Energy sector integration – opportunities and challenges arising from an electrification of heating and transport sectors

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Institute of Engineering Thermodynamics
Energy Systems Analysis

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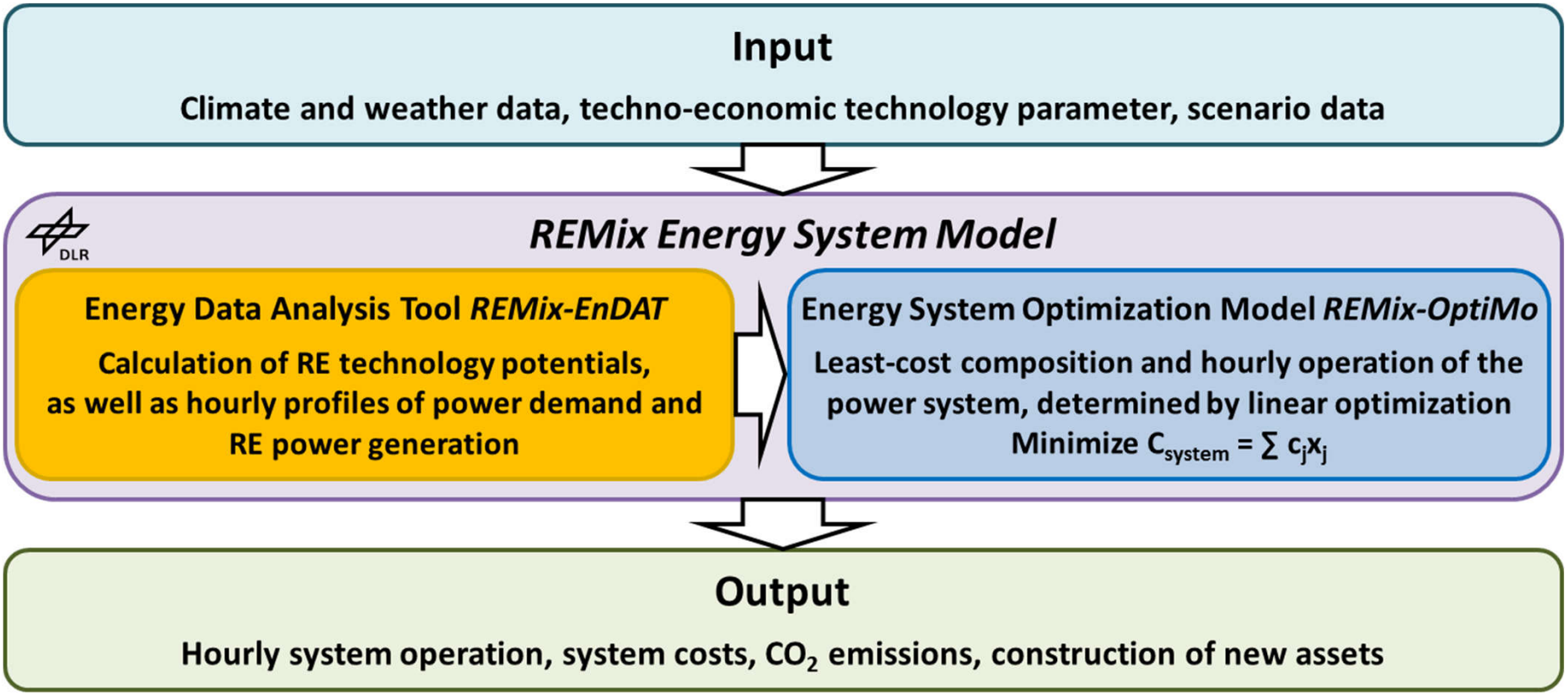
Research questions

- What benefits does sector coupling have for the integration of fluctuating renewable electricity generation at national and European level?
- How does sector coupling compete with other options of interregional load balancing, e.g. the transport network and pumped storage?
- What are the effects of inflexible versus flexible sector coupling?
- What influence does flexible sector coupling have on renewable power curtailment, backup capacity demand, costs and emissions?
- How do regional generation structures affect the cost-optimal design of flexible sector coupling?

REMix Energy System Model



- Deterministic linear optimization model realized in GAMS
- Assessment of investment and hourly system dispatch during one year
- Scope: validation of regional, national and continental long-term energy scenarios

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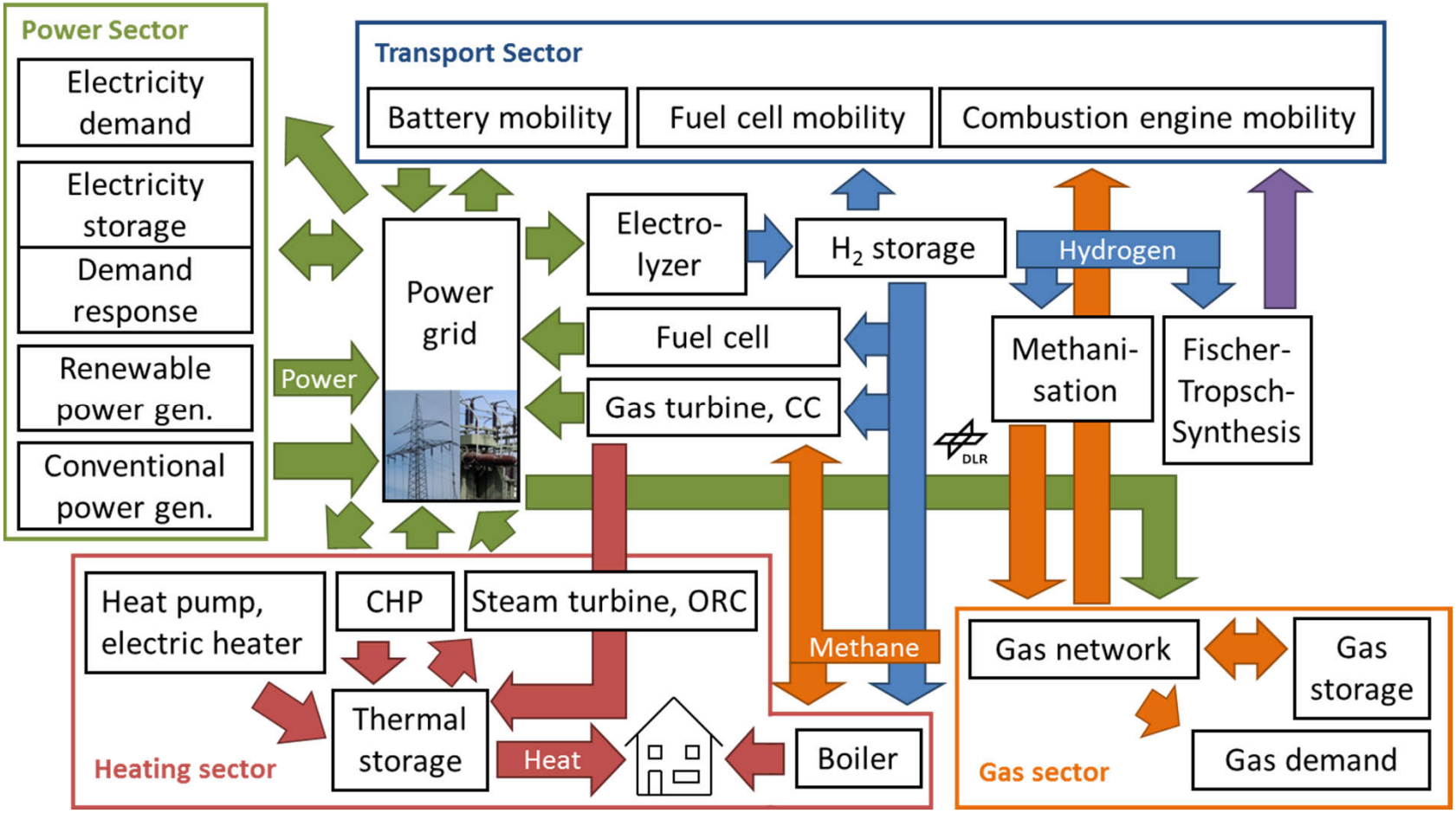
Source: Gils, H.C, Scholz, Y., Pregger, T., Luca de Tena, D., Heide, D. (2017) Integrated modelling of variable renewable energy-based power supply in Europe. Energy, 123: 173-188. http://dx.doi.org/10.1016/j.energy.2017.01.115

Representation of energy sector integration in REMix

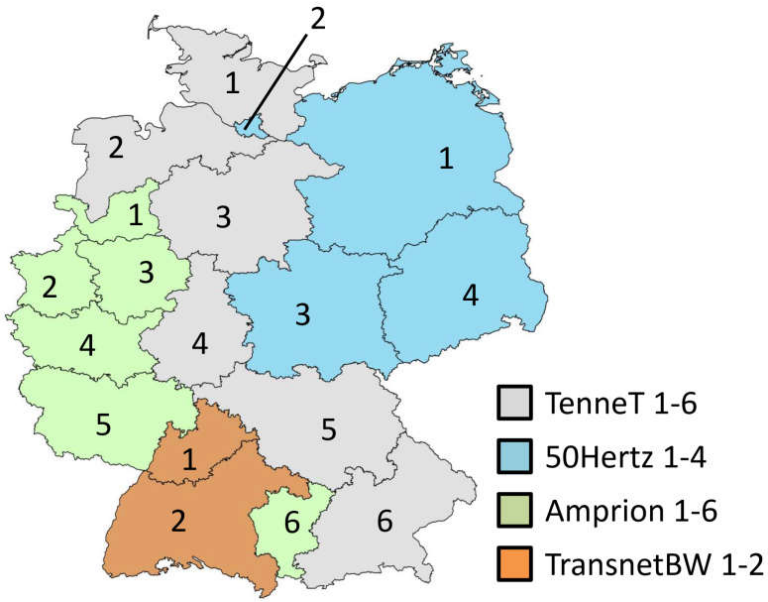


- Continuous and ongoing enhancement of the model scope
- Focus on power demand flexibility provided by energy sector integration

Case study: sector integration in Germany (RegMex)

	Import	Decentralized	Offshore
Grid expansion*	Endogenous expansion in Germany and neighbours	No endogenous grid expansion	Endogenous expansion only in Germany
Self-supply	Each model region provides 65% of its demand	Each model region provides 90% of its demand	Each model region provides 65% of its demand
Given VRE capacities	PV: 74 GW Wind onsh. 69 GW Wind offsh. 29 GW	PV: 74 GW Wind onsh. 69 GW Wind offsh. 29 GW	PV: 74 GW Wind onsh. 69 GW Wind offsh. 45 GW

*excluding connection of offshore wind



- Target year 2050, RE share > 90% for domestic generation
- Scenarios vary in regional allocation of power generation and grid expansion
- Consideration of power exchange within Europe and 18 regions in Germany

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For details see the final report of the RegMex project : https://elib.dlr.de/121339/

RegMex: considered technologies

Generation	Cogeneration	Transmission, Storage	Other sector coupling
Photovoltaic	Biogas engine	AC power grid	Flexible charging/grid feed-in of battery electric vehicles
Run-of-the river	Gas engine	DC power lines	Flexible H_2 electrolysis with tank storage
Reservoir hydro	Extraction CCGT	Pumped hydro storage	Electric heat pumps and boilers with thermal storage
Offshore wind	Micro gas engine	Lithium battery storage	
Onshore wind	Solid Biomass	Hydrogen cavern storage	
Simple cycle GT	All equipped with peak heat boiler, electric boiler and thermal storage	Industrial/commercial DR	
Combined cycle GT			

- Competition of flexible sector integration with expansion of storage and backup
- Comparison of flexible and inflexible energy sector integration
- Optimization of the dimensioning of heat and hydrogen storage

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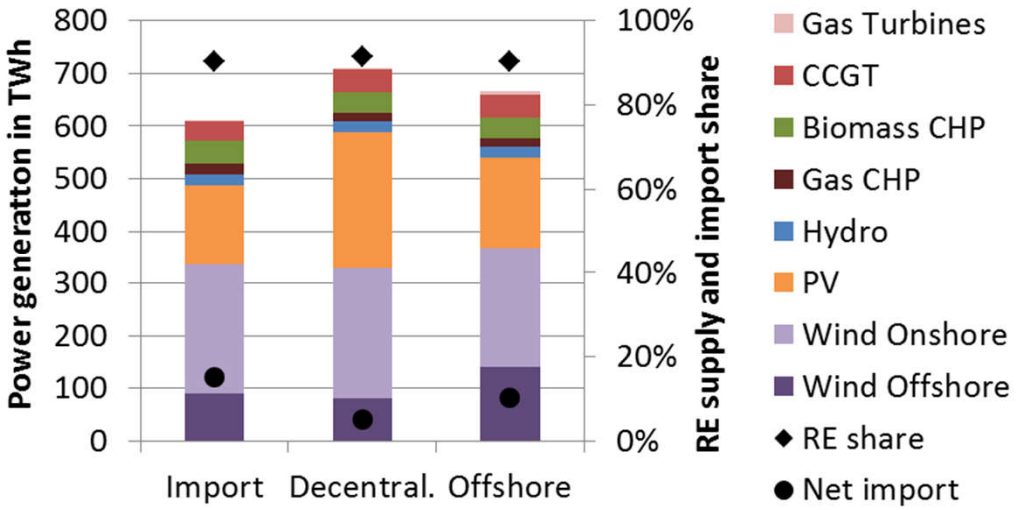
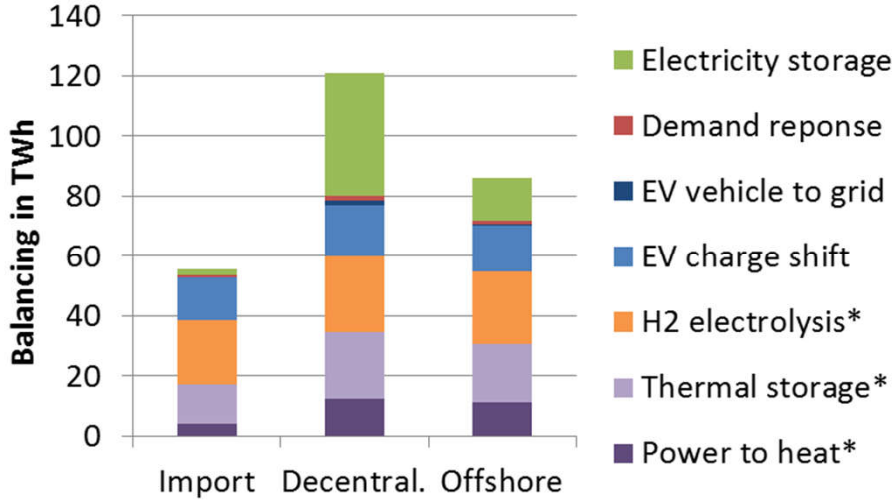
RegMex: usage and impact of flexible sector integration



Power generation



Temporal balancing (* electricity equivalent)

- Around 35% of battery electric vehicle (BEV) charging demand is shifted
- Inflexible heating and BEV charging with high impact in *Decentralized*
  - Increase in demand for electric storage and backup by 60% (15 GW)
  - Doubling of RE curtailment to 30 TWh
  - Increase of CO_2 emissions by ~3-5 %, variable operational costs by 1-3%
- Compensation in *Import* by the grid and available balancing options

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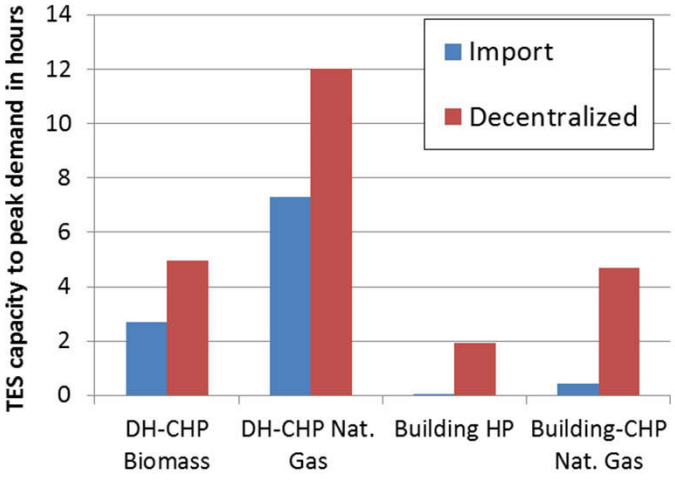
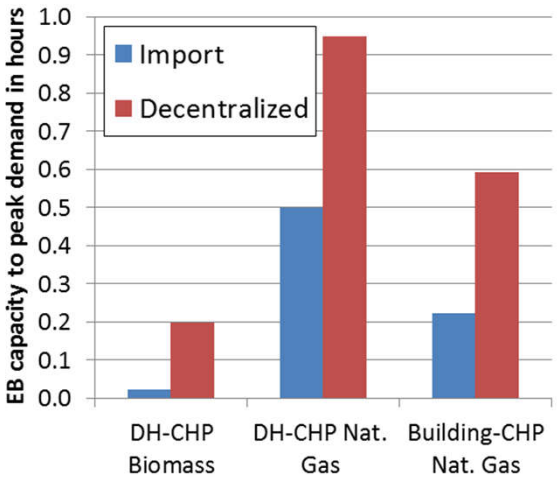
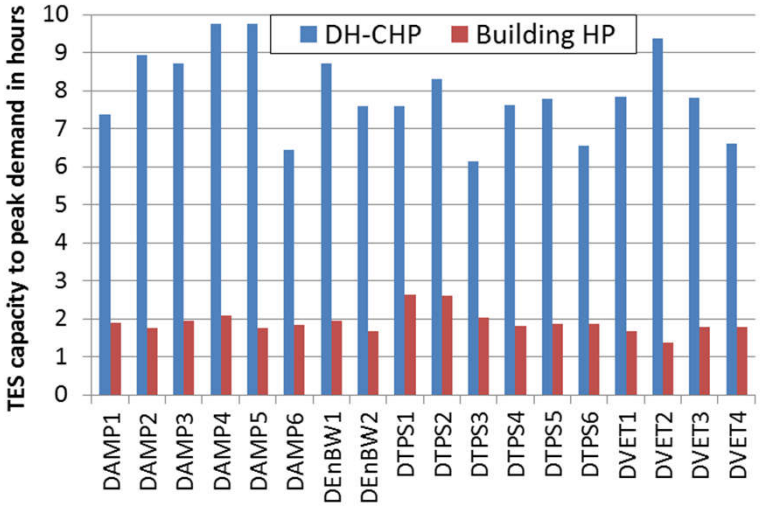
RegMex: heat supply flexibilization details





Capacity of thermal storage (TES) and electric boilers (EB)



Regional TES capacity in *Decentralized*

- Around 10% of the heat demand supplied by CHP and heat pump is stored
- Grid extension reduces least-cost capacity of thermal storage and electric boilers
- Importance of CHP flexibilisation increasing with fuel costs
- Similar dimensioning of TES and EB in all regions

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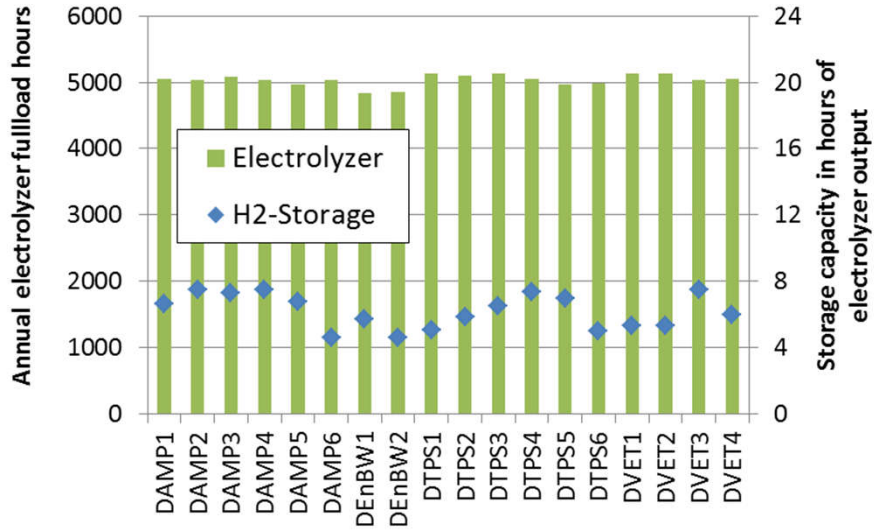
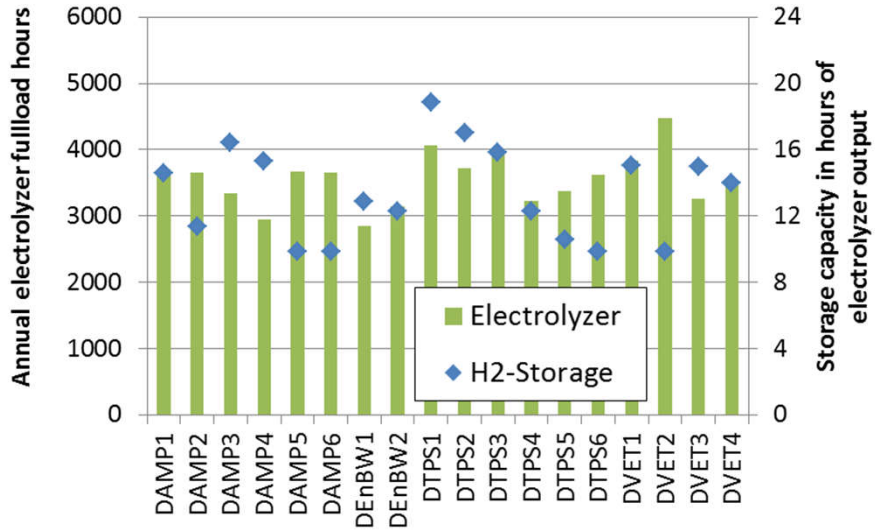
RegMex: decentralized H_2 supply flexibilization details





Capacity of decentralized electrolyzers and hydrogen in *Import* (left) and *Decentralized* (right)

- Around 20% of decentralized H_2 demand is stored
- Grid extension enables much smaller dimensioning of decentralized H_2 system
- Impact of regional supply structure on dimensioning depending on grid extension
- High PV share tends to lower the electrolyzer operation full load hours
- Optimized H_2 infrastructure notably reduces battery storage demand

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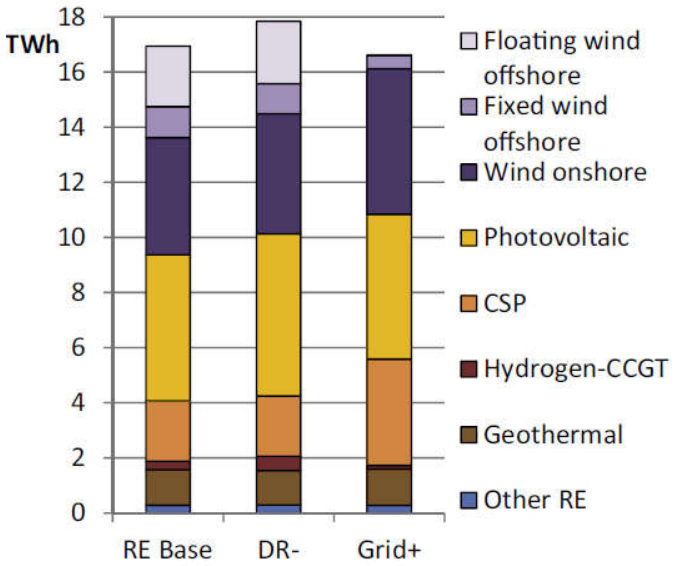
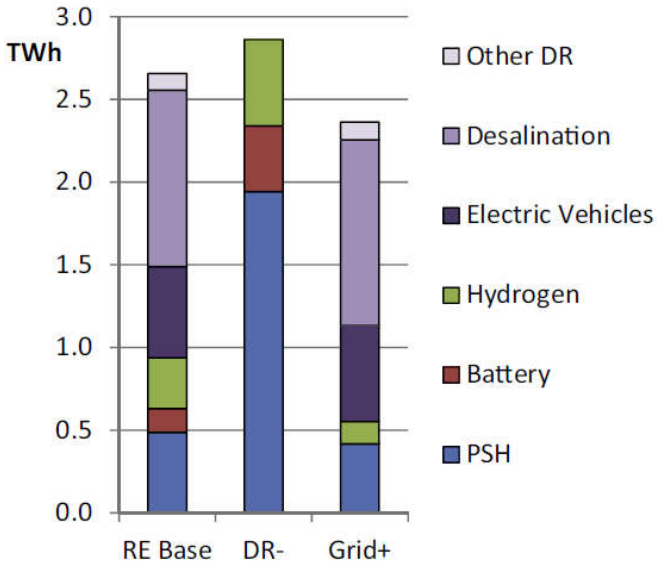
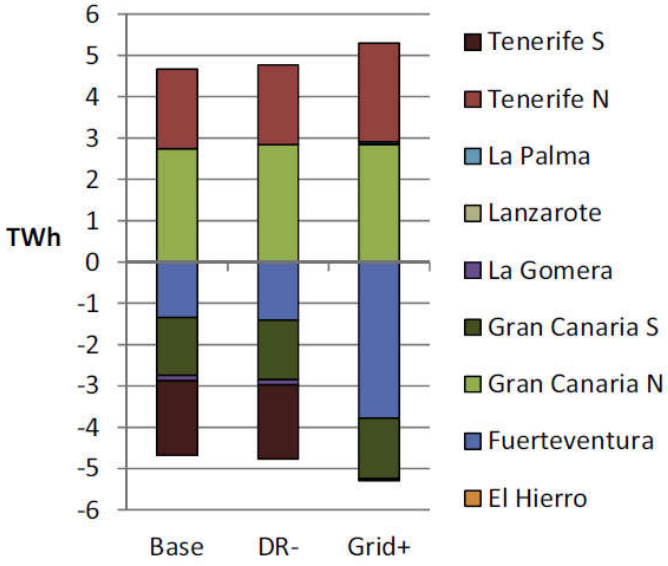
Case study: 100% RE supply on the Canary Islands



Power generation



Temporal Balancing



Spatial Balancing

- Particular challenging island environment:
  - Limited possibility of spatial balancing through power transmission
  - Low availability of biomass and hydro power for dispatchable generation
- Important contribution of controlled battery electric vehicle charging, flexible hydrogen production and re-electrification to load balancing
- High curtailments indicate potential for additional balancing/storage

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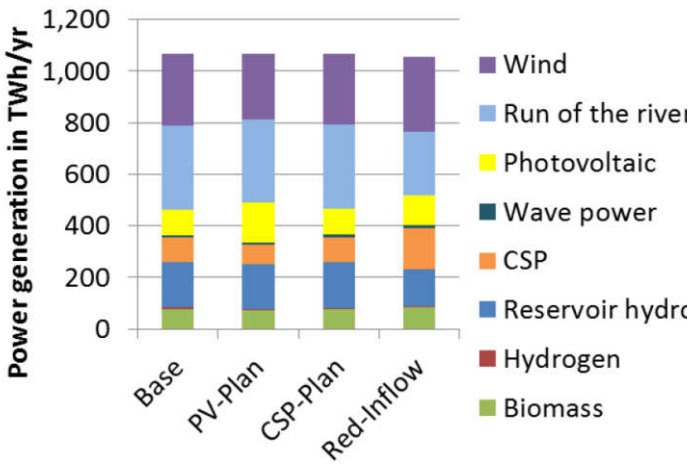
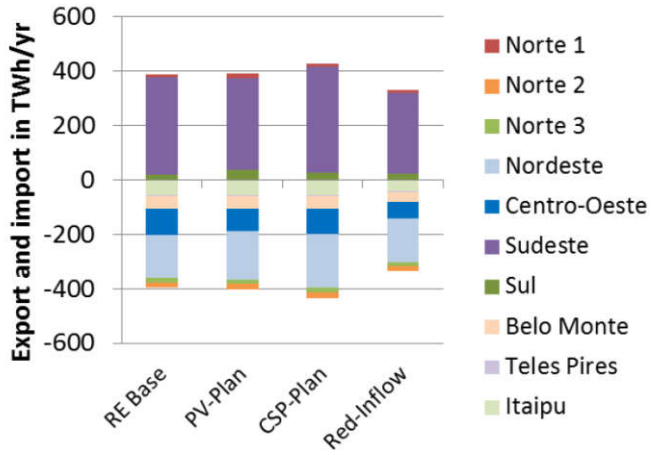
Source: Gils, H.C. and Simon, S. (2017) Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands, Applied Energy, 188: 342-355. http://dx.doi.org/10.1016/j.apenergy.2016.12.023

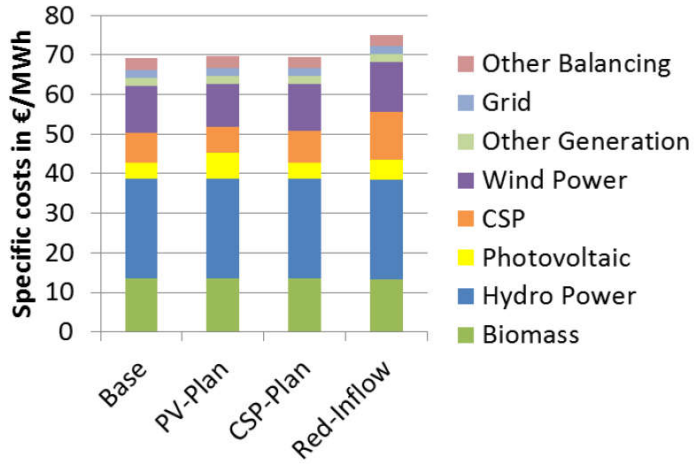
Case study: 100% RE supply in Brazil



Power generation



Spatial Balancing



Power generation costs

- High potential for dispatchable renewable generation: hydro, biomass, CSP
- Flexible sector integration is used if available, mostly controlled electric vehicle charging, but limited role for synthetic fuels/hydrogen
- Thermal storage mostly relevant in Concentrating Solar Power (CSP) stations
- Wind and PV cheaper than additional hydro power
- Reduced inflow to hydro stations favours additional CSP

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Source: Gils, H.C., Simon, S., Soria, R. (2017) 100% renewable energy supply for Brazil – the role of sector coupling and regional development, Energies 10,1859, https://doi.org/10.3390/en10111859

Summary and outlook

- REMix includes all major energy sector integration technologies in high detail
- Evaluation of flexible energy sector integration from overall systems‘ perspective
- Current focus on more detailed implementation of gas sector/synthetic fuels

- Significant demand flexibility of BEV charging, electric heating and H_2 electrolysis, which can complement and replace power transmission and storage
- RE Curtailment, emissions, backup capacity demand and costs can be reduced
- Flexible sector integration particularly important when grid extension is limited
- Energy sector integration has to be designed flexible from the start

Publications

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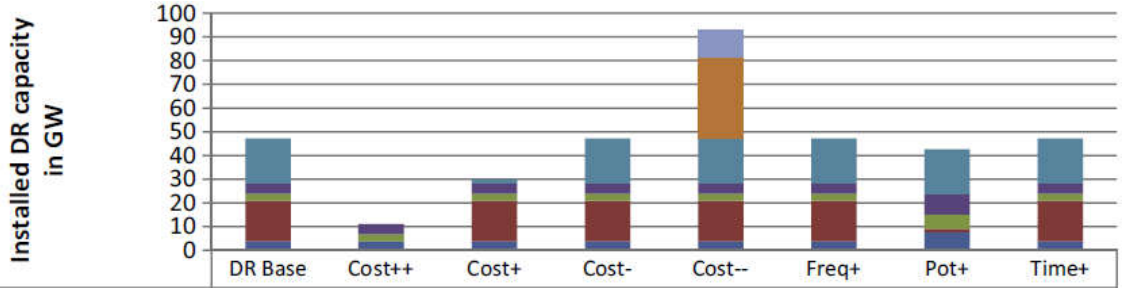
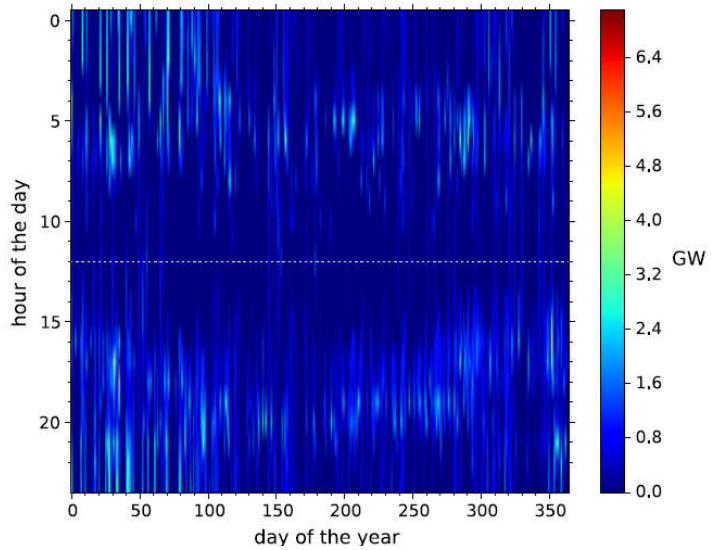
Additional Information

Case study: demand response in Germany



	DR Base	Cost++	Cost+	Cost-	Cost--	Freq+	Pot+	Time+
HeatingAC_Res	0	0	0	0	11.43	0	0	0
WashingEq_Res	0	0	0	0	34.36	0	0	0
StorHeat_ResCom	19.01	0	1.67	19.01	19.01	19.01	19.01	19.01
ProcessShift_Ind	4.32	4.32	4.32	4.32	4.32	4.32	8.65	4.32
CoolingWater_ComInd	2.95	2.95	2.95	2.95	2.95	2.95	5.90	2.95
HVAC_ComInd	17.12	0	17.12	17.12	17.12	17.12	1.44	17.12
ProcessShed_Ind	3.83	3.83	3.83	3.83	3.83	3.83	7.66	3.83

Endogenous investment in demand response



Load reduction by demand response

- 70% wind and solar power generation
- Potentials exploited almost exclusively in industry/commerce
- Residential demand response limited to electric heating and electric vehicles
- Demand response mostly limited to short time residual load peak shaving
- Significant substitution of firm generation capacity
- Particularly suited for combination with PV generation

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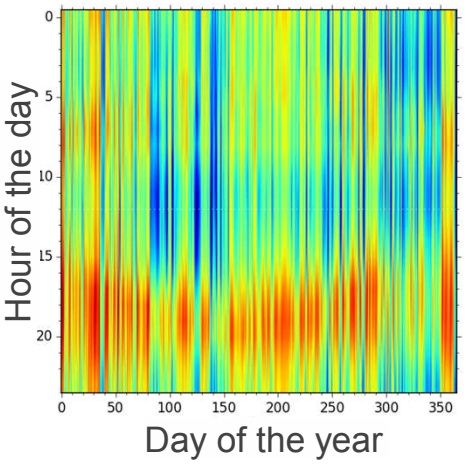
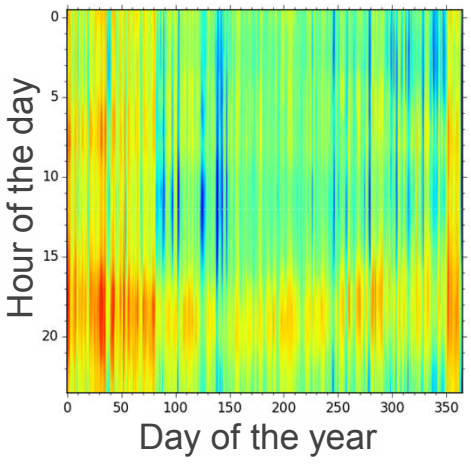
Source: Gils, H. C. (2016) Economic potential for future demand response in Germany – Modelling approach and case study. Applied Energy, 162: 401-415. http://dx.doi.org/10.1016/j.apenergy.2015.10.083

Overview: balancing of intermittent RE power generation

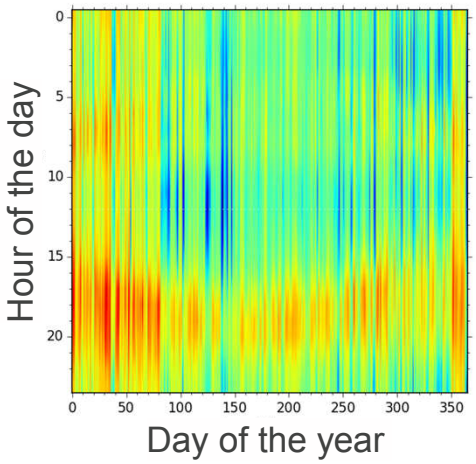
Residual load at 90 % RE power supply…



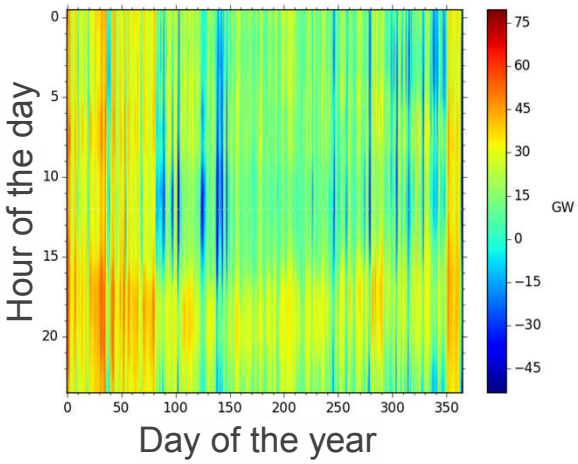
…reduced by the power grid



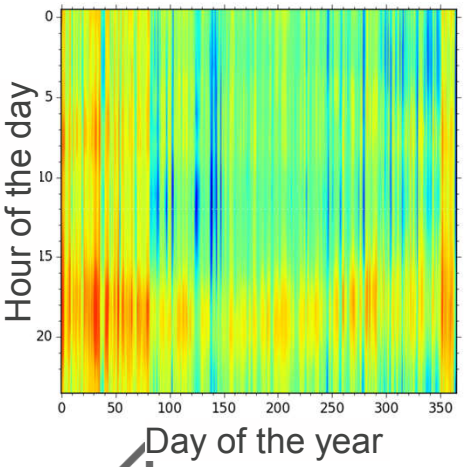
…pumped storage



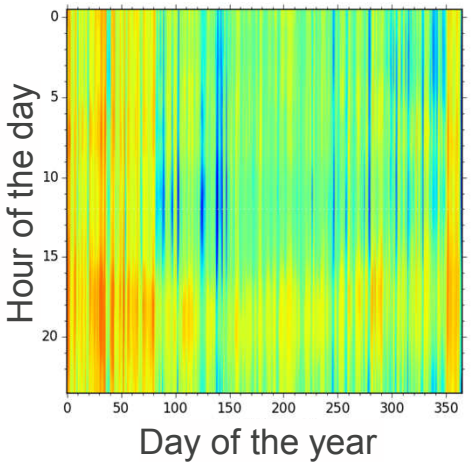
…demand response



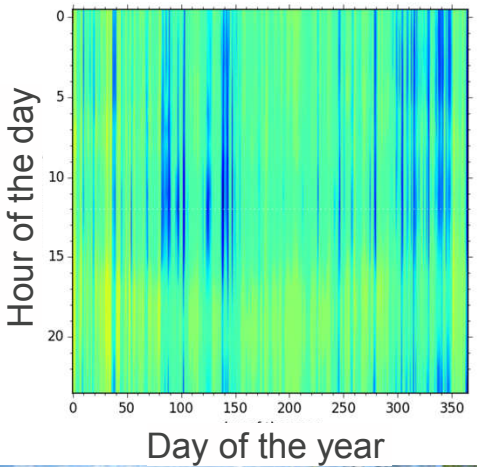
…controlled BEV charging



…flexible electric heating



…flexible CHP operation



…and curtailment