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One-hour talk on this:
https://www.youtube.com/watch?v=7H5OzzUX6cg

YouTube

Strommarkttreffen “Power-to-gas und power-to-liquid”

Optimal hydrogen supply chains: co-benefits for integrating renewable energy sources

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Work in progress – working paper and source code should be available by October 2019

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

1 Research questions and contribution

Sector coupling as a strategy to

- (i) decarbonize other sectors
- (ii) provide flexibility to the power sector → often under-represented in models

Focus here: hydrogen

- Domestic H_2 production and distribution, use for fuel-cell electric vehicles

We determine least-cost hydrogen supply chains

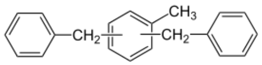
- Considering differences in energy efficiency, investment costs, and storage capabilities
- And considering electricity system interactions → main contribution

This calls for a numerical model

- We extend the open-source model DIETER and apply it to a future power system with high RES
- www.diw.de/dieter

Model: extension of DIETER

New hydrogen module

- Four channels for distributing H_2 to fuel stations
  - Decentral electrolysis
  - Central + gaseous H_2
  - Central + liquified H_2
  - Central + LOHC 

Full co-optimization of power sector and hydrogen system

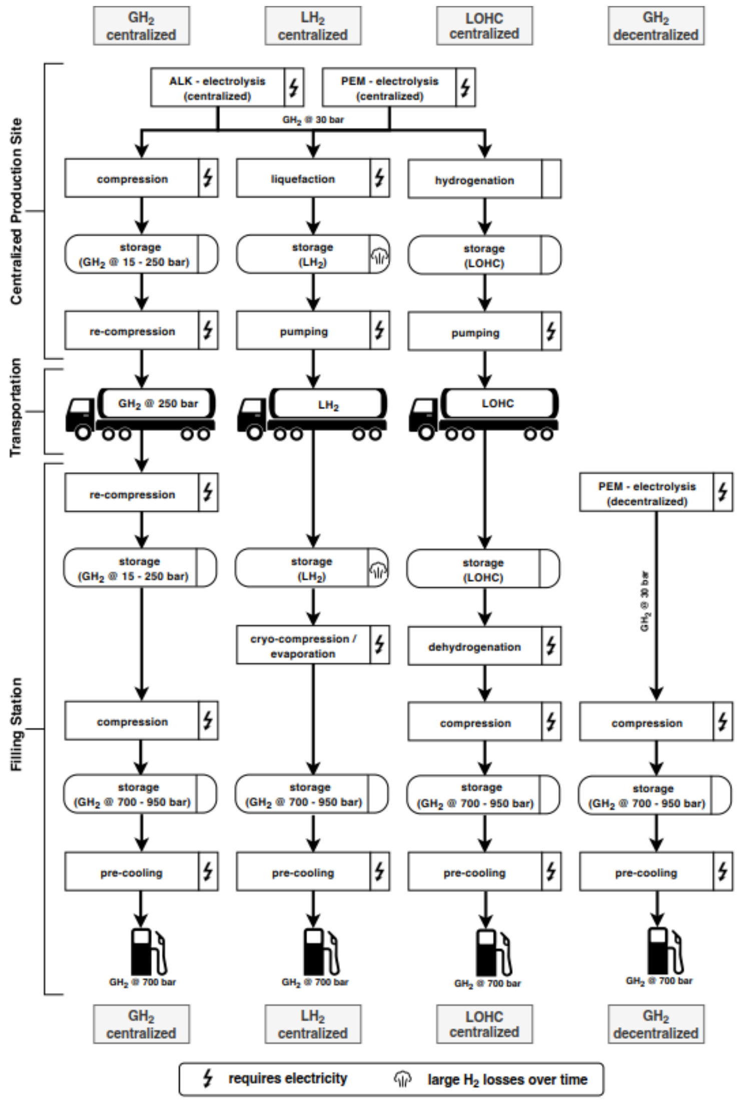
- Model decides on optimal capacities and hourly use
- Given conventional electricity demand and H_2 demand for mobility

Applied to 2030 scenario for Germany

- Power sector: brownfield, guided by NEP scenario
- Hydrogen: greenfield, 0, 5%, 10%, 25% of passenger road traffic (0, 9, 18, 45 TWh_{H2})

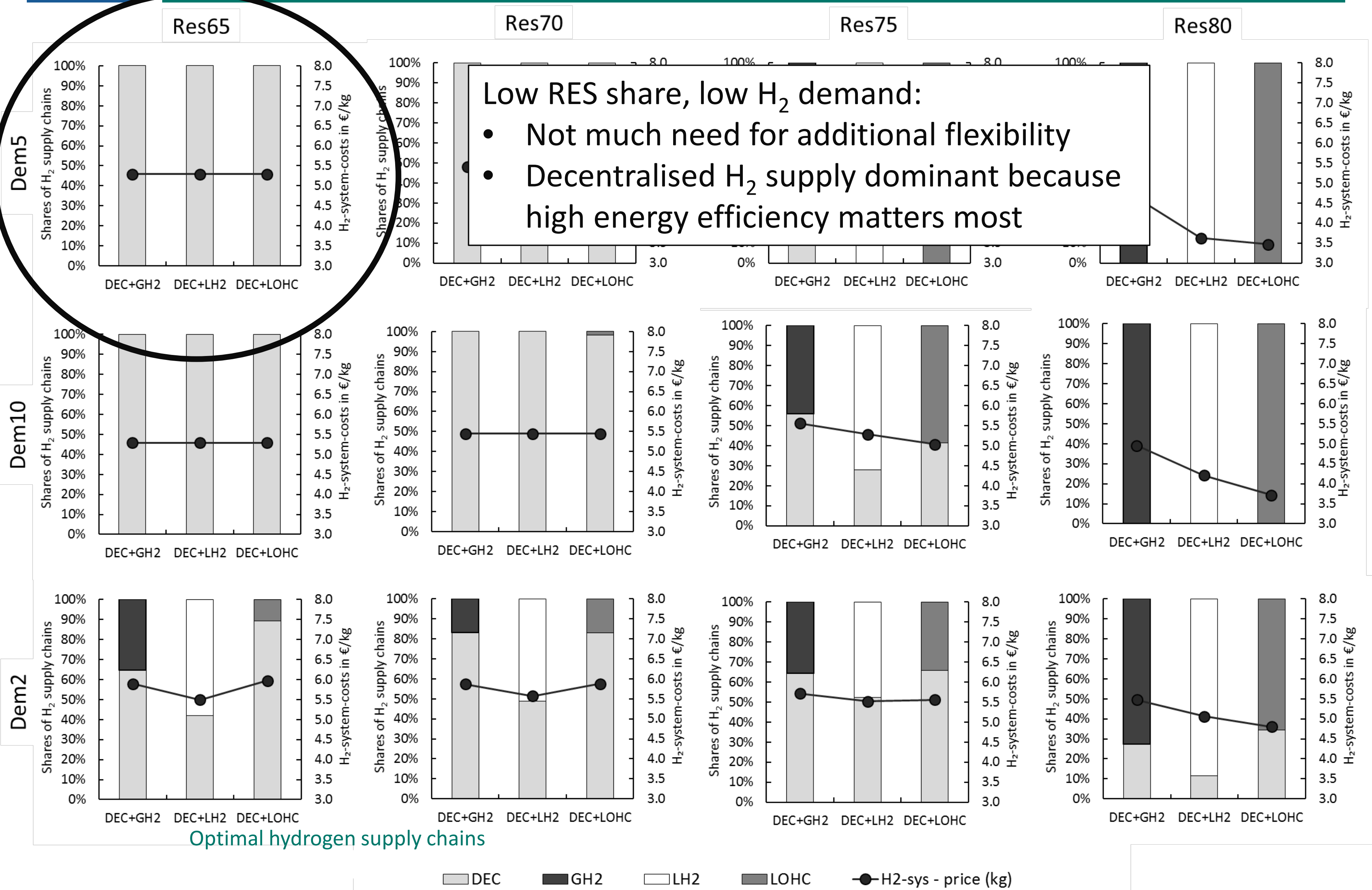
https://commons.wikimedia.org/wiki/File:Dibenzyltoluene_V1.svg

Overview of hydrogen supply chains in the model



→ We investigate not all channels in one model run, but combinations of each centralized with the decentralized channel

4 Results: hydrogen supply chains and H_2 supply costs

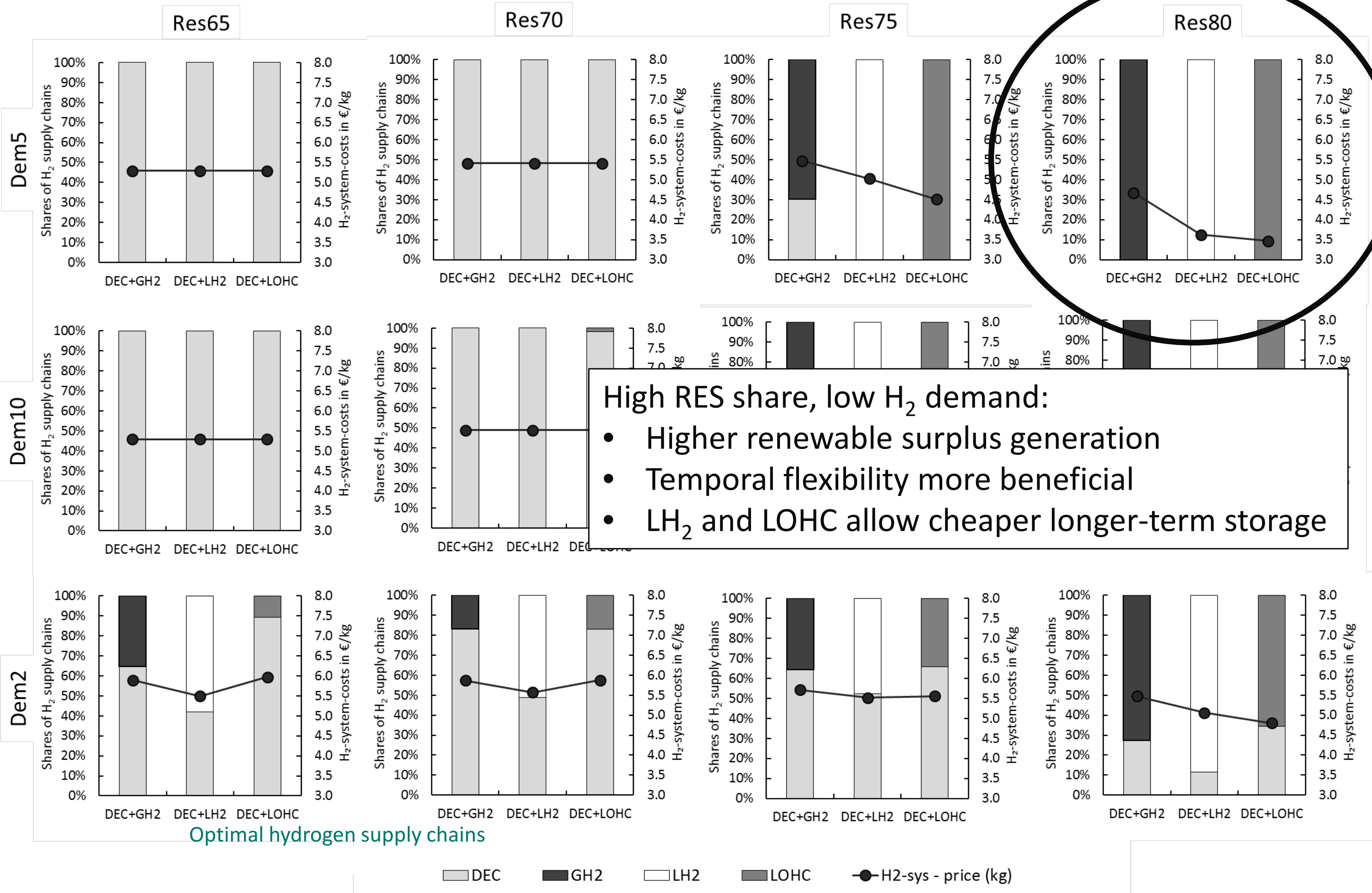


Low RES share, low H_2 demand:

- Not much need for additional flexibility
- Decentralised H_2 supply dominant because high energy efficiency matters most

Optimal hydrogen supply chains

4 Results: hydrogen supply chains and H_2 supply costs



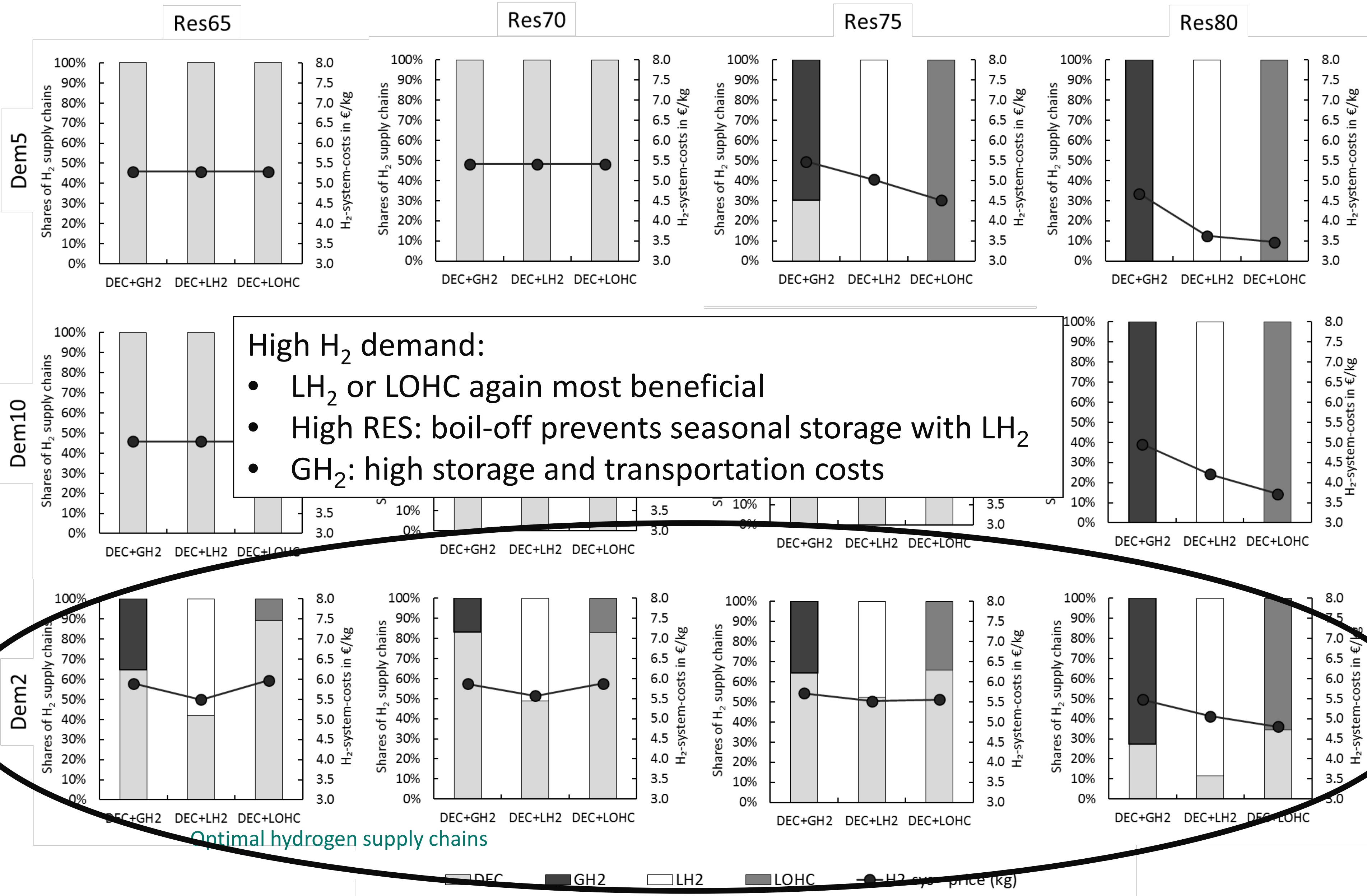
High RES share, low H_2 demand:

- Higher renewable surplus generation
- Temporal flexibility more beneficial
- LH_2 and LOHC allow cheaper longer-term storage

Optimal hydrogen supply chains

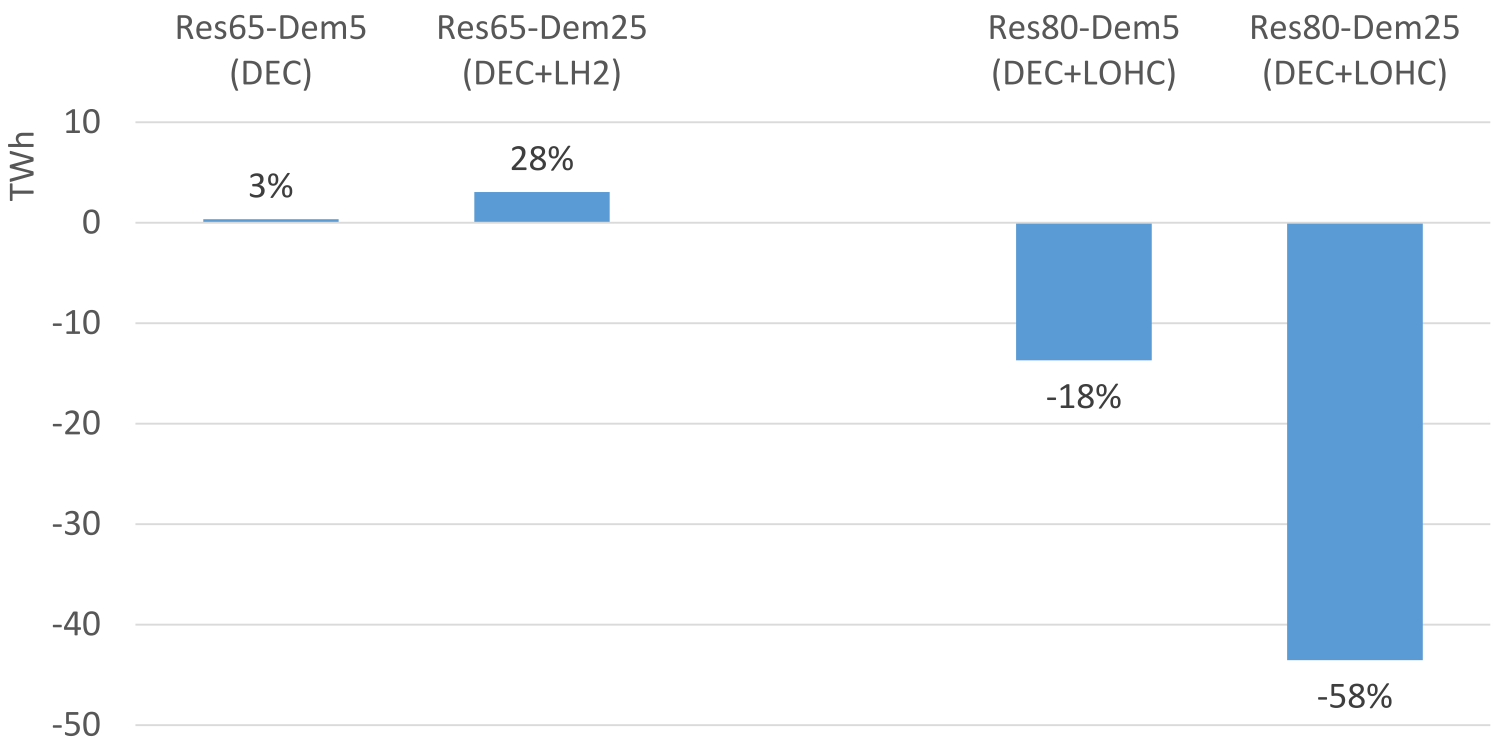
4

Results: hydrogen supply chains and H_2 supply costs



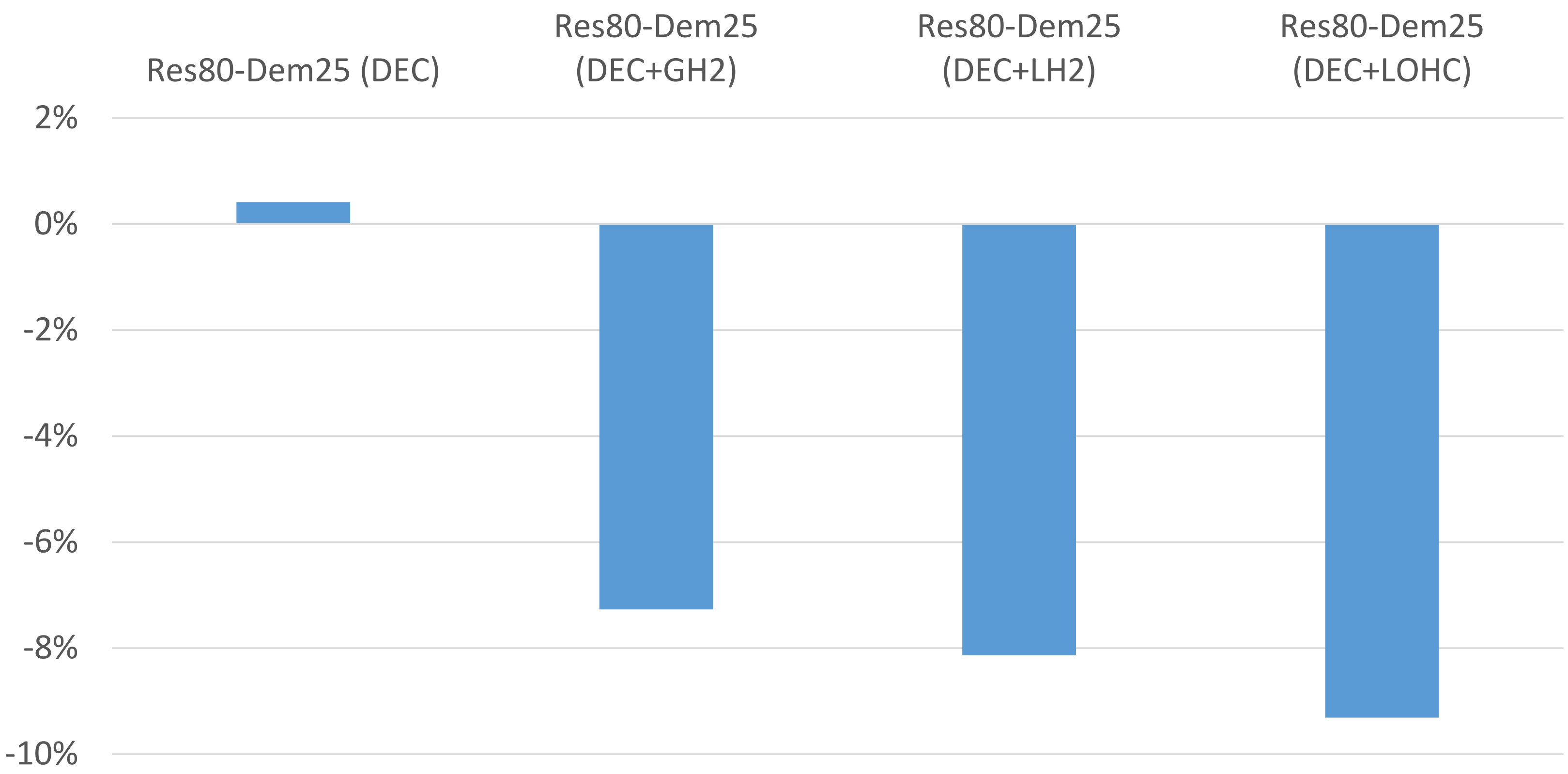
4

Effects on renewable curtailment (vs. respective baseline)



→ LOHC makes use of renewable electricity that would otherwise be curtailed

Effects on system LCOE in 80% RES case (without fixed H_2 costs)



→ Renewable integration co-benefit of H_2 – but not in decentral case w/o storage

Summary and conclusion

Tradeoff between energy efficiency and temporal flexibility

- Energy-efficient decentral electrolysis optimal for lower RES shares
- Less energy-efficient but more flexible centralized electrolysis better for higher RES shares

Sector coupling with H_2

- Can generate substantial co-benefits for integrating wind and solar energy
  → This depends on storage capability of supply chain!

Limitations

- Results are driven by renewable surplus generation – no competing sector coupling options

Thank you for listening

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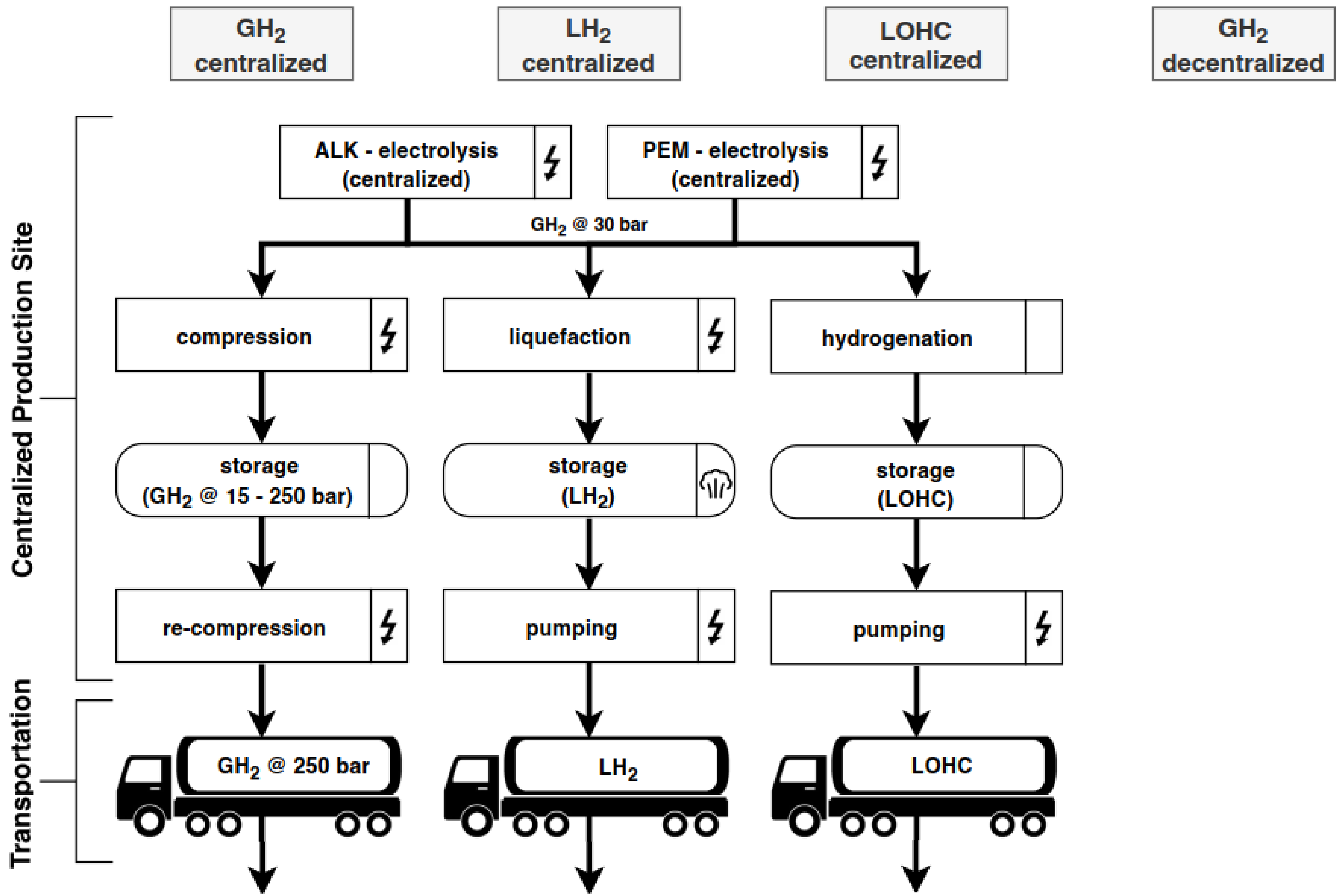
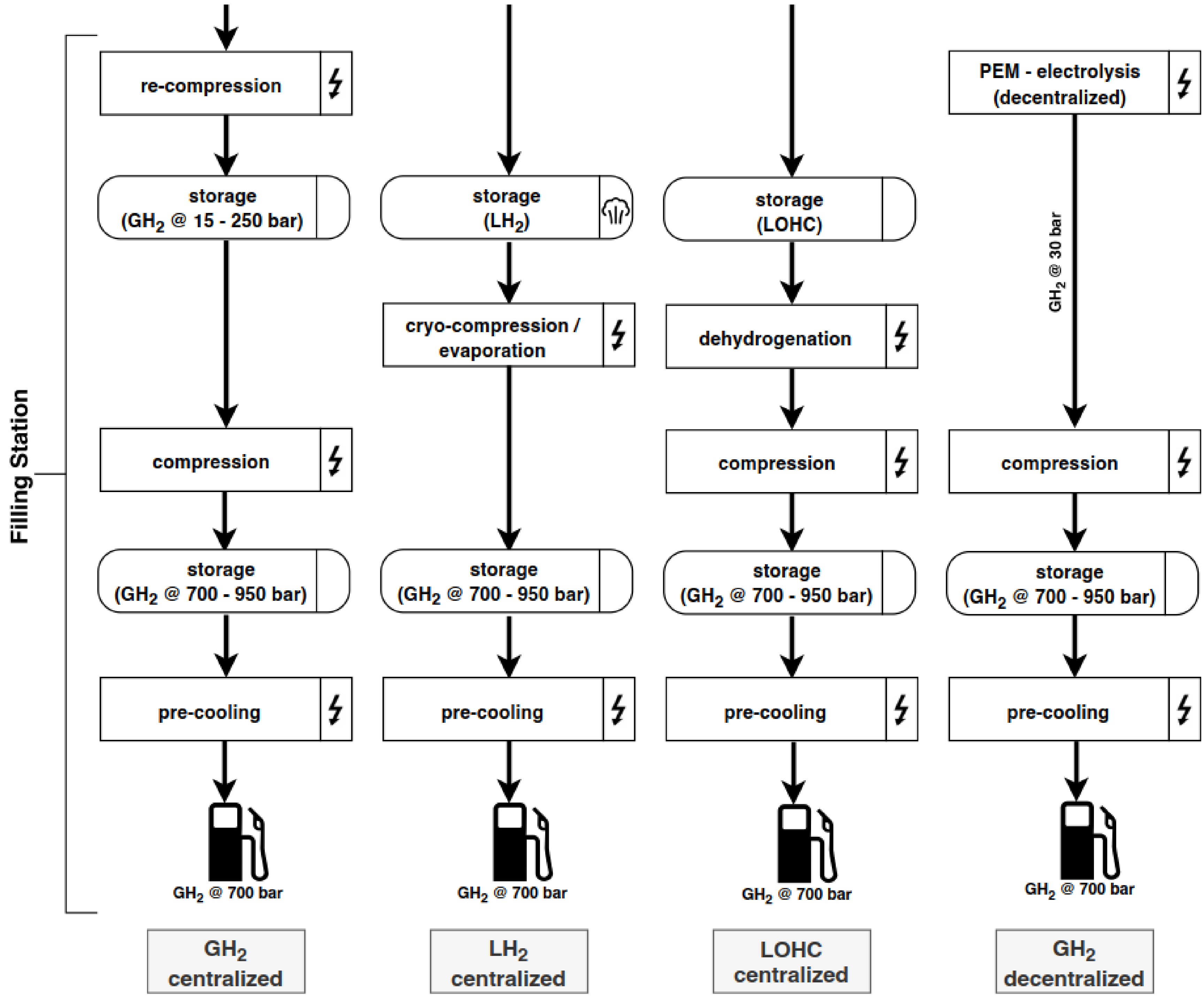
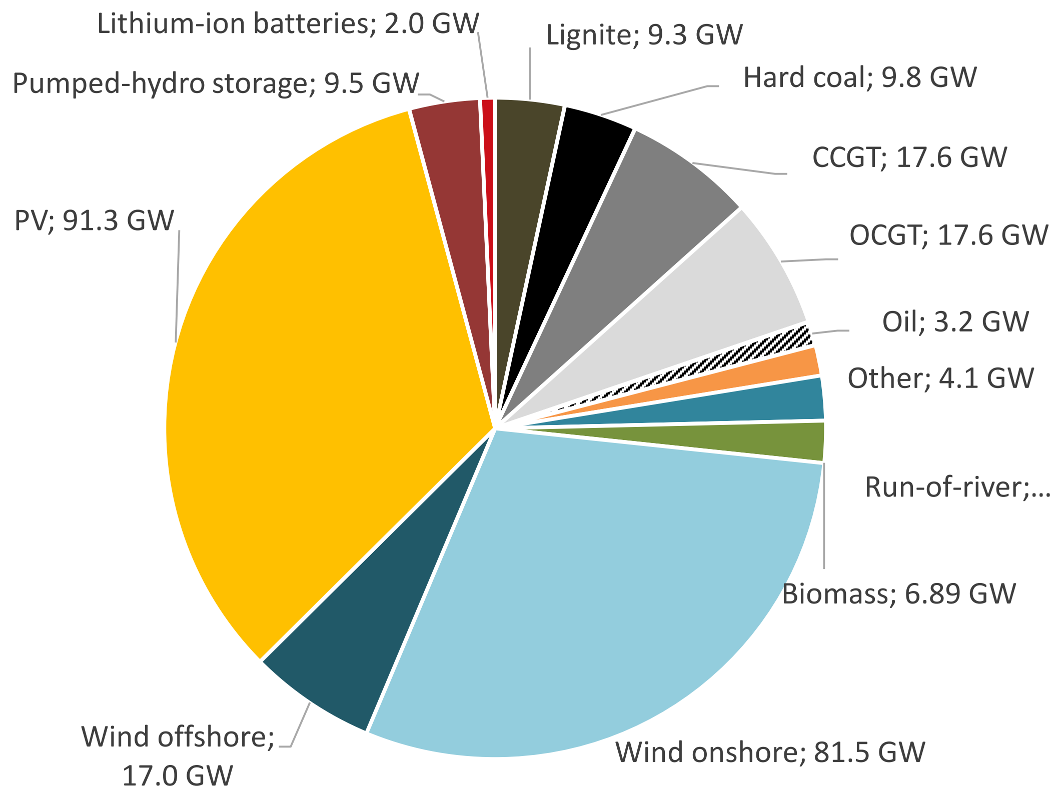

GH2 centralized
LH2 centralized
LOHC centralized
GH2 decentralized
Centralized Production Site
ALK - electrolysis (centralized)
PEM - electrolysis (centralized)
GH2 @ 30 bar
compression
liquefaction
hydrogenation
storage (GH2 @ 15 - 250 bar)
storage (LH2)
storage (LOHC)
re-compression
pumping
pumping
Transportation
GH2 @ 250 bar
LH2
LOHC


Filling Station
re-compression
storage (GH2 @ 15 - 250 bar)
compression
storage (GH2 @ 700 - 950 bar)
pre-cooling
GH2 @ 700 bar
GH2 centralized
storage (LH2)
cryo-compression / evaporation
storage (GH2 @ 700 - 950 bar)
pre-cooling
GH2 @ 700 bar
LH2 centralized
storage (LOHC)
dehydrogenation
compression
storage (GH2 @ 700 - 950 bar)
pre-cooling
GH2 @ 700 bar
LOHC centralized
PEM - electrolysis (decentralized)
GH2 @ 30 bar
compression
storage (GH2 @ 700 - 950 bar)
pre-cooling
GH2 @ 700 bar
GH2 decentralized

Electricity sector

- Brownfield scenario for 2030
- Capacities bounded by current grid development plan (NEP)
- Maximum investment into thermal plants, minimum investments into renewables and storage
- Time series provided by Open Power System Data & ENTSO-E
- Exogenous minimum renewables share of 65%, 70%, 75%, 80%

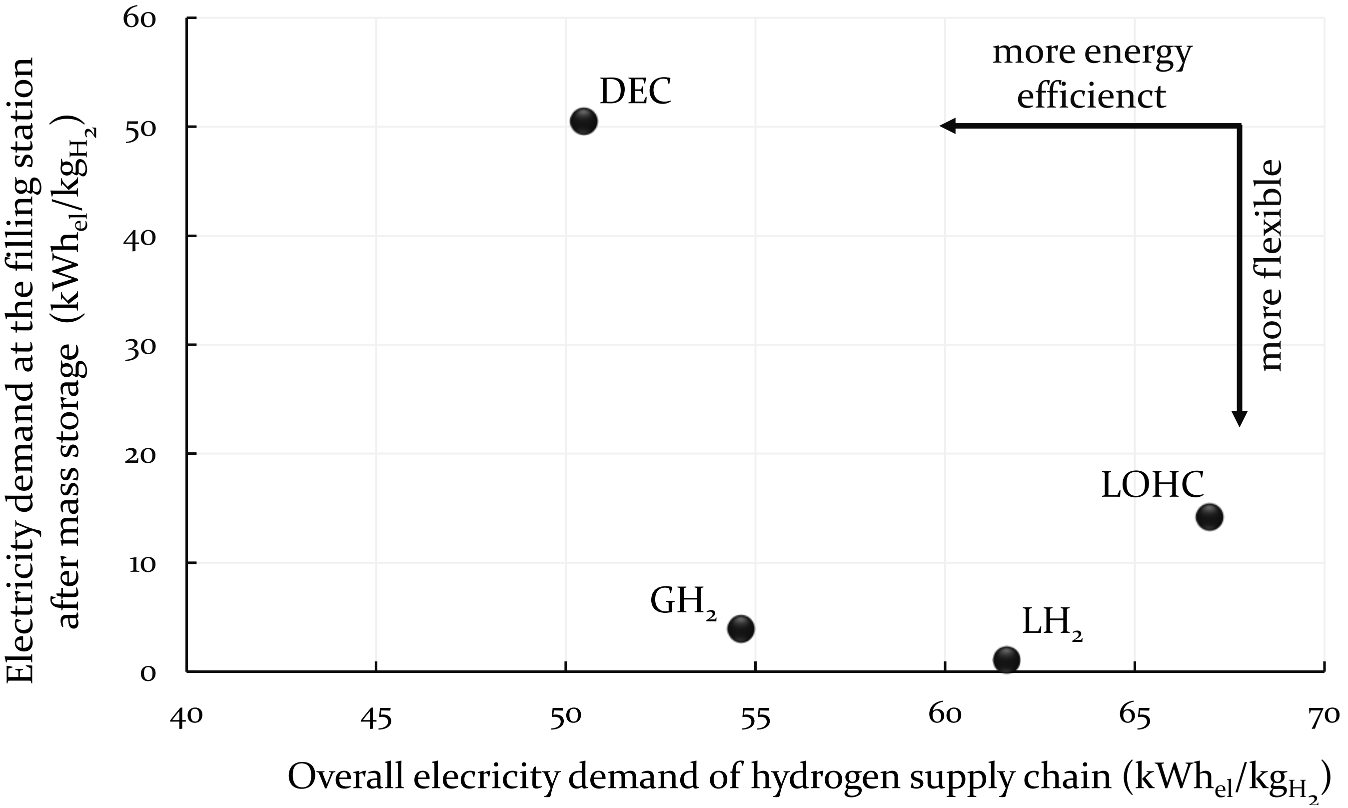


Hydrogen infrastructure

- Fully „greenfield“
- H_2 demand for mobility: 0, 5%, 10%, 25% of passenger road traffic in Germany (0, 9, 18, 45 TWh_{H2})
- General assumptions: each fuel station can only offer H_2 from one channel

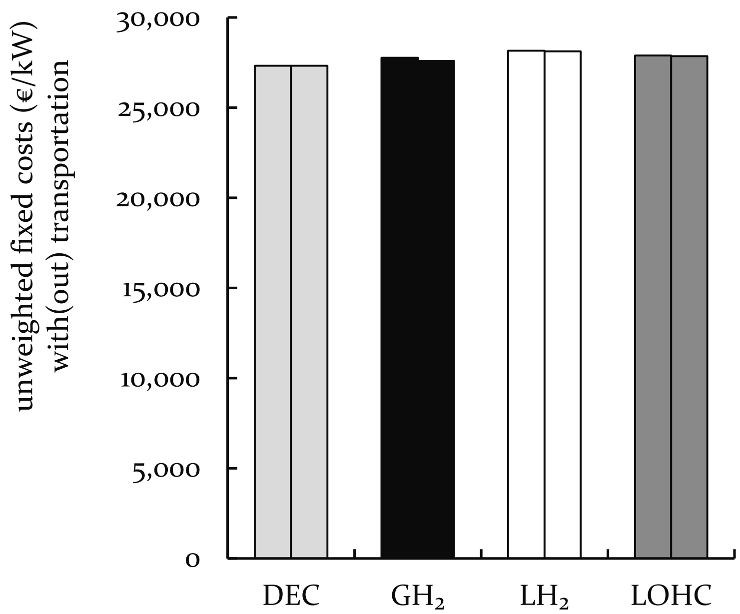
Some intuition:
potential drivers of results

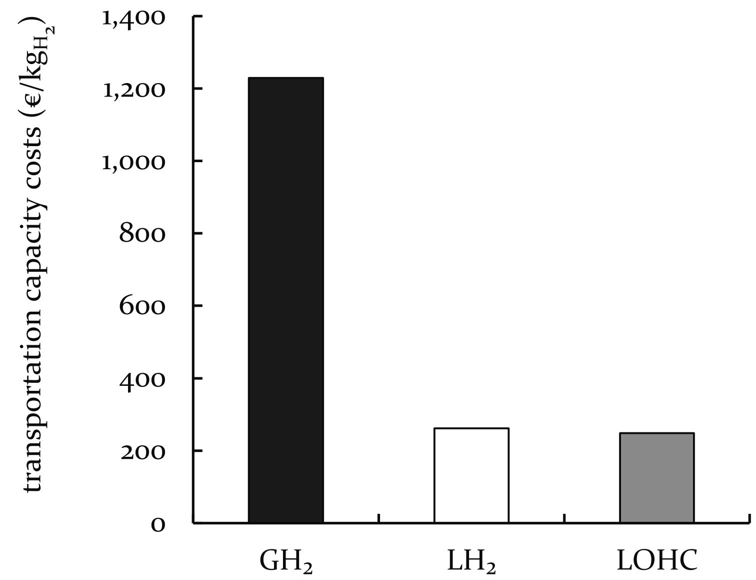
3 Drivers I: Tradeoff between overall efficiency and flexibility



→ LOHC dominated by GH_2 and LH_2 (worse in both dimensions in direct comparison)

3 Drivers II: Fixed investment and transportation capacity costs

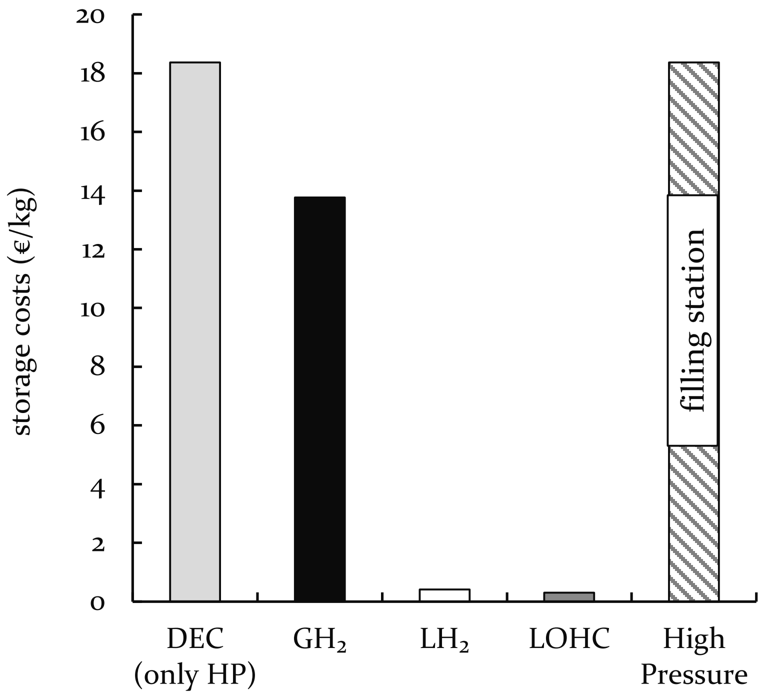




→ Only 3% spread between cheapest and most expensive supply chain

→ Transportation costs highest for GH_2 , low effective load capacity of GH_2 trailer

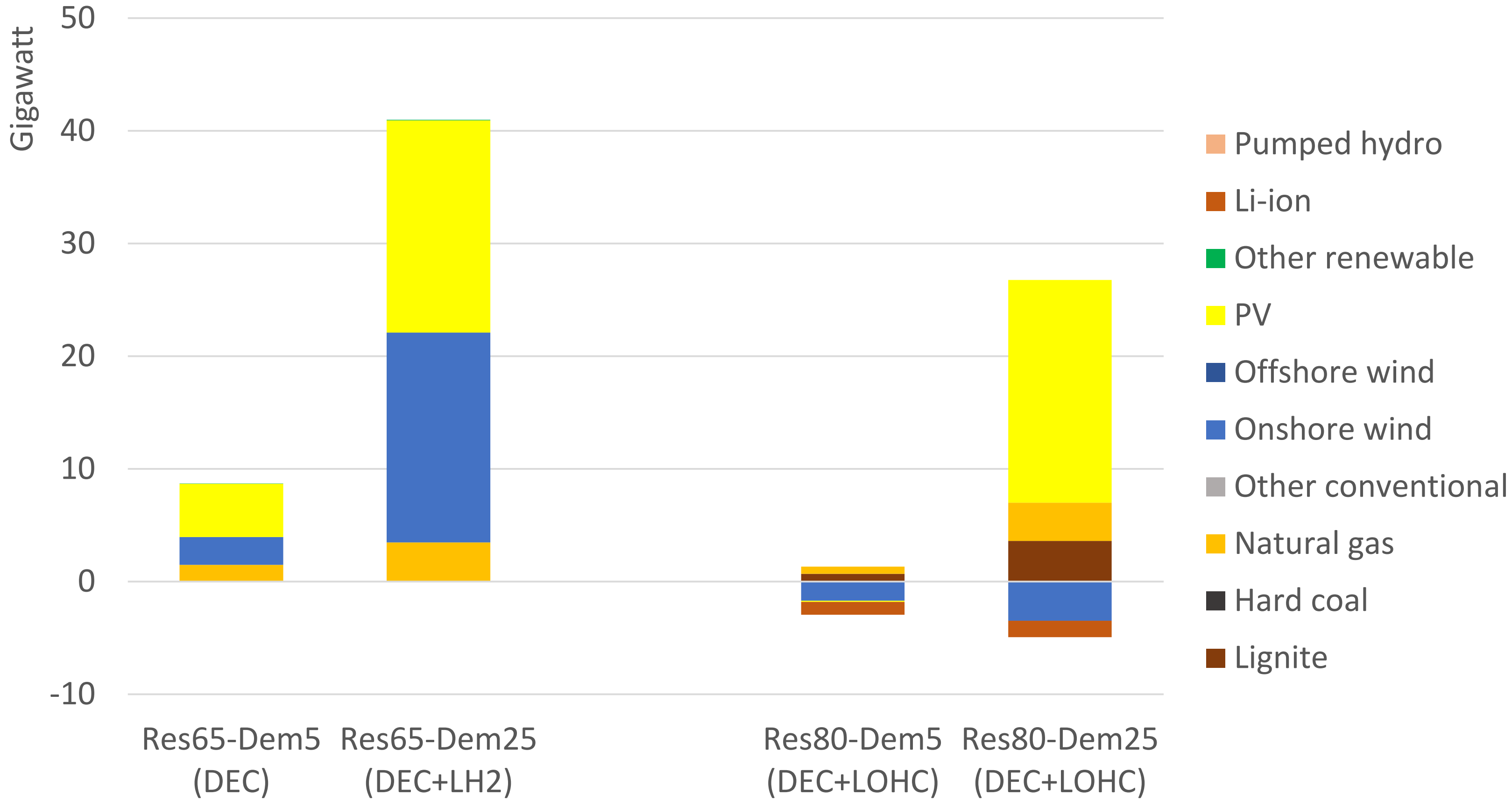
3 Drivers III: Storage costs (and losses)



- Substantially lower storage costs for LH_2 and LOHC
- Expensive high pressure storage at the filling station → only buffer storage
- LH_2 also suffers from boil-off (about 20%/week)

→ Intuition not so clear → Analysis with numerical optimization model required

4 Effects on generation capacity (vs. respective baseline)



→ More PV and (a bit) less storage

→ Less capacity needed in high-RES scenario (better utilization)

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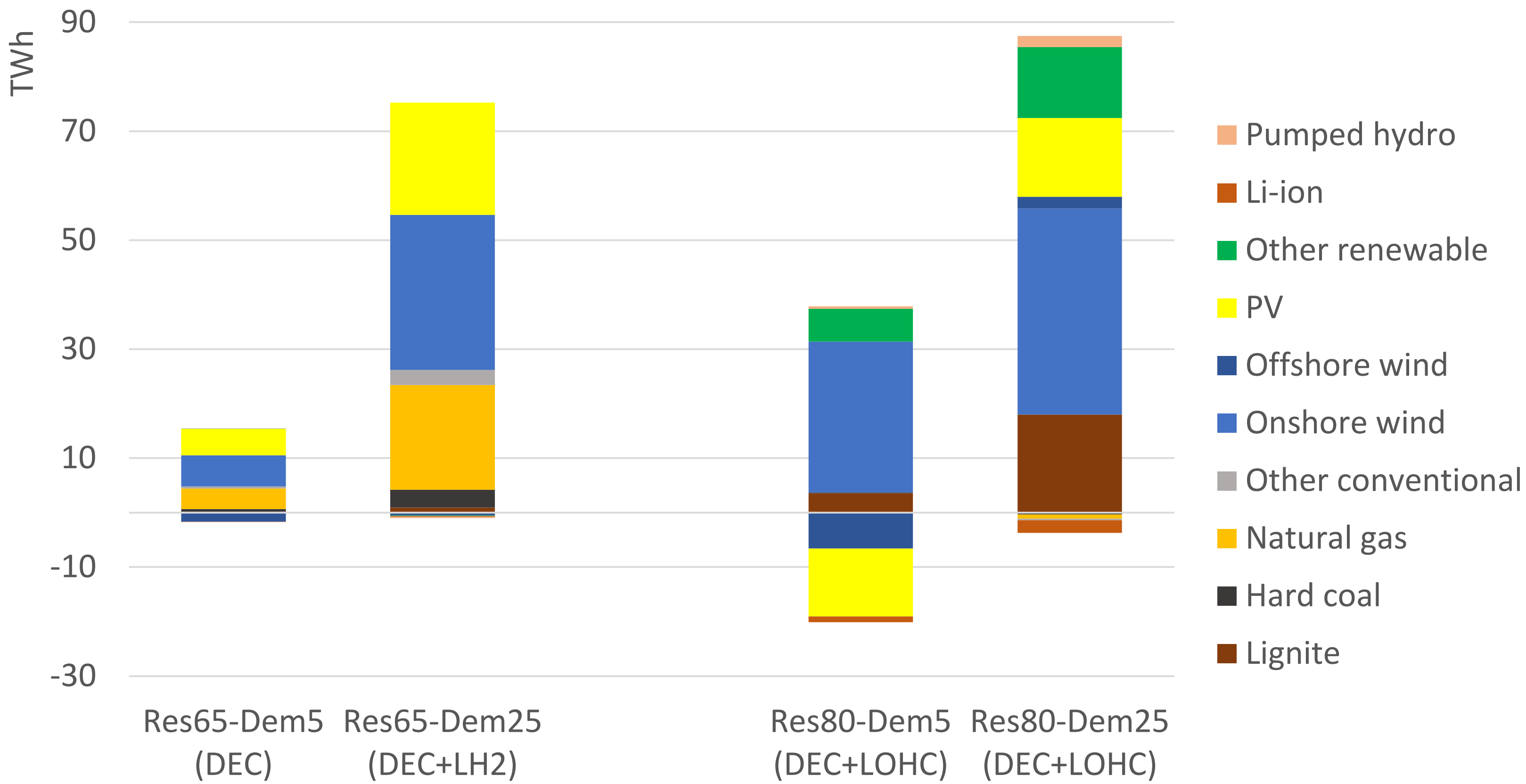
4 Effects on yearly electricity generation (vs. respective baseline)



→ Storage capability of LOHC and LH_2 allows additional integration of wind power