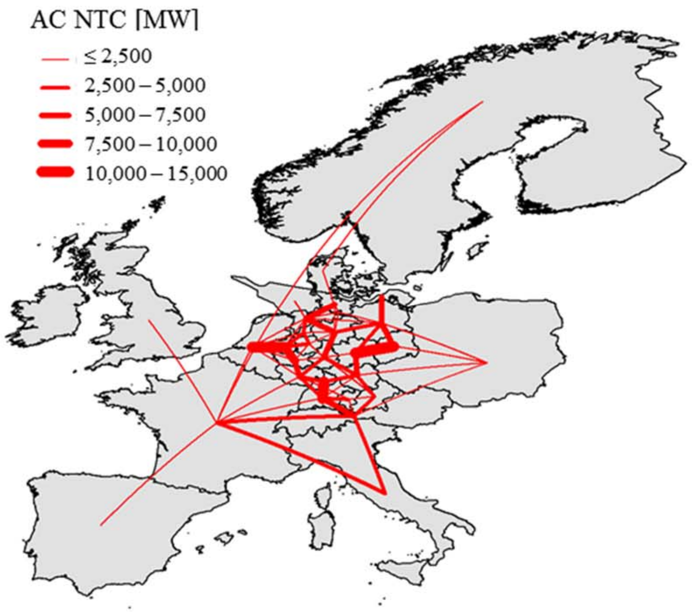
[5] F. Cebulla, “Storage demand in highly renewable energy scenarios for Europe: The influence of methodology and data assumptions in model-based assessments,” University of Stuttgart, 2017, submitted.

[6] F. Cebulla and T. Fichter, “Merit order or unit-commitment: How does thermal power plant modeling affect storage demand in energy system models?,” *Renewable Energy*, vol. 105, pp. 117–132, 2017.



Backup
Transmission grid assumptions





Scenario	Technology	Invest land [k€/km]	Invest sea [k€/km][a]	Interest rate [-]	Amor. time [a]	$O\&M_{fix}$
G+	AC 380kV	1,000	1,000	0.06	40	0.003
G+	HVDC_2200_UC	913	1,815	0.06	40	0.010
G+	HVDC_3200	384	2,640	0.06	40	0.010

[a] For the modeling of the AC transmission grid no differentiation between land and sea investment costs is considered. The values of invest land and invest sea are therefore identical and should not be understood additively.

Backup
Cost assumptions

Technology	Invest [k€]	Unit	Life time [a]	$O\&M_{fix}$ [%/a]
AC 380 kV	1,000	Km	40	0.3
HVDC 2200	913[a] 1,815[b]	Km	40	1.0
HVDC 3200	384[a] 2,640[b]	Km	40	1.0
Photovoltaic	900	MW	20	1.0
Wind onshore	900	MW	18	4.0
Wind offshore	1,300	MW	18	5.5
Pumped hydro	450 10	MW MWh	20 60	1.0
Compressed air	570 47	MW MWh	20 40	1.0
Lithium-ion	50 150	MW MWh	25 25	0.5
Hydrogen	1,200 1	MW MWh	15 30	2.0
Redox-flow	630 100	MW MWh	20 20	3.2

[a] Land-based
[b] Sea-based