Value of diversification in 100% renewable energy scenarios

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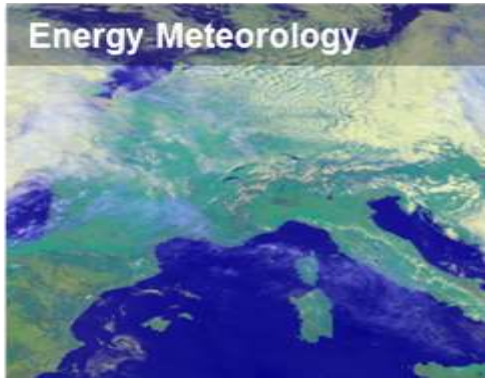
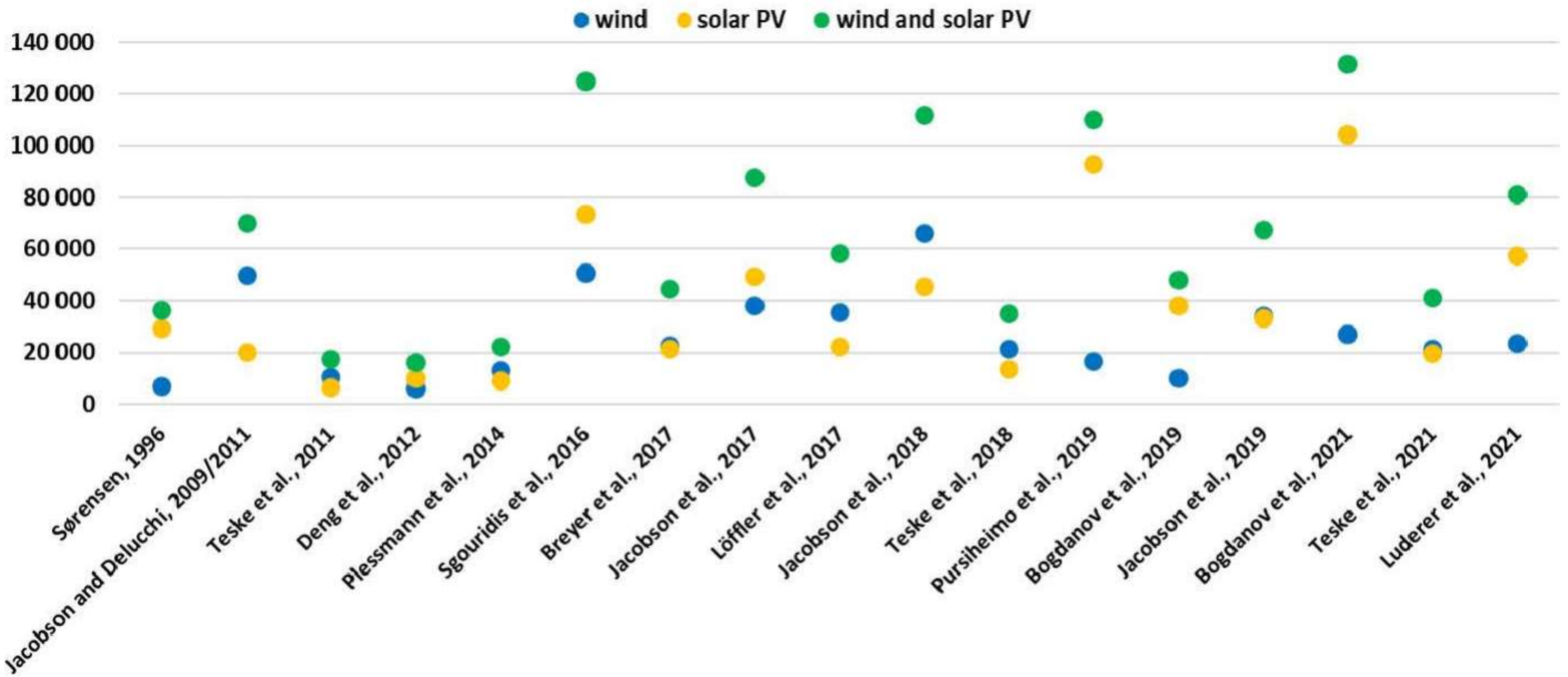
DLR activities in energy scenario development and assessment

- Studies on the energy transition and green hydrogen supply since the 1970s,
  e.g. book „Hydrogen as an Energy Carrier“ from Winter/Nitsch of 1988 (Springer)
- Lead scenarios for the German Ministry for the Environment starting around 2000,
  e.g. German „Long term scenarios 2012“ with a first bottom-up outlook on 95% GHG reduction
- Development of global and country scenarios for NGOs since 2005,
  e.g. Teske et al. 2019 „Achieving the Paris Climate Agreement Goals…“
- Infrastructure modelling in high temporal and spatial resolution since around 2005 (REMix model)
- Research on methods for socio-technical scenarios, agent-based market analyses, prospective LCA-based assessment and analysis of critical resource demand, resilience, RE potentials, …



Various technological options for future energy systems conceivable



Solar PV and wind electricity generation in TWh/yr in global 100% RE scenarios in the year 2050

Source: [Breyer et al (2022)]

Which target system is to be preferred depends on numerous parameters, which can be weighted differently

Energy efficiency

Resilience

Supply costs

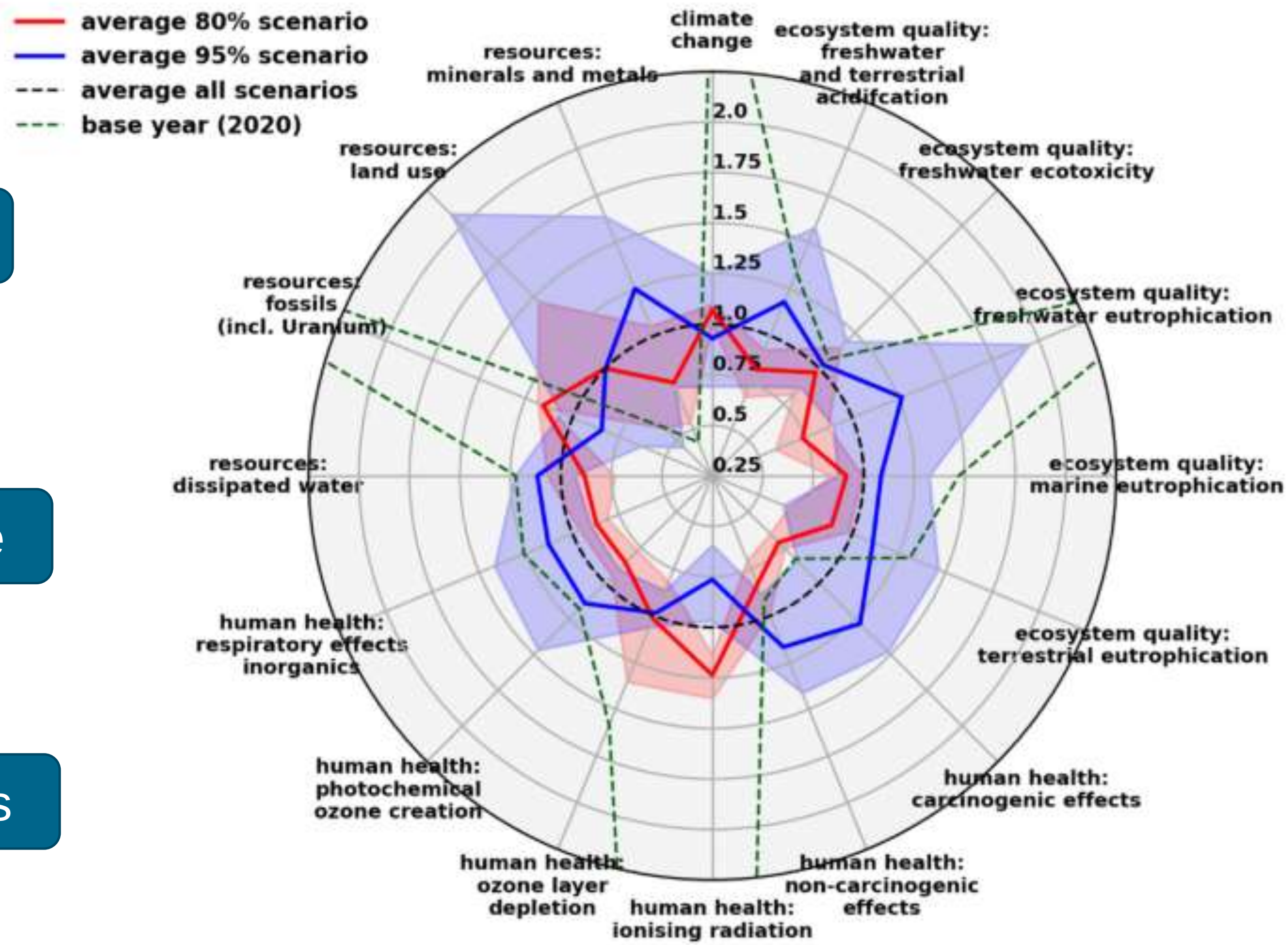
Land /water use

Social acceptance

Import dependency

Mineral ressources

…

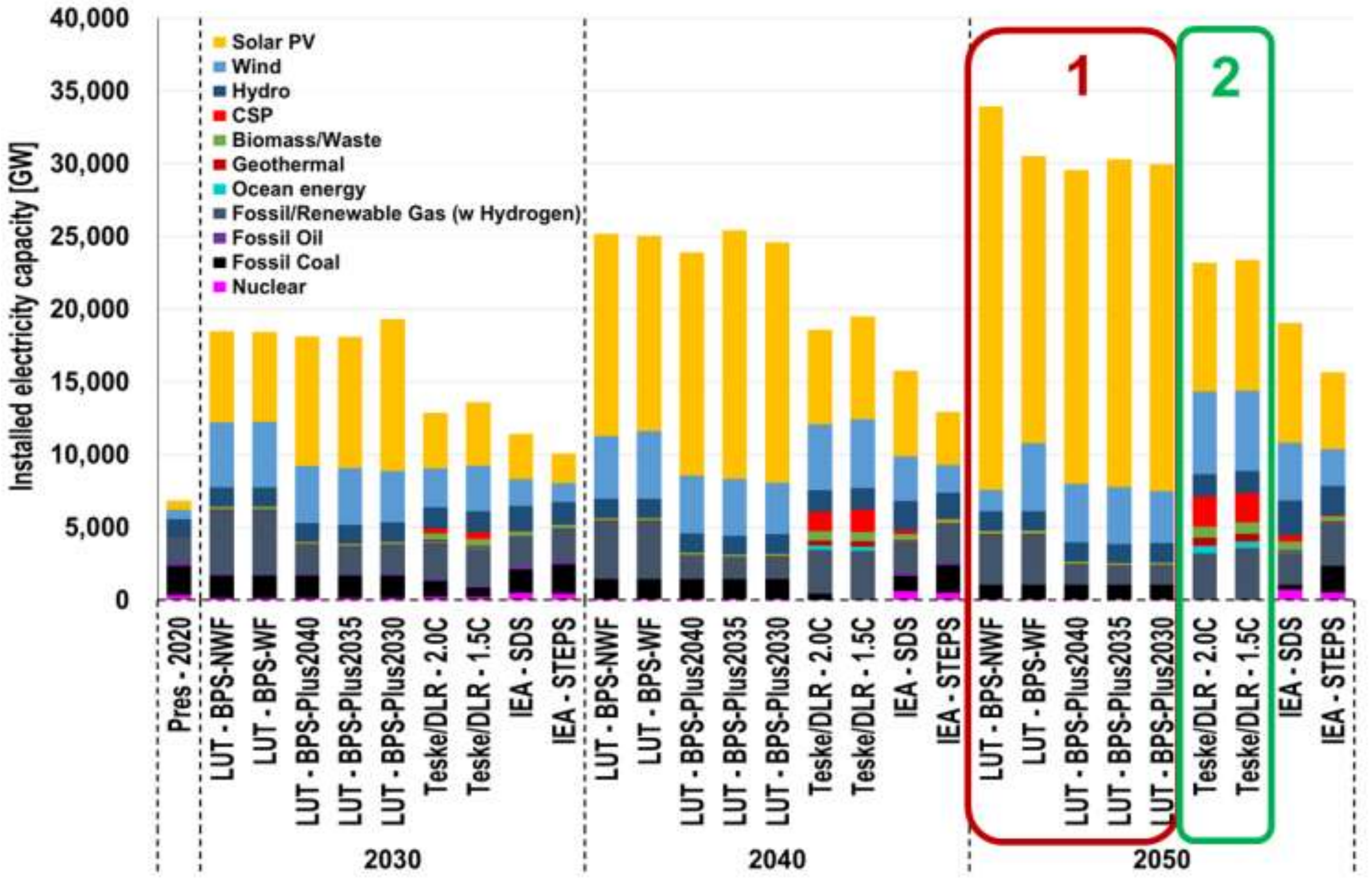


Source: Naegler et al (2022)

100% renewable energy power supply systems: Example of cost optimization (1) vs. diversity approach (2)

Teske et al. 2019 scenarios (2) with diverse power generation structure from storyline & simulation approach:

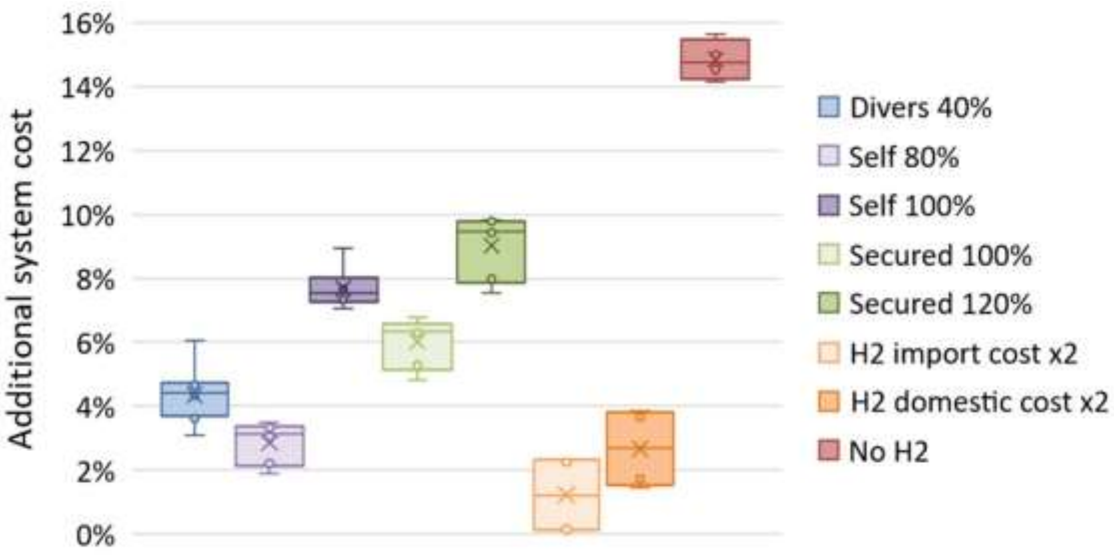
- Higher security of supply through technological diversity
- Consideration of technology accep-tance and thus lower societal risks
- Parallel expansion of technologies offers broader economic opportunities
- Possible co-benefits of esp. CSP* (heat use, water desalination)
- Compared to optimized LUT scenarios (1), LCOE** are 10% to 20% higher.

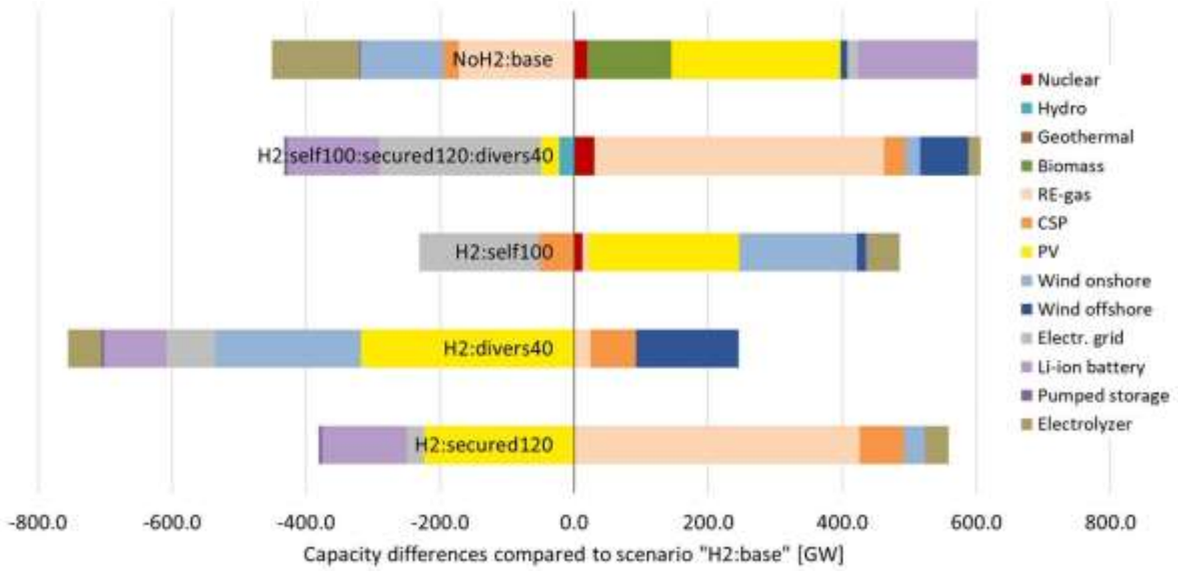


* Concentrating Solar Power ** Levelized costs of electricity Sources: Aghahosseini et al. 2022; Teske et al. 2019

Europe in detail: diversity of supply reduces risks and increases resilience at comparably low additional cost

- Power supply diversity favorable in many regards
  - 2050 system cost for Europe 3-6% higher if no technology supplies more than 40%
  - Reduced vulnerability towards external stress cases (extreme weather, hacker attacks)
- Diversity in 100% RE power systems mostly through CSP and offshore technologies

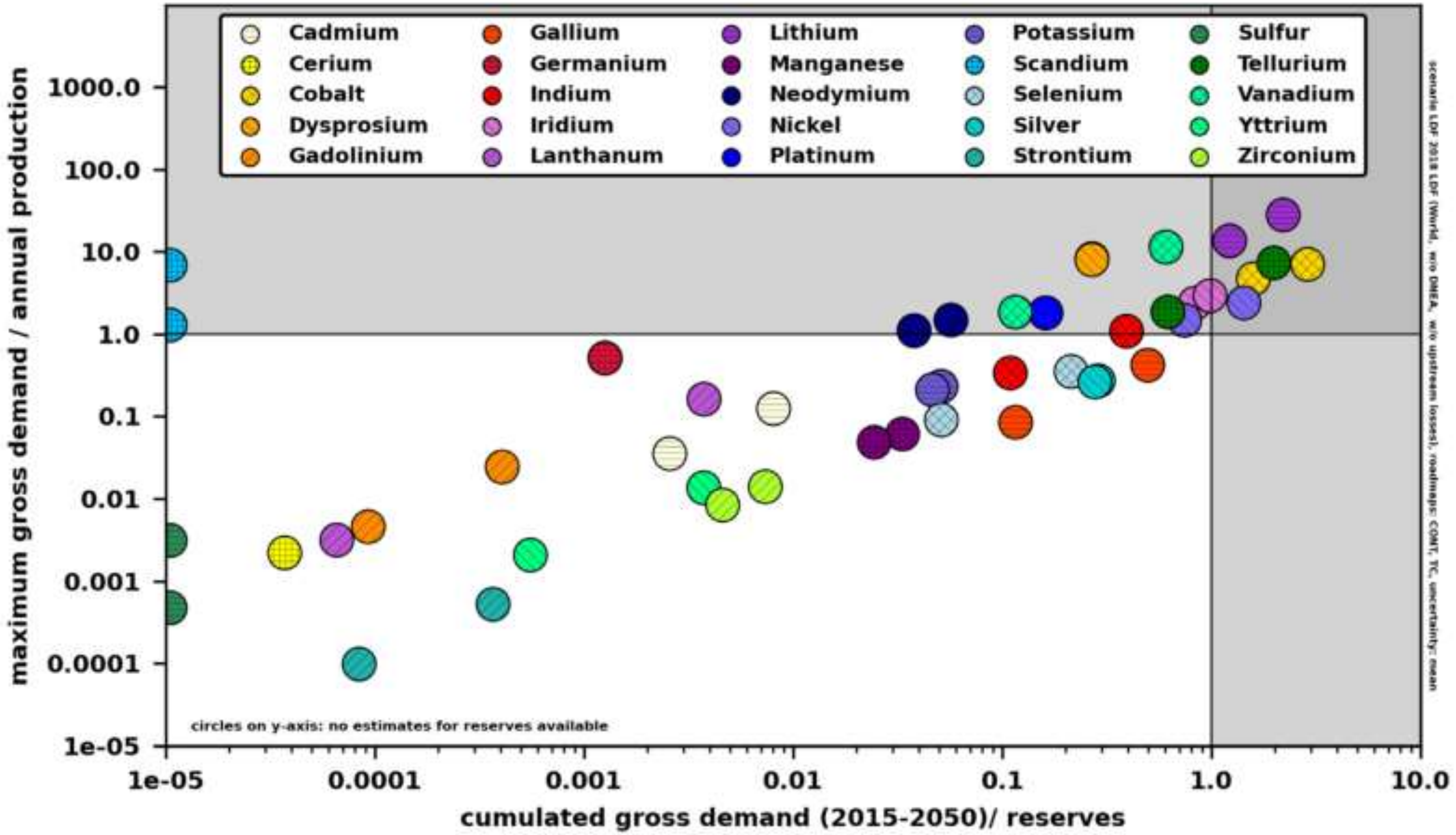




Source: Sasanpour et al. (2021)

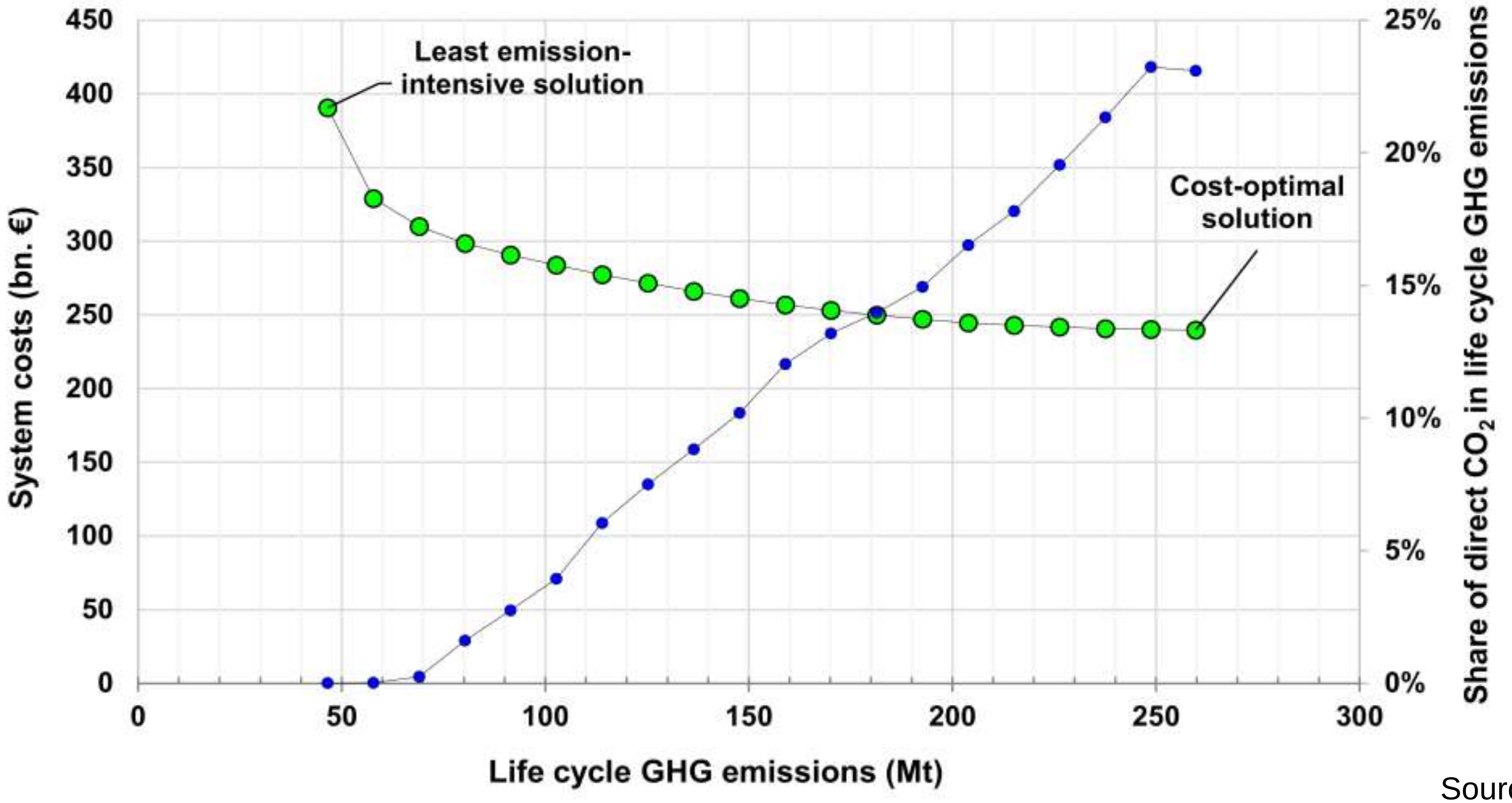
Energy scenarios pay too little attention to risks associated with costs and availability of scarce materials

- Increasing demand for critical raw materials in energy and transport technologies
- Short- to mid-term shortages possible for e.g. Lithium, Cobalt and Nickel required in stationary and mobile batteries
- Energy system transformation strategies should take into account potential raw material bottlenecks and price increases
- Efforts for recycling and lower specific demands required



Source: Schlichenmeyer et al. (2022)

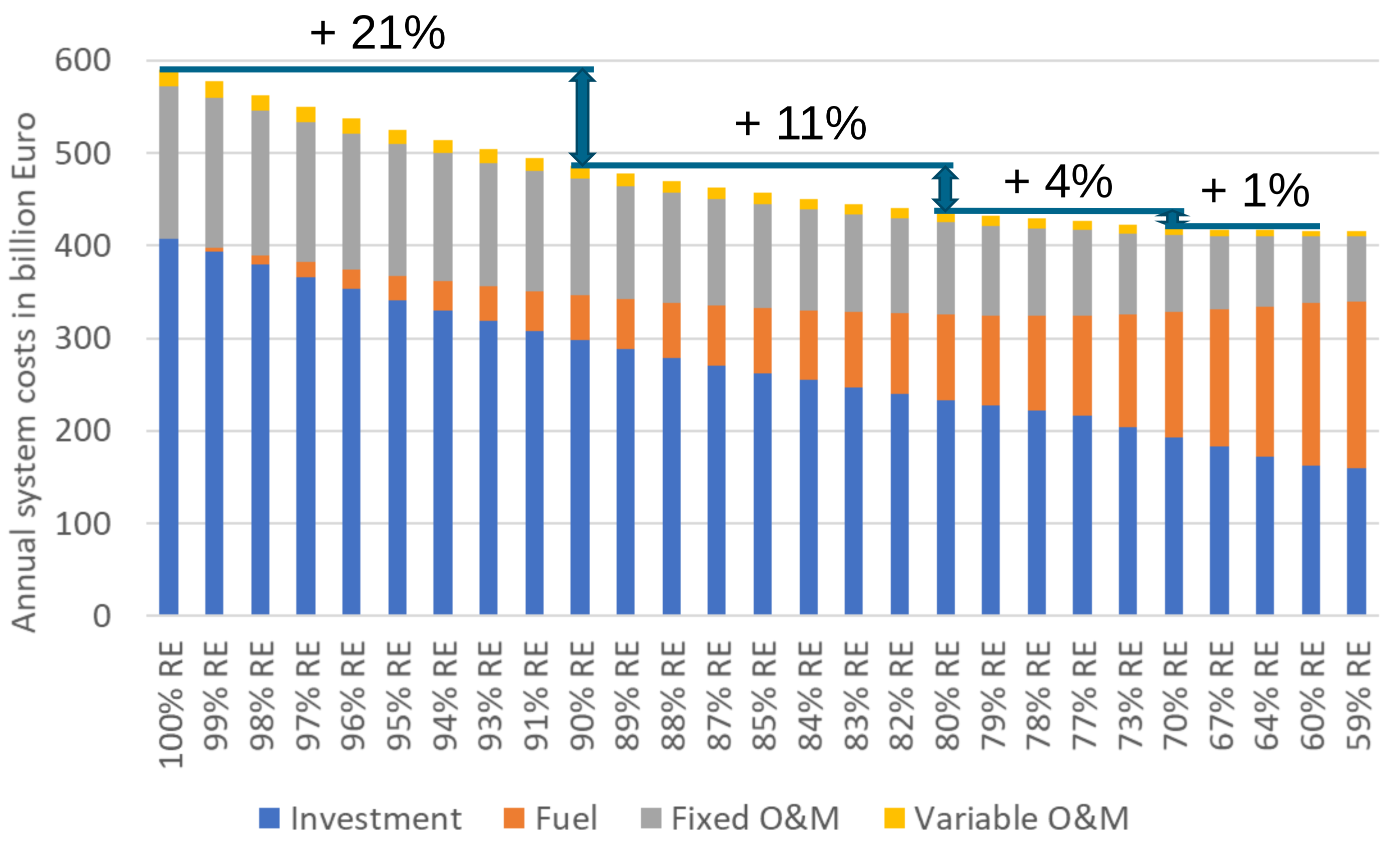
Role of material recycling and tradeoffs between costs and resource usage must be further explored



Source: Junne et al. (2021)

- Consideration of a criticality index in multi-objective system optimization
- Better data on resource availability and demands in future energy and transport systems and beyond?
- Uncertainties with regard to future recycling/circulation potentials and substitution possibilities

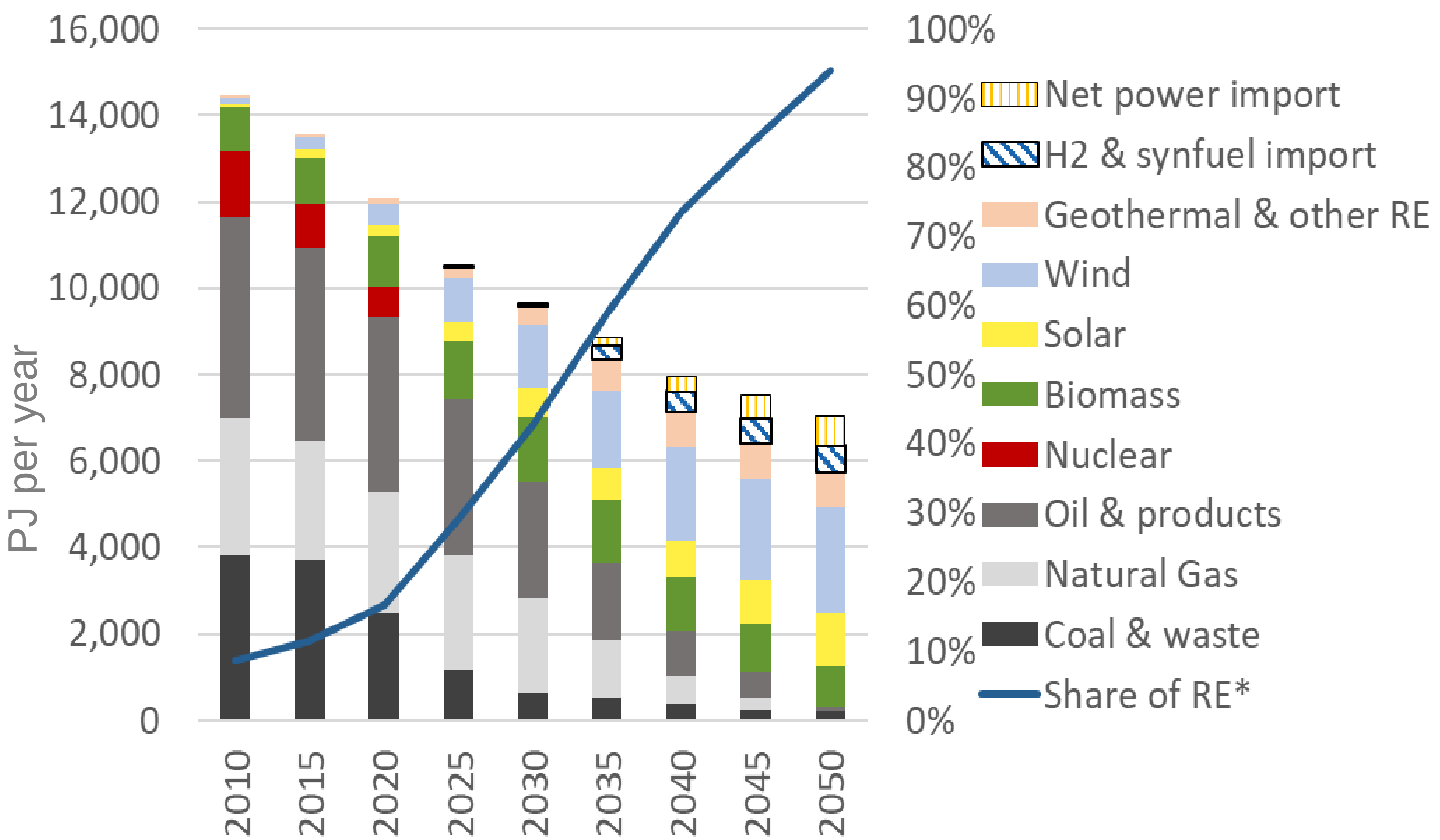
Tradeoff between implementation of a zero-emissions system and negative emissions need to be explored in more detail



- Specific cost of emission reductions increase sharply for high RE shares
- This contrasts with uncertain costs for CDR and CCS
- Conclusive assessment requires comprehensive consideration of infrastructure costs for RE, fossil fuel use, and negative emissions

Consideration of a highly stylized power system for central Europe, adopted from Gils et al. (2022).
The relative numbers provide an estimate of the additional costs of further increasing the RE share.

Import strategies will be important part of the solution for many countries: example net-zero scenario for Germany



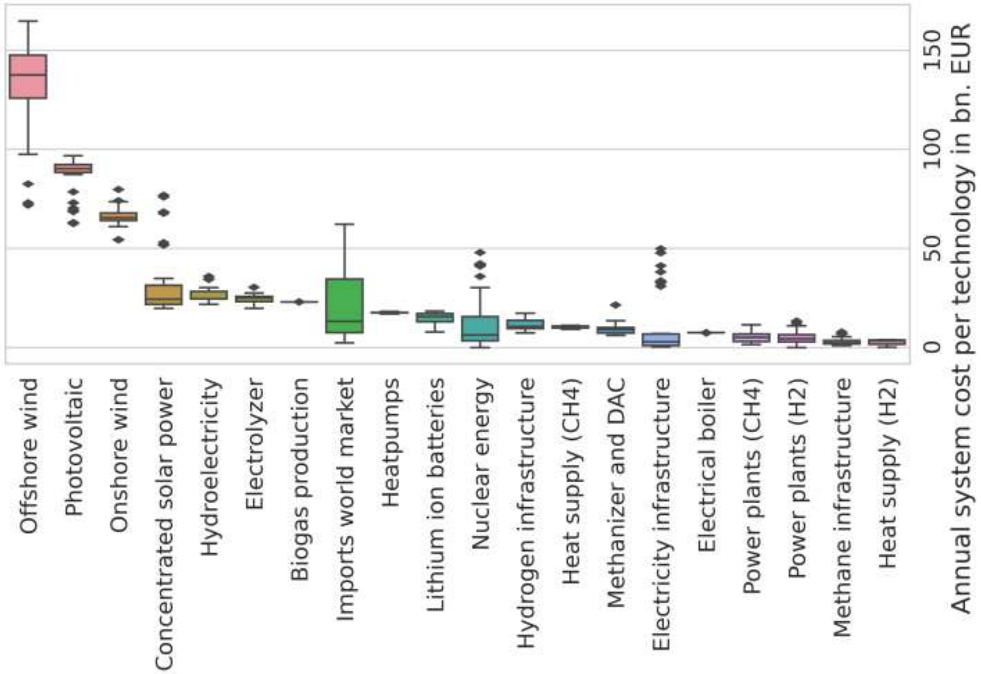
- Scenarios should consider all energy needs and infrastructures
- Sector coupling addresses (in)direct electrification of heat and transport
- E-fuels for hard-to-abate activities drive electricity demand strongly
- Example Germany: from ~600 to approx. 1500-2500 TWh/yr in 2050

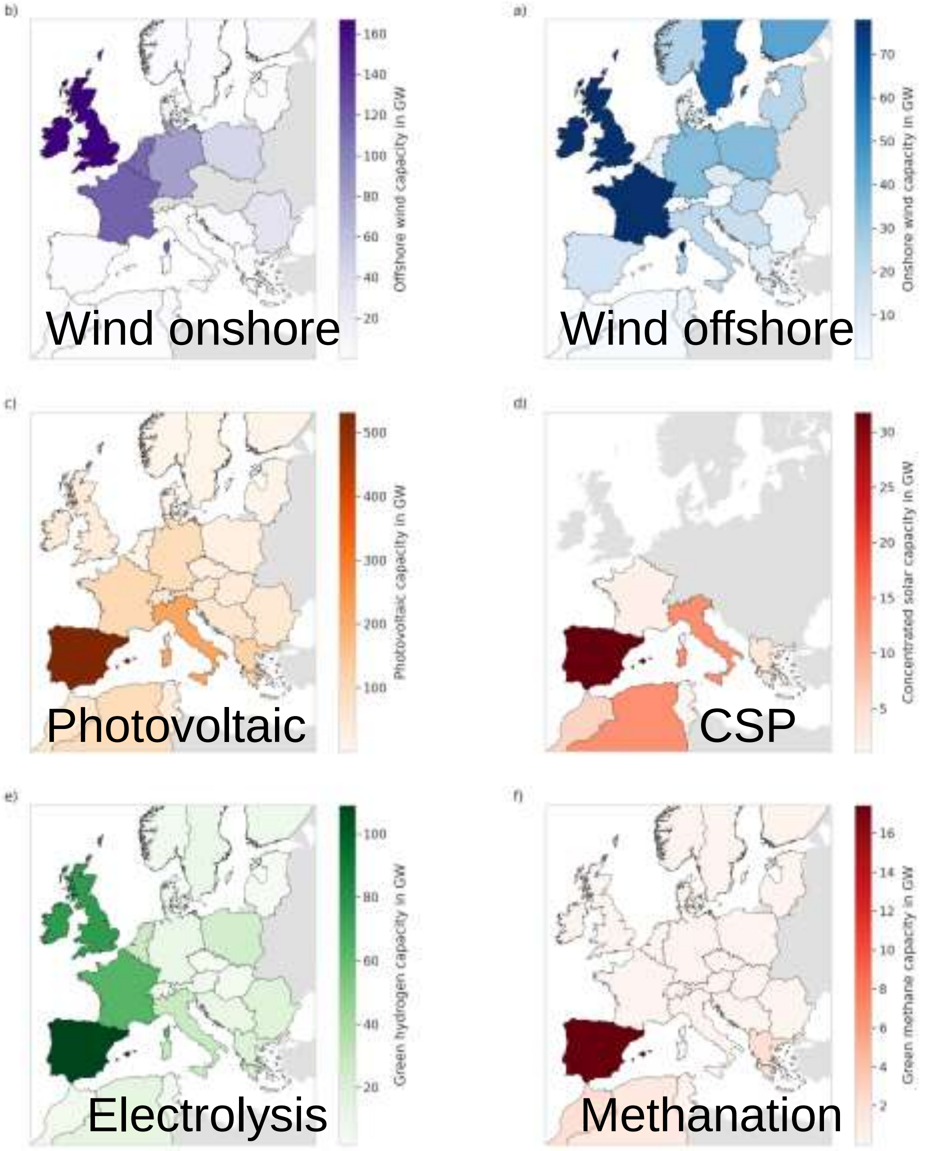
Imports must be considered in infrastructure development

Primary energy supply in the Net-zero scenario for Germany according to Simon et al. (2022).
Total (theoretical) green electricity demand in this high-efficient scenario reaches 1500 TWh in 2050, of which more than 500 TWh are imported as power, H_2 or e-fuels. CDR measures are assumed for the last ~5% CO_2 reduction.

While there is some flexibility in the regional use of RE, robust investments can be seen in different scenarios

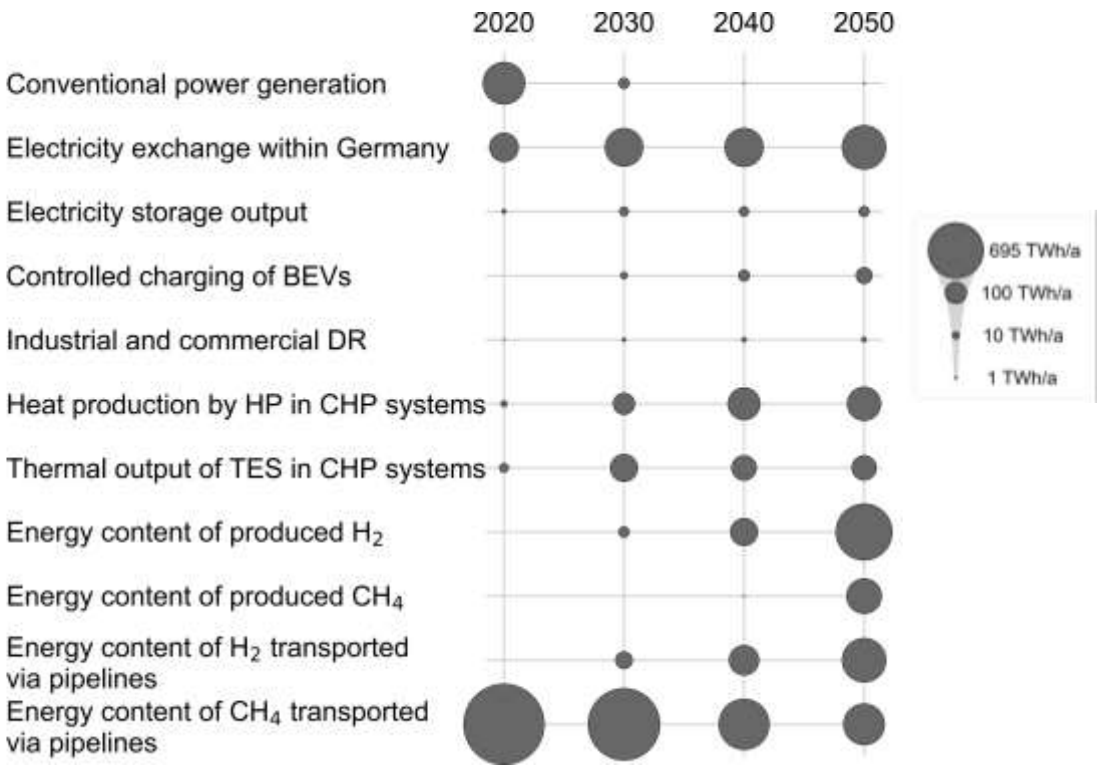
- Decision on import strategy has high impact on RE allocation
- Repurposing CH_4 pipelines is no-regret option
- H_2 flows depending on scenario storyline





Source: Wetzel et al (2023)

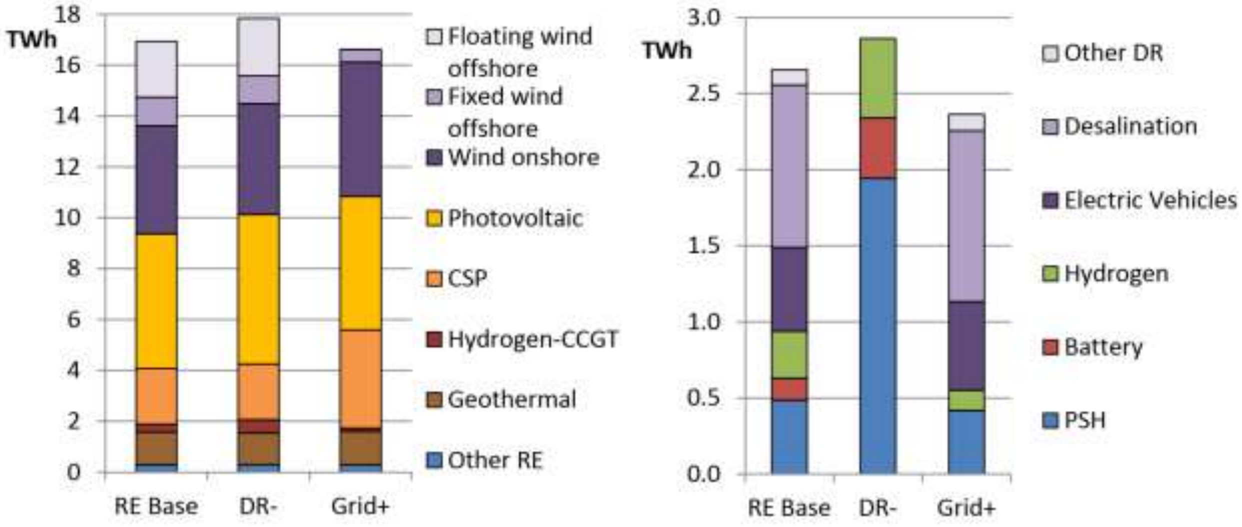
Use of decentralized flexibility lowers supply costs and reduces the need for transport networks



Source: Gils et al. (2021)

Decentralized power system flexibility is competitive and not displaced by large-scale grid expansion and hydrogen production

Dispatchable renewables to be combined with a broad range of flexibility options



Source: Gils et al. (2017)

Incentives for the installation and operation of decentralized flexibility technologies required

Conclusions

- Diversity of supply reduces risks and increases resilience at comparably low additional cost
- Tradeoff between implementation of a zero-emissions system and negative emissions need to be explored in more detail
- Energy scenarios pay too little attention to risks associated with costs and availability of scarce materials
- Role of material recycling and tradeoffs between costs and resource usage must be further explored
- Import strategies will be important part of the solution for many countries
- While there is some flexibility in the regional use of RE, robust investments can be seen in different scenarios
- Use of decentralized flexibility lowers supply costs and reduces the need for transport networks

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