Potential contribution of low-temperature thermal energy storage to the integration of intermittent renewable power generation in Europe

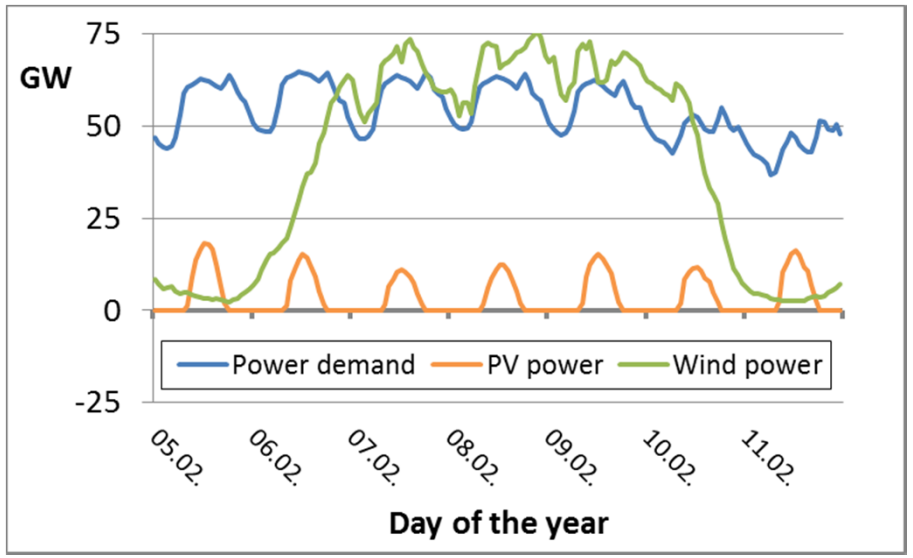
4th Swiss Symposium Thermal Energy Storage
Luzern, 20 January 2017

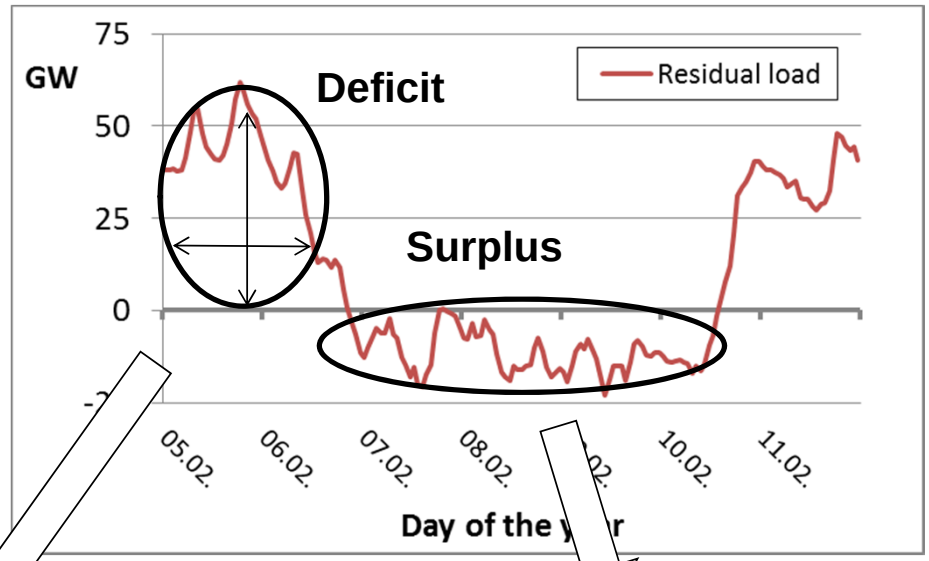
Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Dr. Hans Christian Gils
Institute of Engineering Thermodynamics
Systems Analysis and Technology Assessment

DLR

Research focus: VRE based power supply systems





Load balancing options

Coverage of deficits

- Adjustable power plants
- Storage discharging
- Power demand reduction
- Electricity import

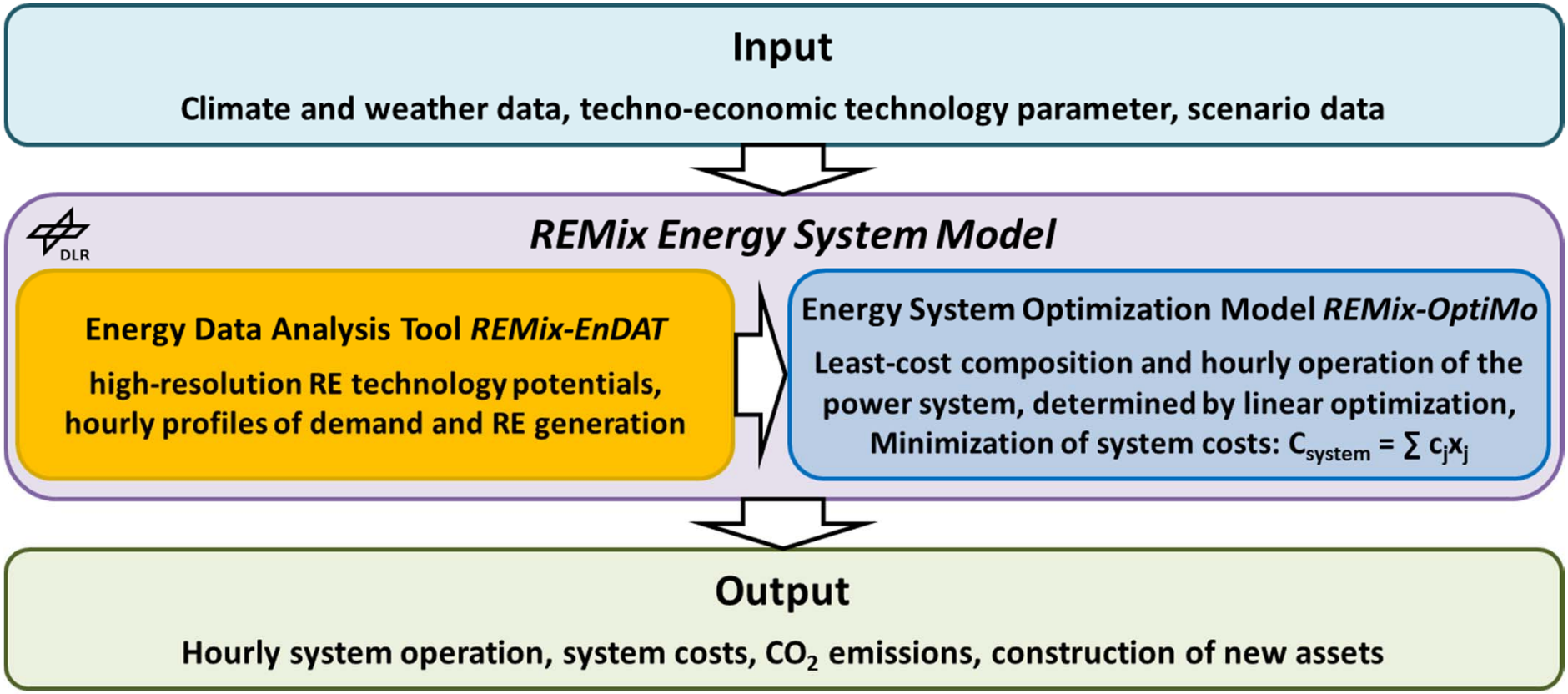
Utilization of surpluses

- Storage charging
- Usage in other demand sectors
- Power demand increase
- Electricity export

Research questions

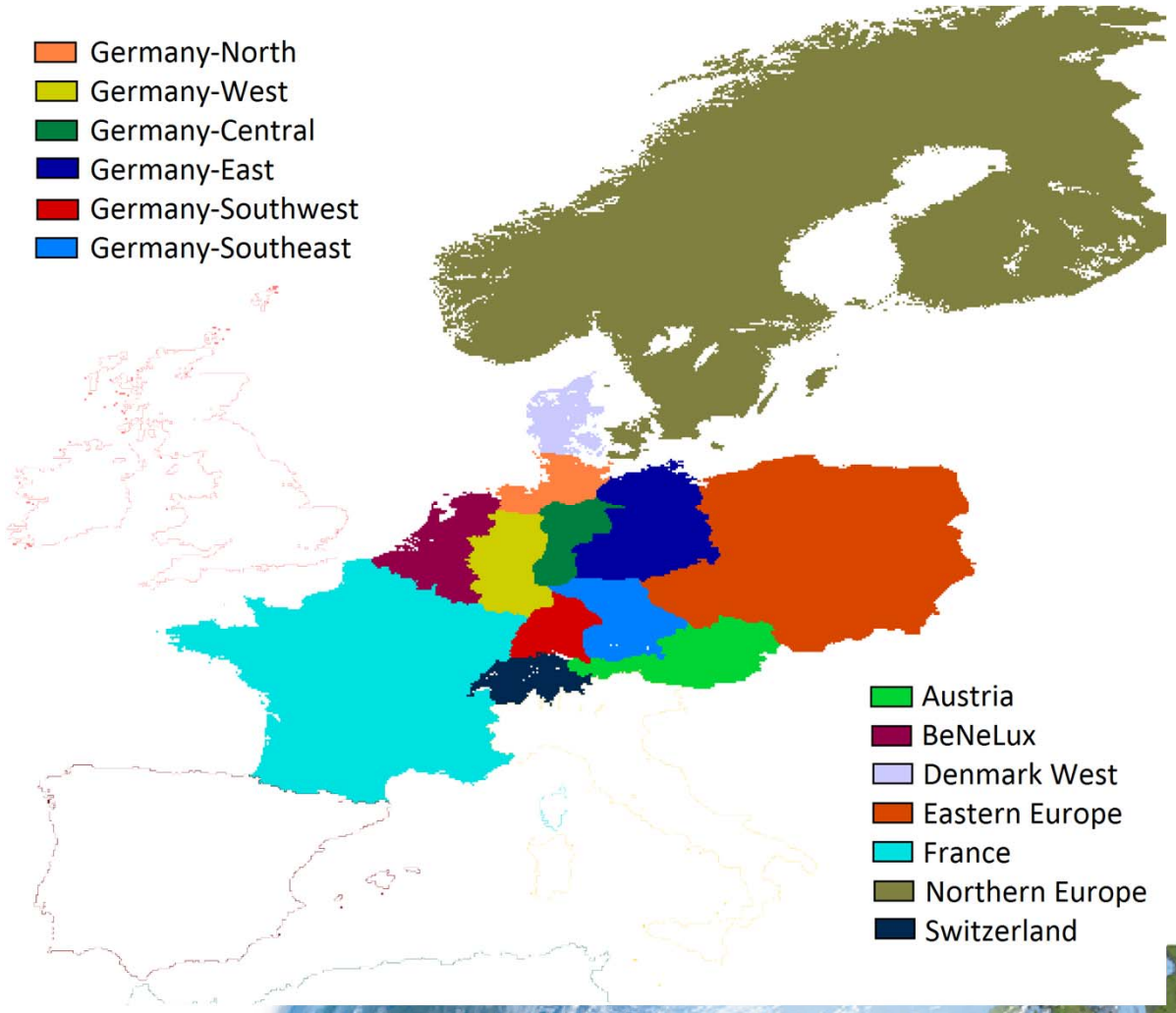
- To what extent can a more flexible operation of electric heat pumps (HP) and district heating (DH) contribute to a mostly renewable power supply in Europe?
- Is the deployment of thermal energy storage (TES) competitive with other balancing options?
- How does a more flexible heat supply interact with other balancing options?

REMix modelling approach



- Deterministic linear optimization of investment and hourly system dispatch during one year

REMix case study on power-controlled heat – regions



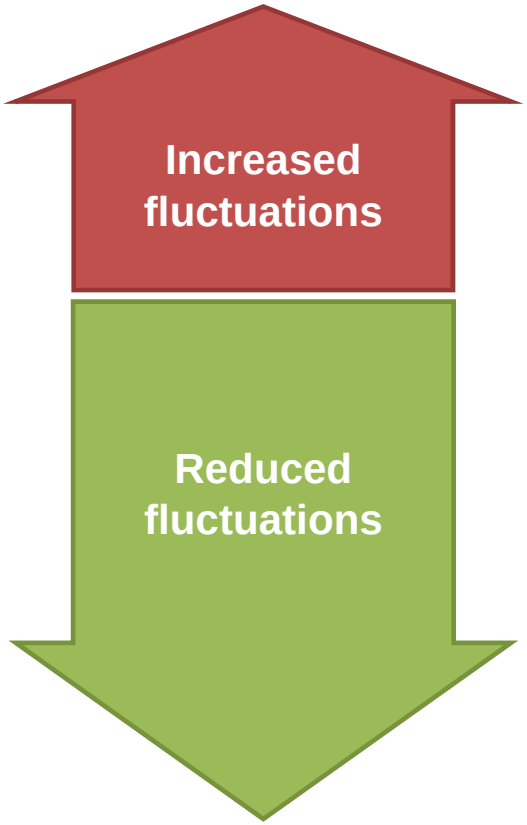
REMix case study on power-controlled heat – technologies

Renewable	Conventional	Public CHP	Industrial CHP	Balancing
Biomass Power	Nuclear Power	Biogas Engine CHP	Biomass-fired Steam Turbine	HVAC power grid
Geothermal Power	Lignite Power	Natural Gas Engine CHP	Coal-fired Steam Turbine	HVDC transmission lines
Concentrating Solar Power	Coal Power	Biomass-fired Steam Turbine	Lignite-fired Steam Turbine	Pumped Storage Hydro
Solar Photovoltaic Power	Combined Cycle	Extraction CCGT	Gas Turbine CHP	Thermal Energy Storage
Offshore Wind Power	Gas Turbine	Backpressure CCGT	Natural Gas Engine CHP	Flexible electrolyzers
Onshore Wind Power		Coal-fired Steam Turbine		Hydrogen storage
Reservoir Hydro Power		Lignite-fired Steam Turbine		Hydrogen-based transport
Run-of-river Hydro Power		Waste-fired Steam Turbine		Electric vehicles
		Biogas Micro-Engine CHP		Electric heat pumps
		Nat. Gas Micro-Engine CHP		Electric boilers

REMix case study on power-controlled heat – approach

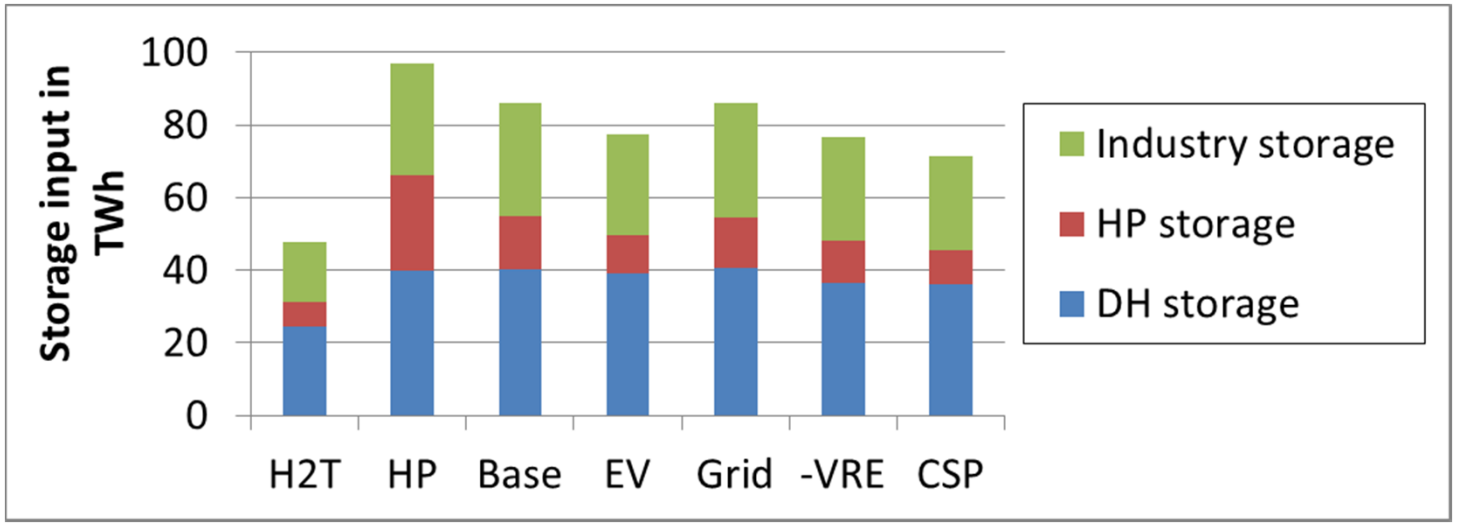
- Scenario analysis for a predefined power and heat supply structure
  - Power supply: >80% RE, >60% VRE, ~20% CHP, ~9% gas power plants w/o CHP
  - Endogenous installation of gas power plants as back-up generation capacity
  - Residential/Commercial heating: 30% DH, 5% building CHP, 21% electric HP, 44% other
  - Industrial heating ($\vartheta < 500°C$): 62% CHP, 4% electric HP, 34% other
- Focus on the analysis of the balancing of VRE fluctuations
  - Comparison of systems with/without power-controlled heat supply
  - Endogenous investment in thermal storage and electric boilers in DH supply
  - Impact on back-up capacity demand, system operation, costs and emissions

REMix case study on power-controlled heat – scenarios



H_2T	Hydrogen usage in the transport sector Production in **flexible electrolysis**
HP	**Increased heat pump** supply shares (38% Res./Com., 8% Ind.)
Base	Base scenario, electricity demand 2100 TWh, VRE capacities: PV 229 GW, wind onshore 219 GW, offshore 115 GW
-EV	**Flexible charging of electric vehicles** (60% of the fleet)
Grid	Endogenous **grid capacity expansion**
-VRE	**Reduced** full load hours of **wind and solar** (-7% / -19%)
CSP	**Import of dispatchable RE electricity** from CSP Reduced wind and PV capacities in Europe

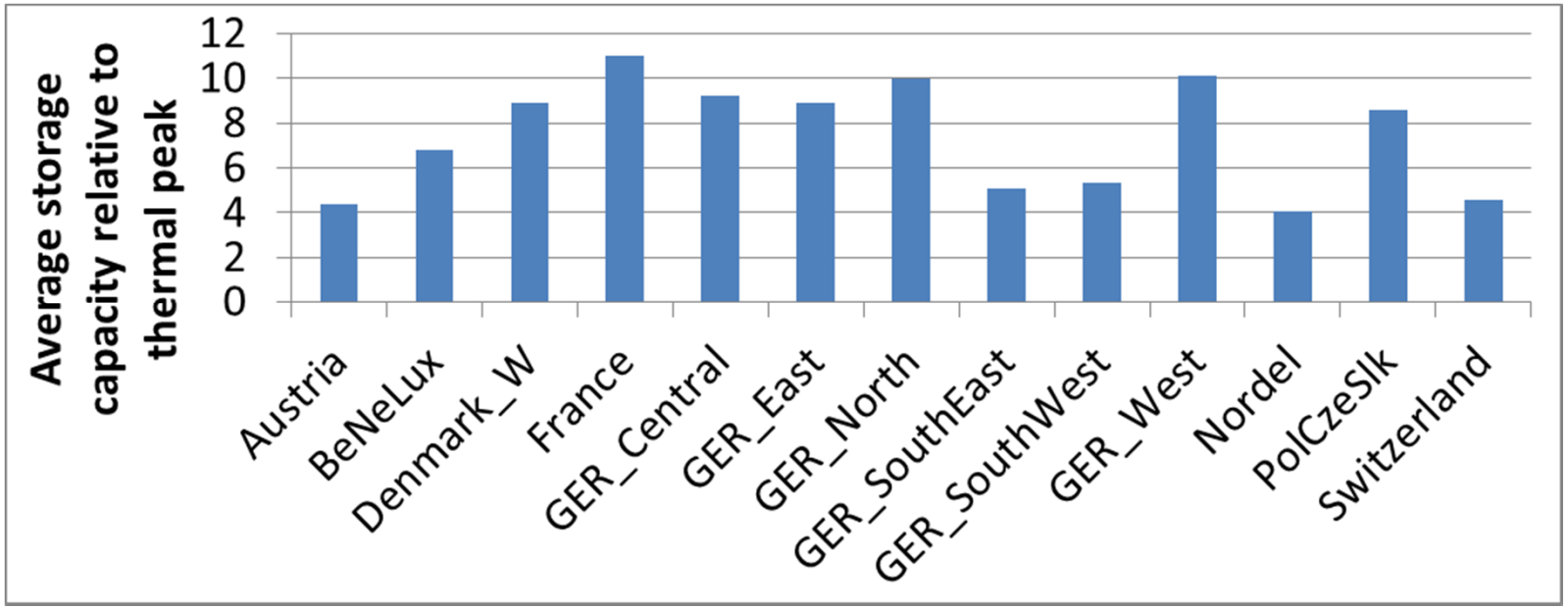
REMix output – investment and usage of TES



H2T – Flexible electrolysers
HP – Increased HP share
Base – Reference
EV – Controlled EV charging
Grid – Grid extension
-VRE – Reduced VRE generation
CSP – CSP-Import

- Investment in DH-TES across all scenarios, with capacities of 500-600 GWh
- Exogenously defined: additional 200 GWh in Industry, and 140 (260) GWh in HP systems
- Around 10% of the annual DH heat demand go through the TES
- CSP and load shifting (Electrolyser, EV) reduce TES use
- Additional HP do not affect investment in and usage of DH-TES

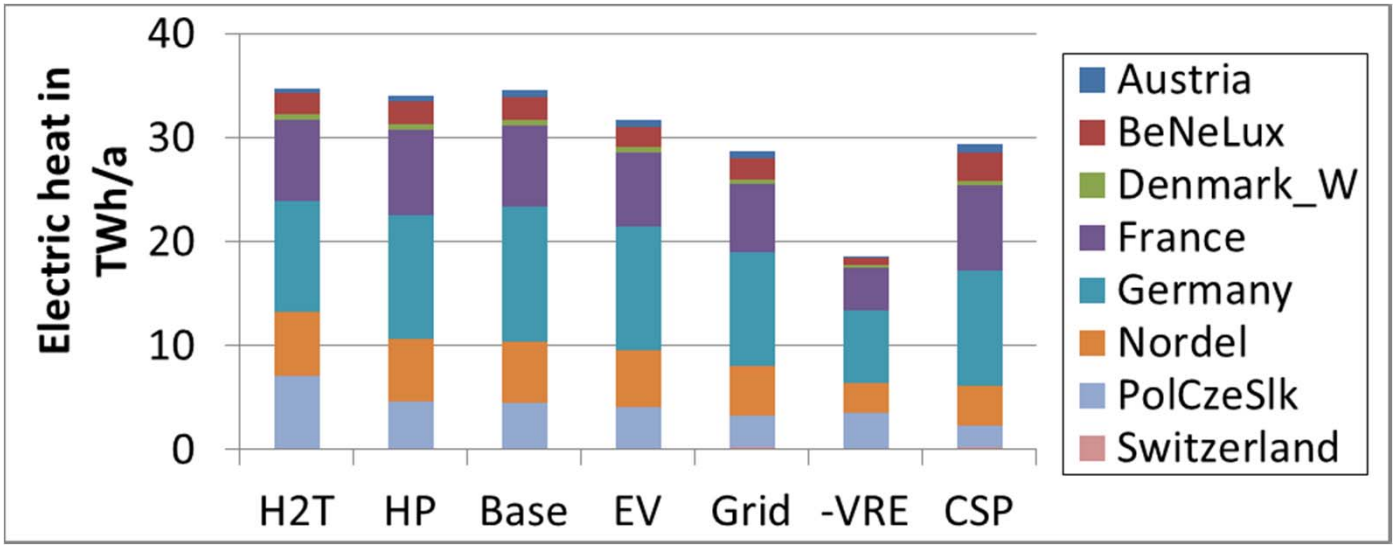
REMix output – regional storage layout



Values shown for scenario *Base*

- Relative storage capacity lowest in regions with high hydro power capacity
- Highest capacities in regions with wind power dominated supply
- Predefined capacities for HP (2 h) and industrial CHP (4 h), based on previous study for Germany

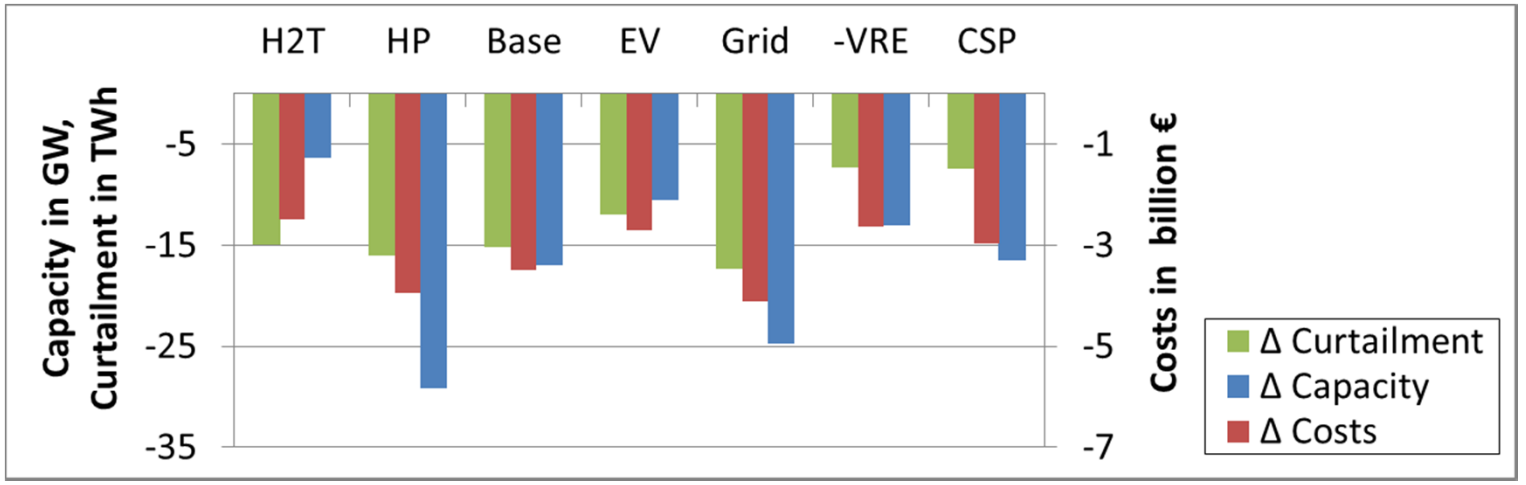
REMix output – investment and usage of electric boilers



H2T – Flexible electrolysers
HP – Increased HP share
Base – Reference
EV – Controlled EV charging
Grid – Grid extension
-VRE – Reduced VRE generation
CSP – CSP-Import

- Model endogenous installation of electric boilers in DH systems reaches up to 43 GW (el)
- Significantly lower values only in scenarios with less VRE generation (CSP & -VRE)
- Grid extension, controlled EV charging and CSP imports slightly reduce electric heating
- Increased HP and flexible hydrogen production can balance additional VRE generation
- Low wind power availability has major impact

REMix output – system benefits



H2T – Flexible electrolysers
HP – Increased HP share
Base – Reference
EV – Controlled EV charging
Grid – Grid extension
-VRE – Reduced VRE generation
CSP – CSP-Import

- w/o flexibility: system costs 86-107 bln €, curtailment 11-23 TWh, back-up 96-163 GW
- Maximum reductions achieved:
  - ➢costs 4.1 bln € (4.3%) in scenario *Grid*
  - ➢curtailment 17 TWh (71%) in scenario *Grid*
  - ➢back-up 29 GW (18%) in scenario *HP* (mostly due to flexible HP operation)

Summary, conclusion and discussion

- Model-endogenous investment in TES and electric boilers across all scenarios
- Geographical concentration to wind power dominated regions
- Least-cost dimensioning influenced by CHP technology, fuel and size
- Balancing strongly related to generation structure and available technologies
  - Grid extension has positive impact on economics of flexible heating
  - Controlled EV charging and flexible electrolysis can not substitute TES
  - Yearly and hourly wind and solar generation have high influence
- Power-controlled heat supply is a cost-effective measure to increase RE integration
  - TES should be deployed hand-in-hand with VRE power generation
  - Electric heat production from VRE generation peaks has high potential
- Usage on smaller temporal and spatial scales was not assessed

References and contact

Gils, H. C. (2012). A GIS-based Assessment of the District Heating Potential in Europe. Proceedings of the 12th Symposium Energy Innovation. https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2012/files/lf/LF_Gils.pdf

Pregger, T.; Nitsch, J., Naegler, T. (2013). Long-term scenarios and strategies for the deployment of renewable energies in Germany Energy Policy, 59: 350-360. http://dx.doi.org/10.1016/j.enpol.2013.03.049

Gils, H. C., Cofala, J., Wagner, F., and Schoepp, W. (2013). GIS-based assessment of the district heating potential in the USA. Energy, 58: 318-329. http://dx.doi.org/10.1016/j.energy.2013.06.028

Naegler, T., Simon, S., Klein, M., and Gils, H. C. (2015). Quantification of the European industrial heat demand by branch and temperature level. International Journal of Energy Research, 39: 2019–2030. http://dx.doi.org/10.1002/er.3436

Gils, H. C. (2015). Balancing of intermittent renewable power generation by demand response and thermal energy storage, PhD thesis, University of Stuttgart, http://dx.doi.org/10.18419/opus-6888

Gils, H. C. (2016). Economic potential for future demand response in Germany – Modelling approach and case study. Applied Energy, 162: 401-415. http://dx.doi.org/10.1016/j.apenergy.2015.10.083

Gils, H.C. and Simon, S. (2017) Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands, Applied Energy, 188: 342-355. http://dx.doi.org/10.1016/j.apenergy.2016.12.023

Scholz, Y., Gils, H.C., Pietzcker, R. (2017) Application of a high-detail energy system model to derive power sector characteristics at high wind and solar shares, Energy Economics, in Press. http://dx.doi.org/10.1016/j.eneco.2016.06.021

Contact: Hans Christian Gils, DLR, Institute of Engineering Thermodynamics, Systems Analysis and Technology Assessment
Pfaffenwaldring 38 | 70569 Stuttgart | Germany | Phone +49 711 6862-477 | hans-christian.gils@dlr.de | www.DLR.de/tt

Dieser Vortrag basiert in Teilen auf Ergebnissen der vom Bundesministerium für Wirtschaft und Energie geförderten Projekte „Lastausgleich“ (FKZ 0328009) und „Multi-Sektor-Kopplung“ (FKZ 03ET4038)

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

DLR