DIW BERLIN

Australian-German Climate and Energy College and the Energy Transition Hub Seminar

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

Fabian Stöckl. Wolf-Peter Schill, Alexander Zerrahn

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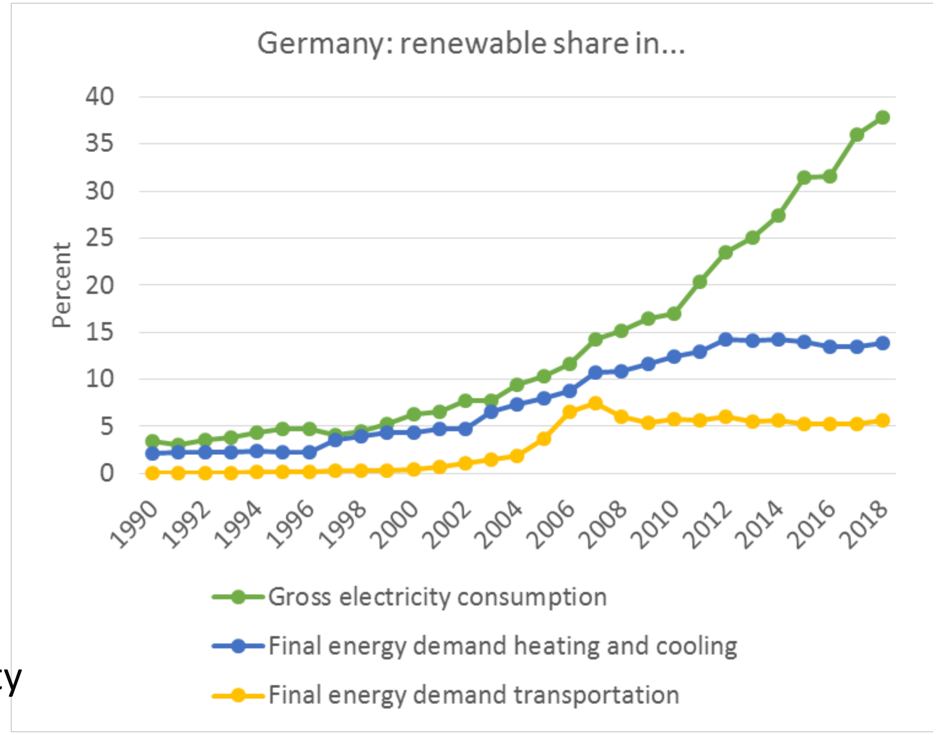
ENERGY TRANSITION HUB an Australian-German innovation partnership

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

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

German energy and climate policy targets

- Strongly increasing use of variable renewable energy sources
- Decarbonization of all energy sectors



BMWI, AGEE Stat: Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland

Sector coupling as a strategy to

- (i) decarbonize other sectors
- (ii) provide flexibility to the power sector
  → often under-represented in IA models
- E.g., produce hydrogen with renewable electricity and use it for mobility, heating, industry, …

Focus here

- Domestic H_2 production and distribution
- Use of H_2 for fuel-cell electric vehicles
- Research carried out in Kopernikus project P2X, supported by BMBF

Research questions and contribution

We aim to determine least-cost hydrogen supply chains…

- … considering differences in energy efficiency, investment costs, and storage capabilities
- … and considering electricity system interactions

This calls for a numerical model

- We develop an open-source model and apply it to a future (German) power system with high shares of renewables

Outcomes of interest

- Hydrogen: optimal technology mix, supply costs, and their drivers
- Electricity system: effects on capacity and dispatch, costs

What is new?

- Previous studies often did not account for power sector interactions of flexible hydrogen supply
- Fully open-source / open data analysis

The model

Visit DIETER

- Open-source GAMS code under MIT license
- www.diw.de/dieter
- https://github.com/diw-berlin/dieter

Cost minimization

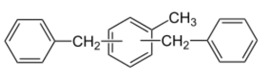
- Dispatch and investment
- Hourly resolution over one year
- Thermal and renewable technologies
- Different types of electricity storage
- Demand-side management, reserves
- Residential heating, electric vehicles

Linear program

- Deterministic, perfect foresight
- No transmission constraints

Model: extension of DIETER

New hydrogen module

- Two electrolysis technologies
- Four channels for distributing H_2 to fuel stations, including
  - Gaseous H_2
  - Liquified H_2
  - LOHC 

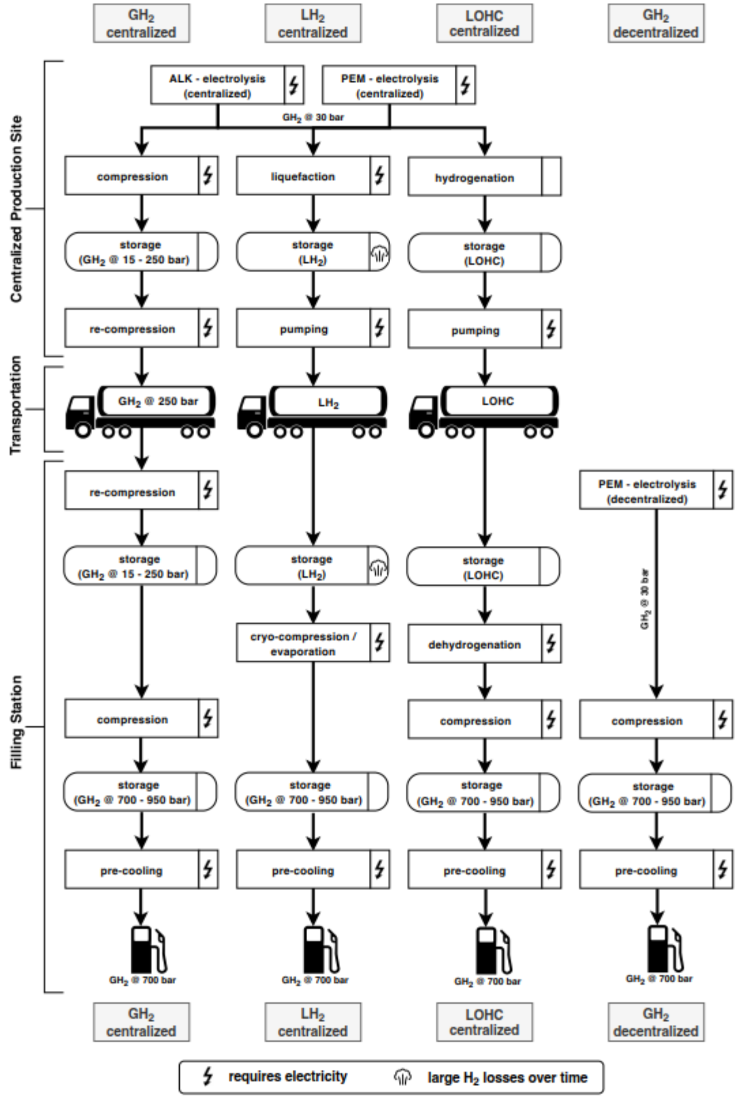
- Different storage options
- Follow-up work: reconversion to electricity

Full co-optimization

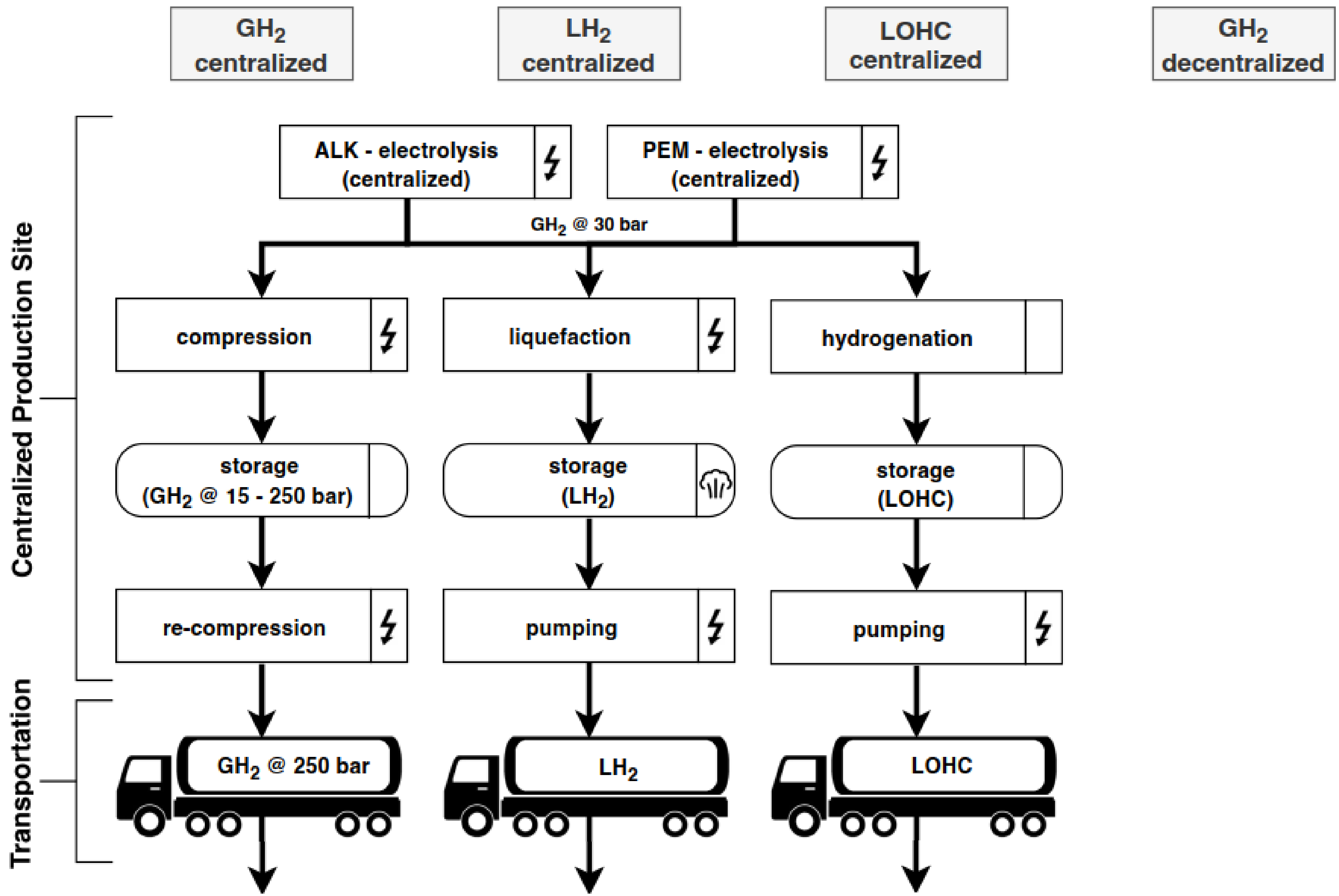
- Model decides on optimal capacities and hourly use
- Given conventional electricity demand and H_2 demand for mobility

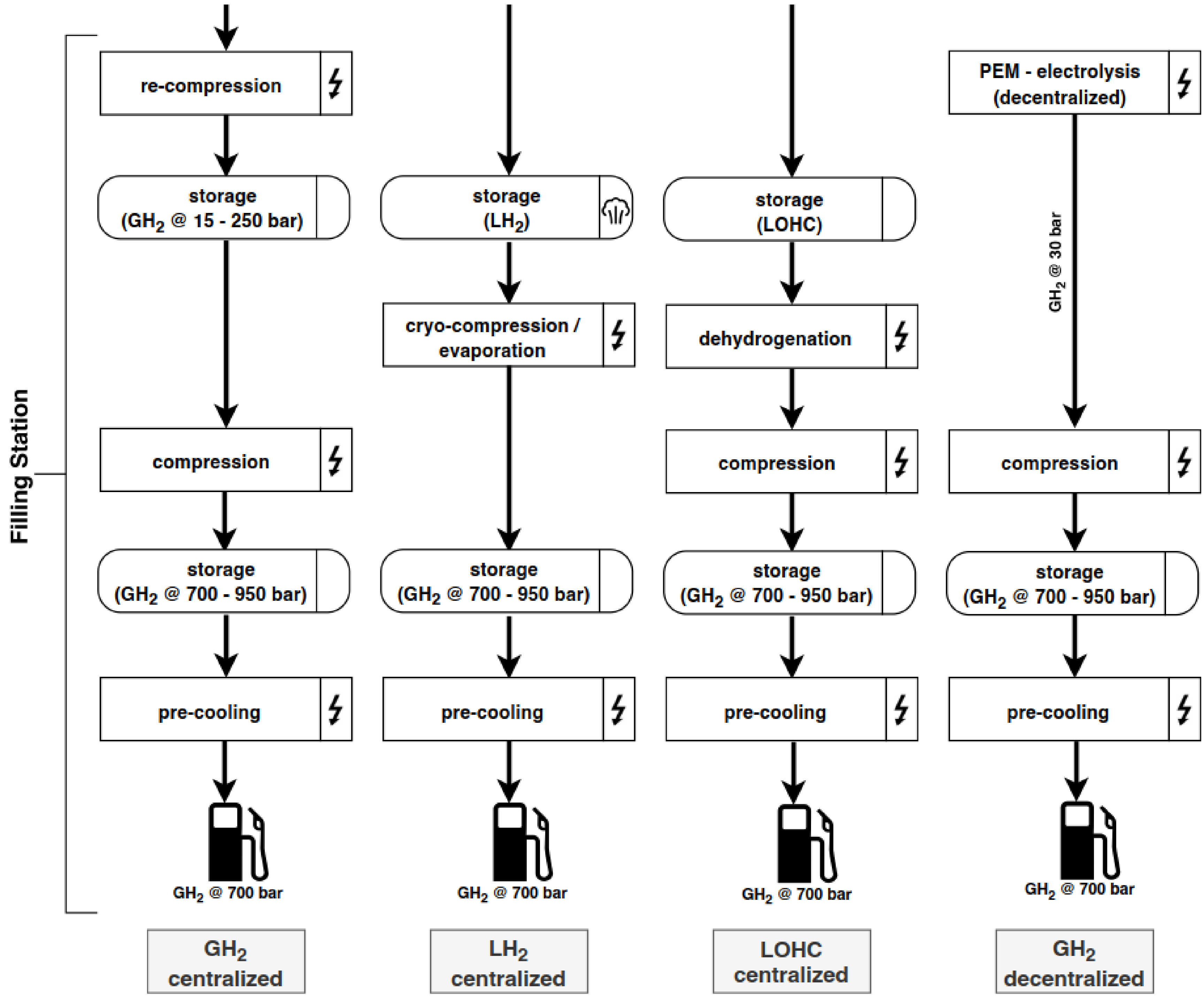
https://commons.wikimedia.org/wiki/File:Dibenzyltoluene_V1.svg

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

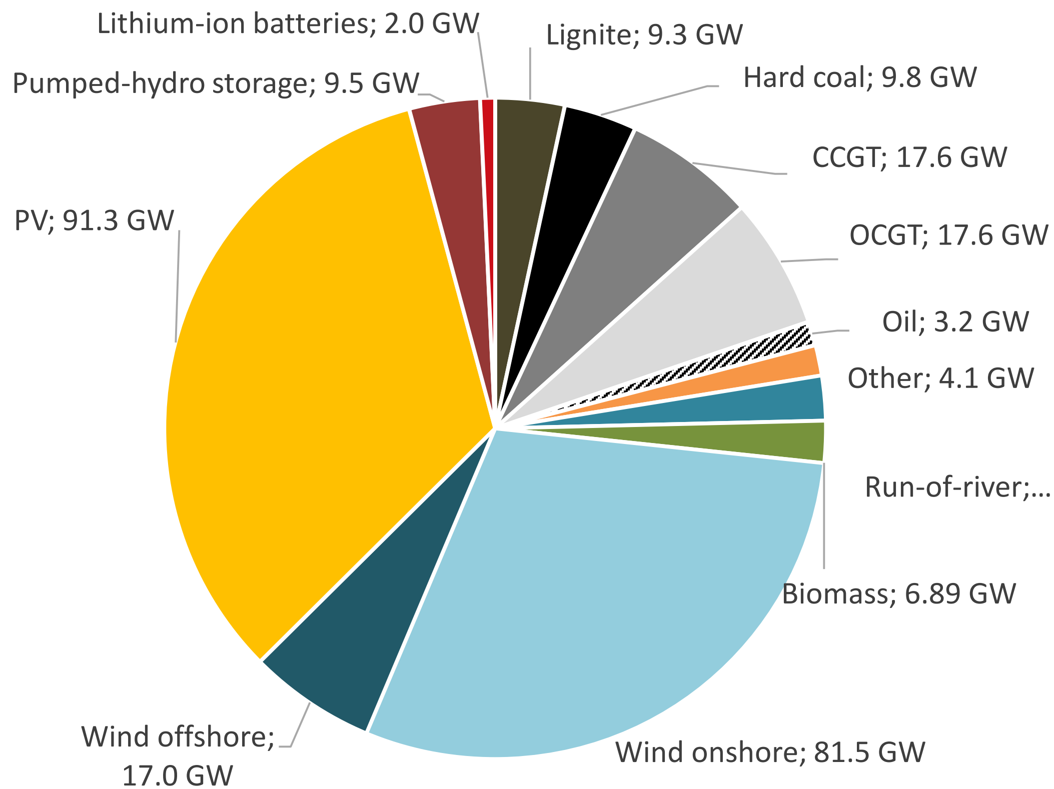

GH2 centralized
LH2 centralized
LOHC centralized
GH2 decentralized
Centralized Production Site
Transportation
ALK - electrolysis (centralized)
PEM - electrolysis (centralized)
GH2 @ 30 bar
compression
liquefaction
hydrogenation
storage (GH2 @ 15 - 250 bar)
storage (LH2)
storage (LOHC)
re-compression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

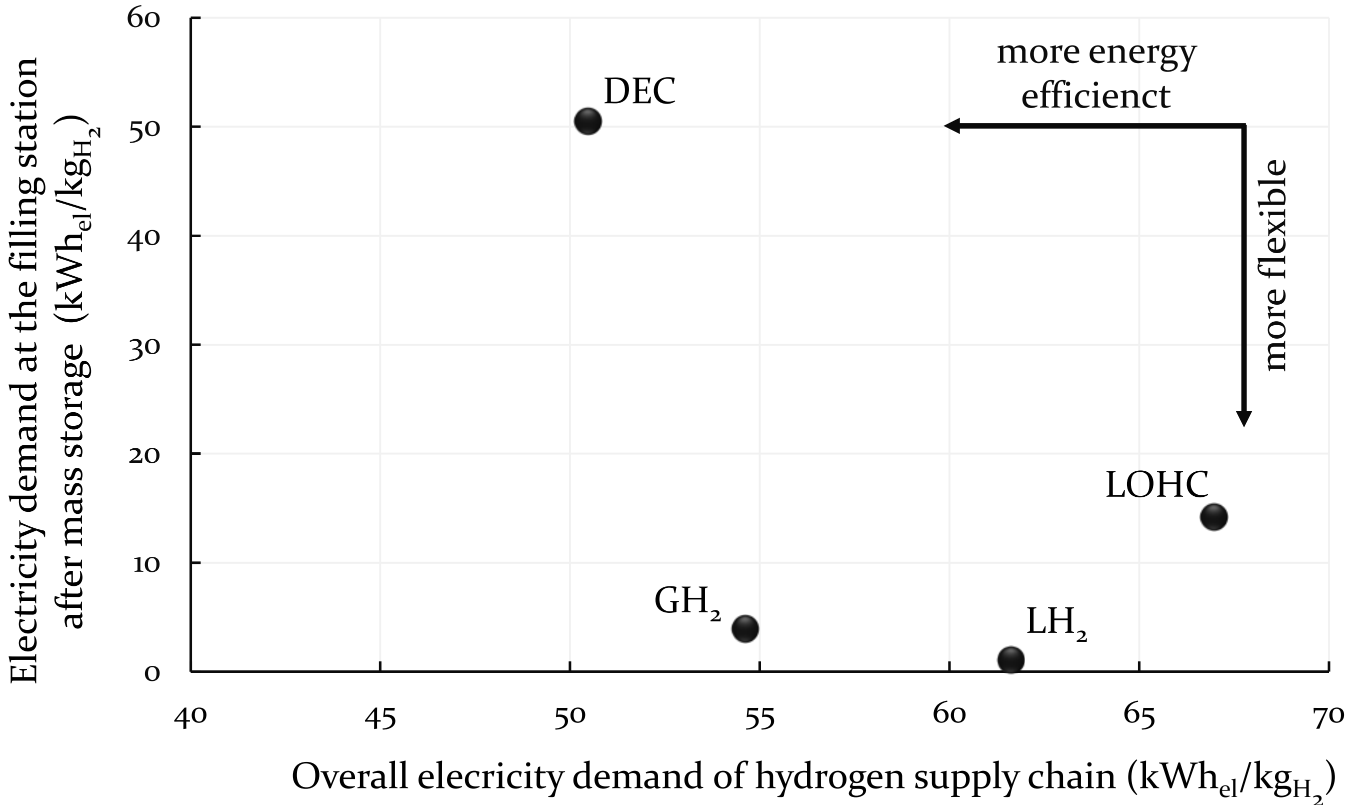


Hydrogen infrastructure

- 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

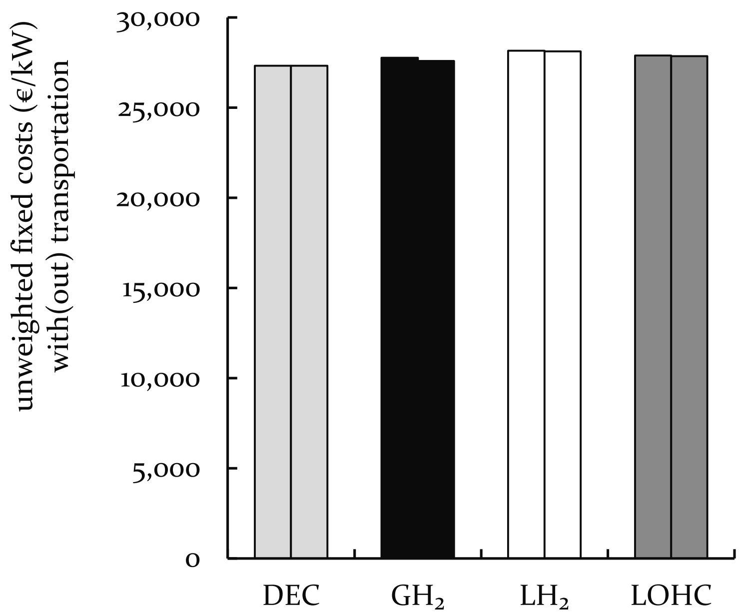
Some intuition:
potential drivers of results

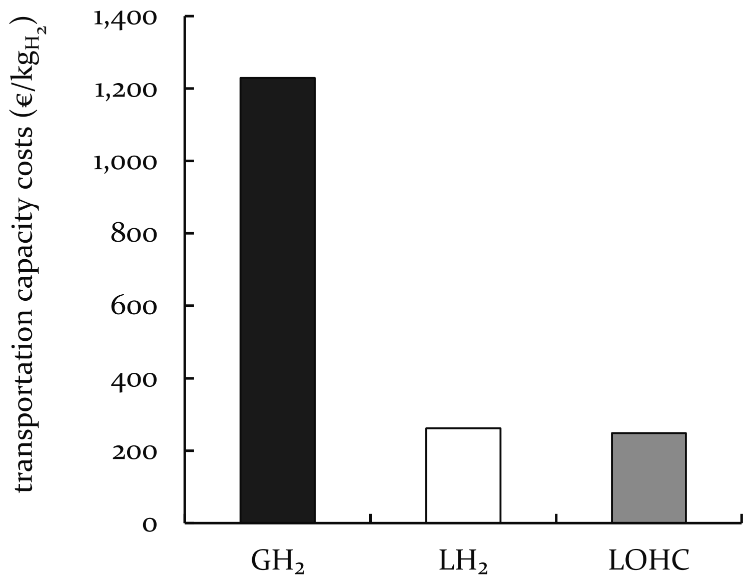
Drivers I: Tradeoff between overall efficiency and flexibility



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

3 Drivers II: Fixed investment and transportation capacity costs

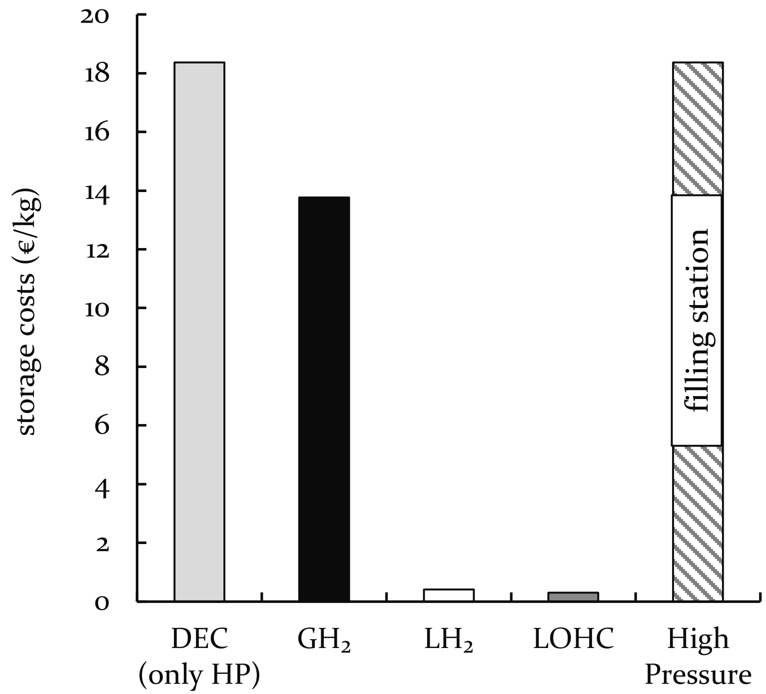




→ Only 3% spread between cheapest and most expensive supply chain

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

Drivers III: Storage costs (and losses)

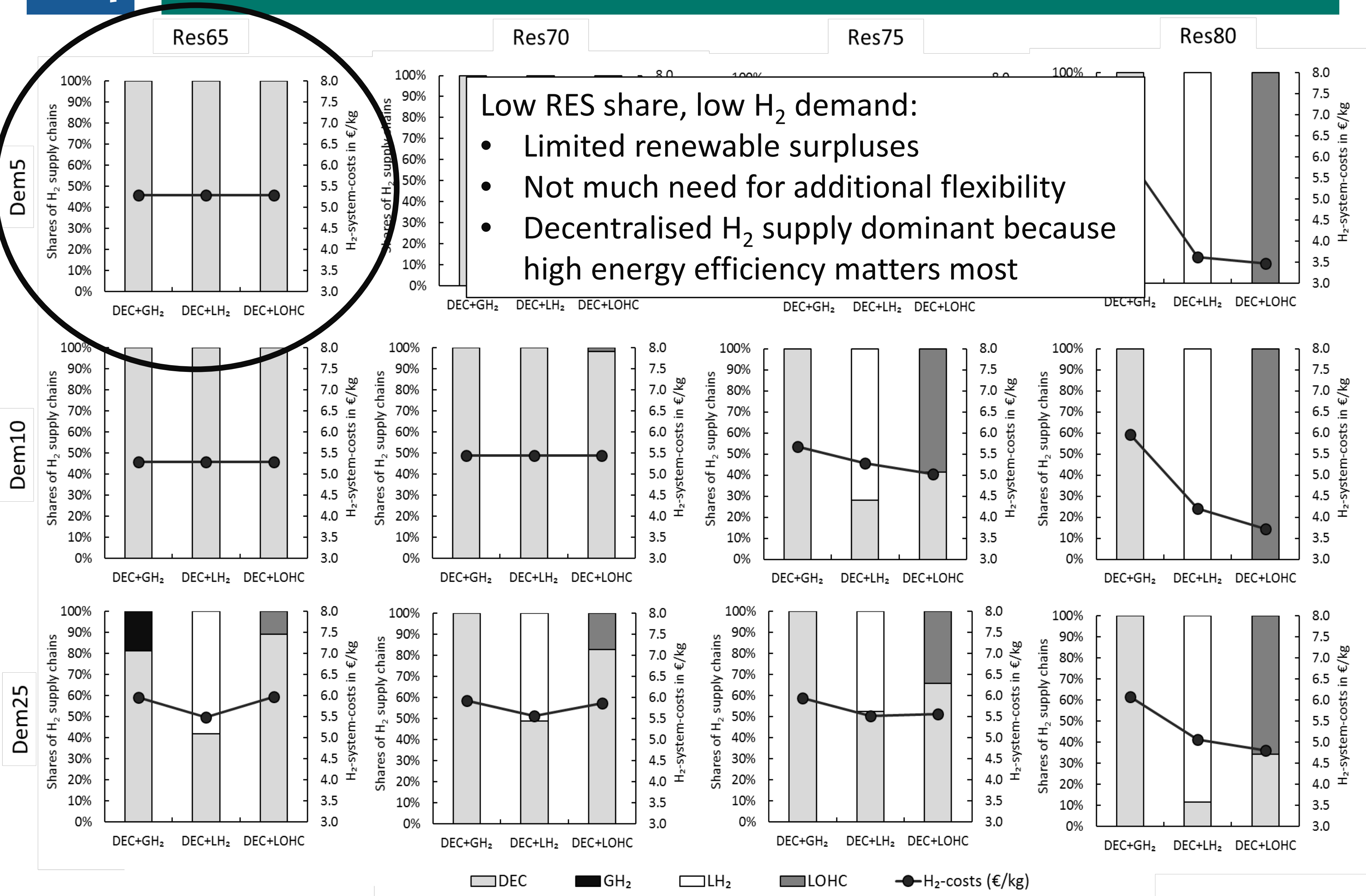


- Substantially lower storage costs for LH_2 and LOHC
- Expensive high pressure storage at the filling station → only buffer storage
- LH_2 also suffers from boil-off (about 20%/week)

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

Results: hydrogen supply

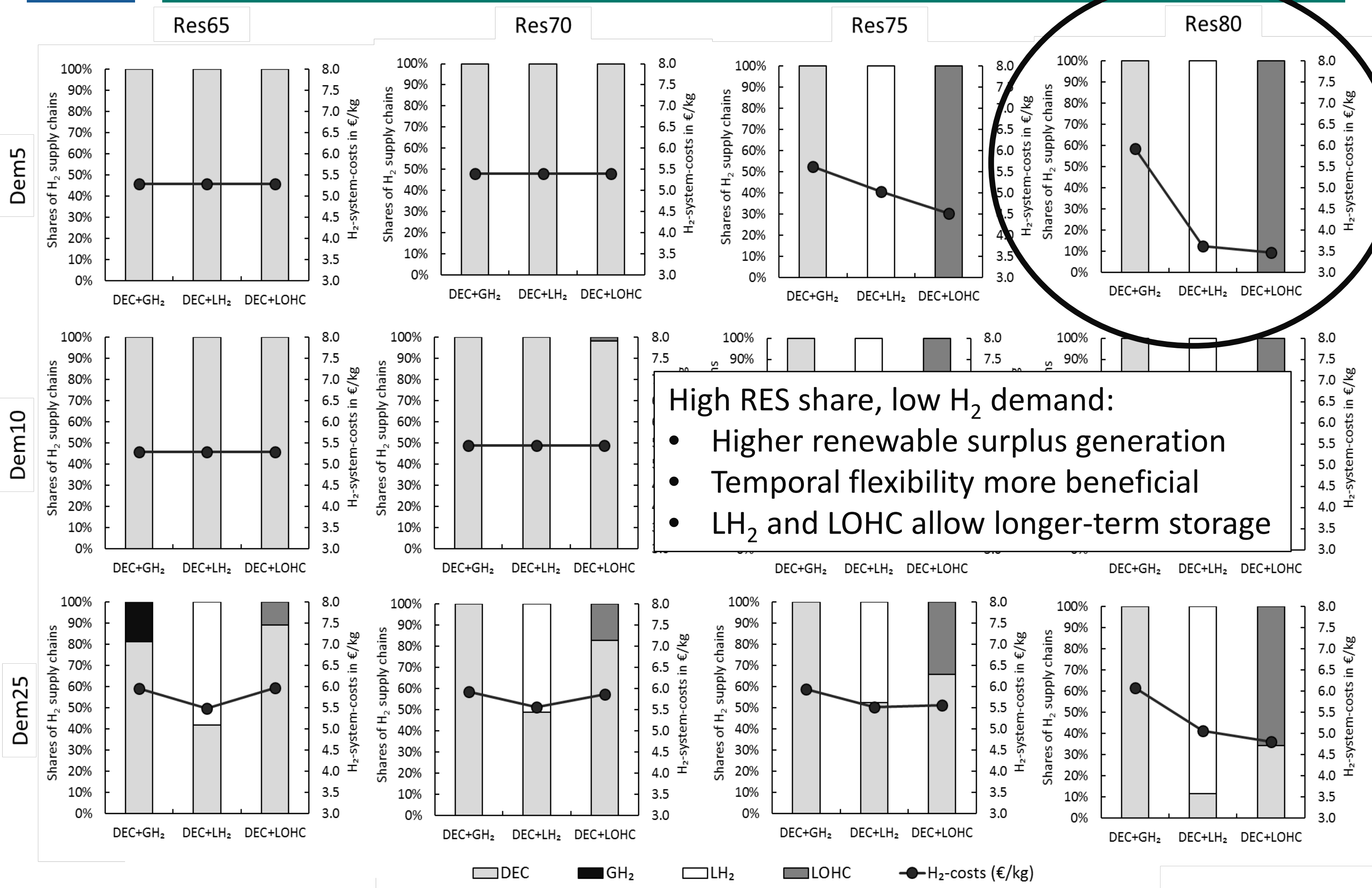
4 Results: hydrogen supply chains and H_2 supply costs



Low RES share, low H_2 demand:

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

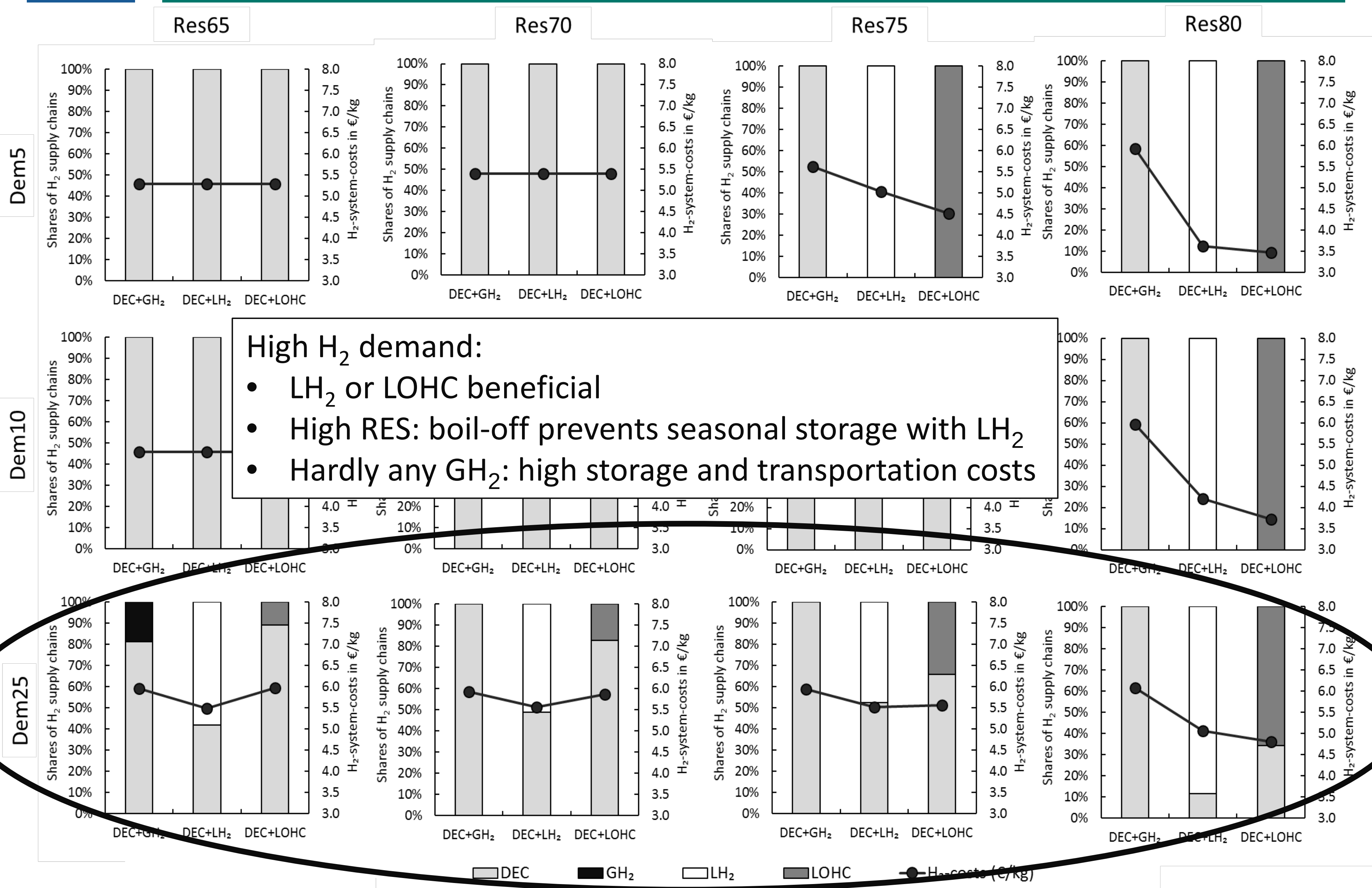
4 Results: hydrogen supply chains and H_2 supply costs



High RES share, low H_2 demand:

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

4 Results: hydrogen supply chains and H_2 supply costs

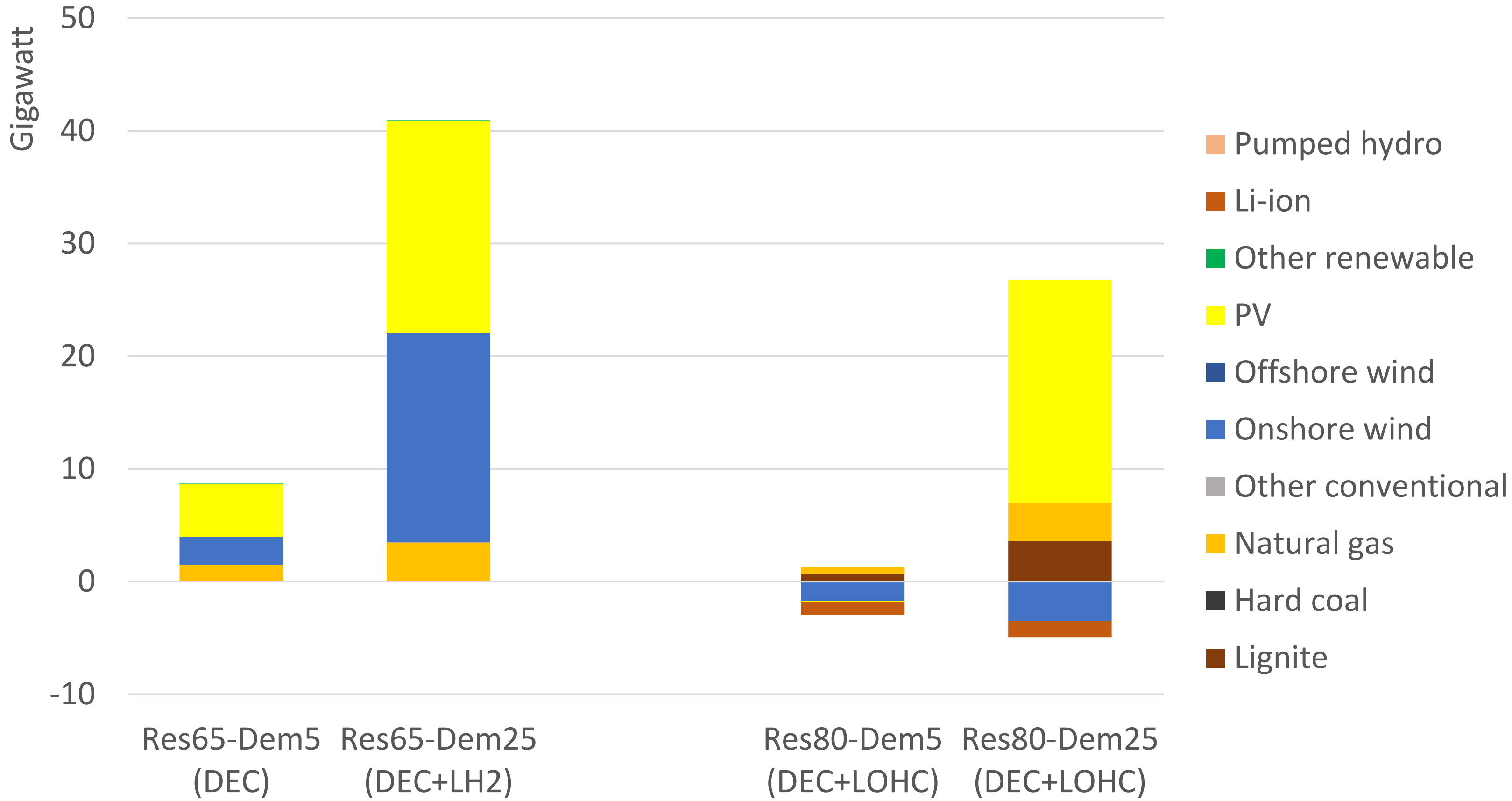


High H_2 demand:

- LH_2 or LOHC beneficial
- High RES: boil-off prevents seasonal storage with LH_2
- Hardly any GH_2: high storage and transportation costs

Results: electricity system

4 Effects on generation capacity (vs. respective baseline)

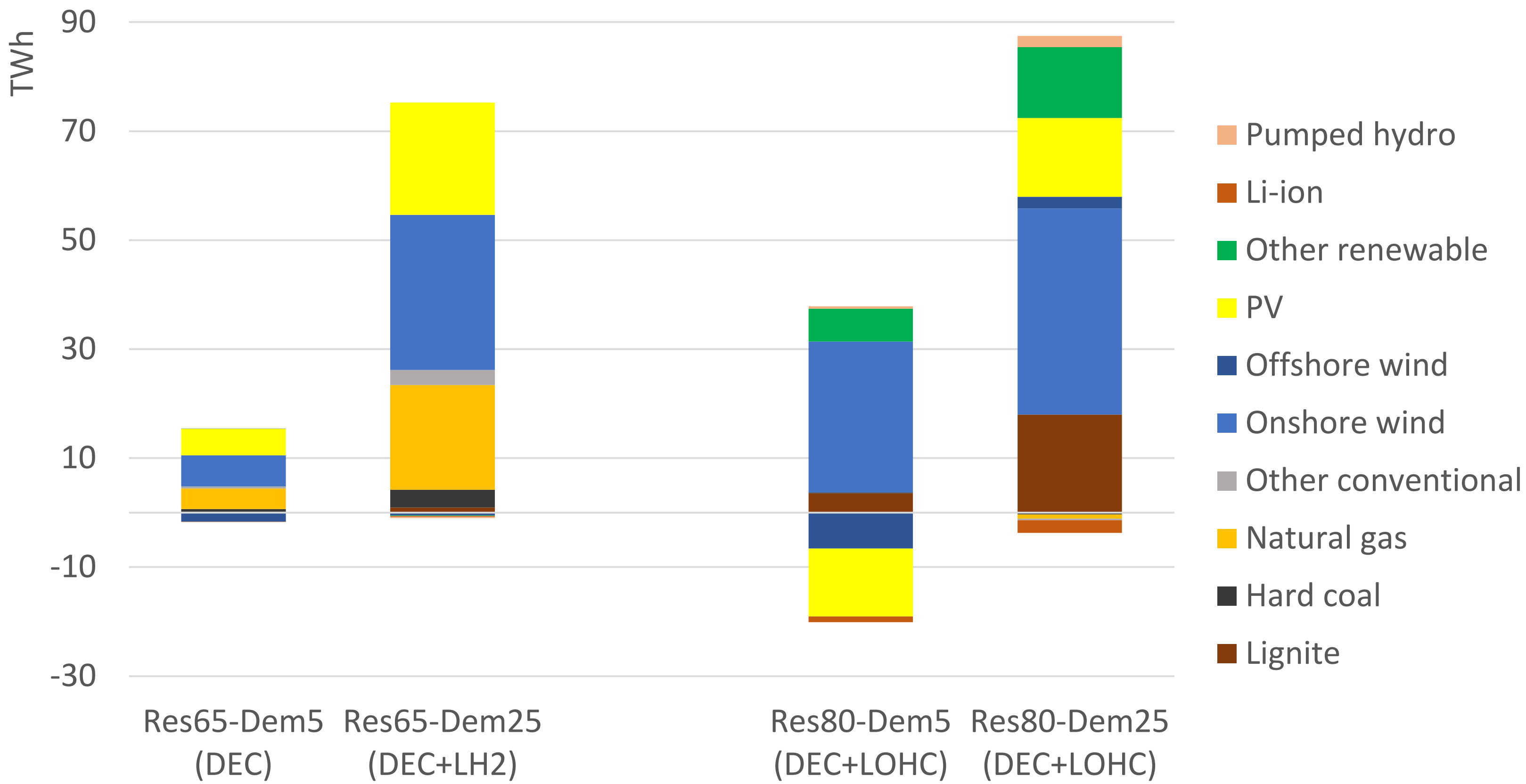


→ More PV and (a bit) less storage

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

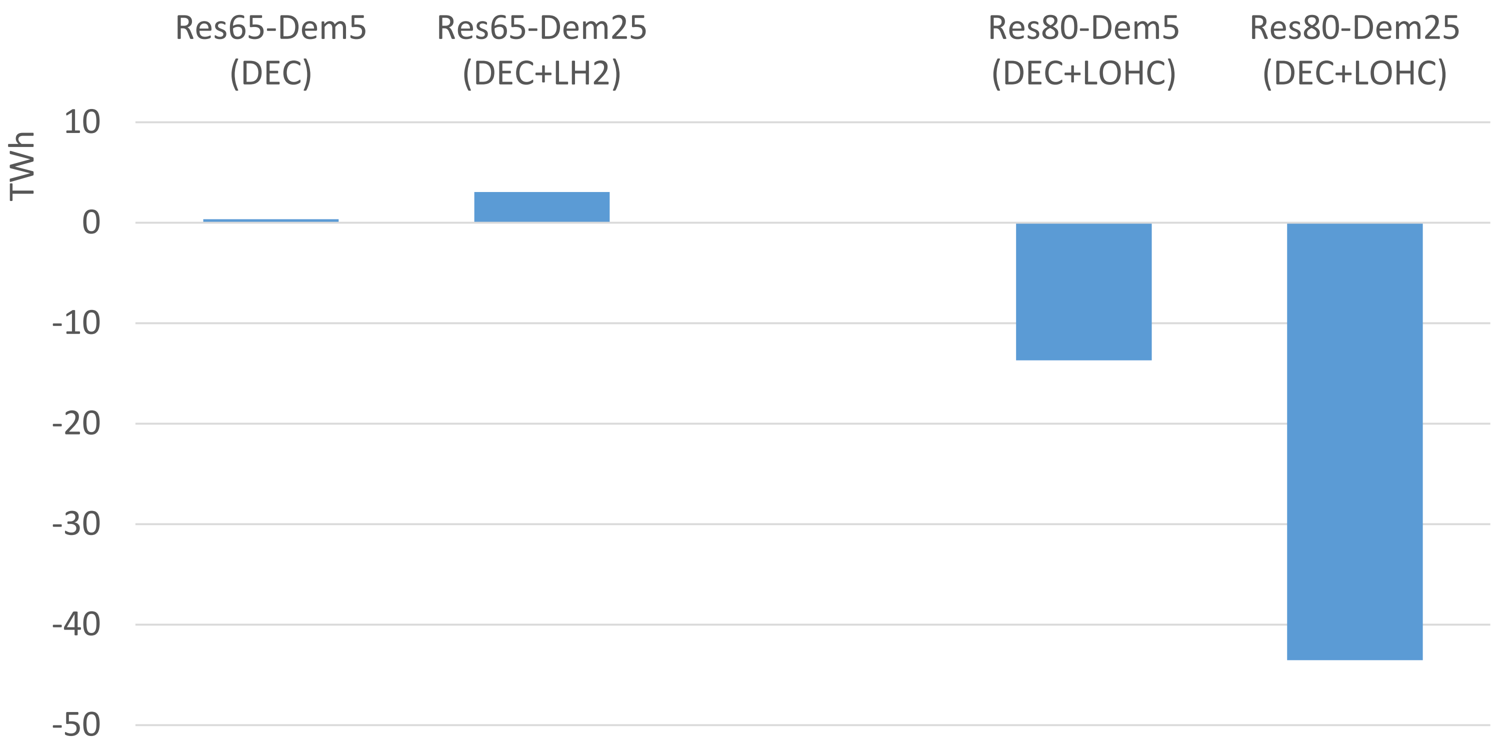
4

Effects on yearly electricity generation (vs. respective baseline)



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

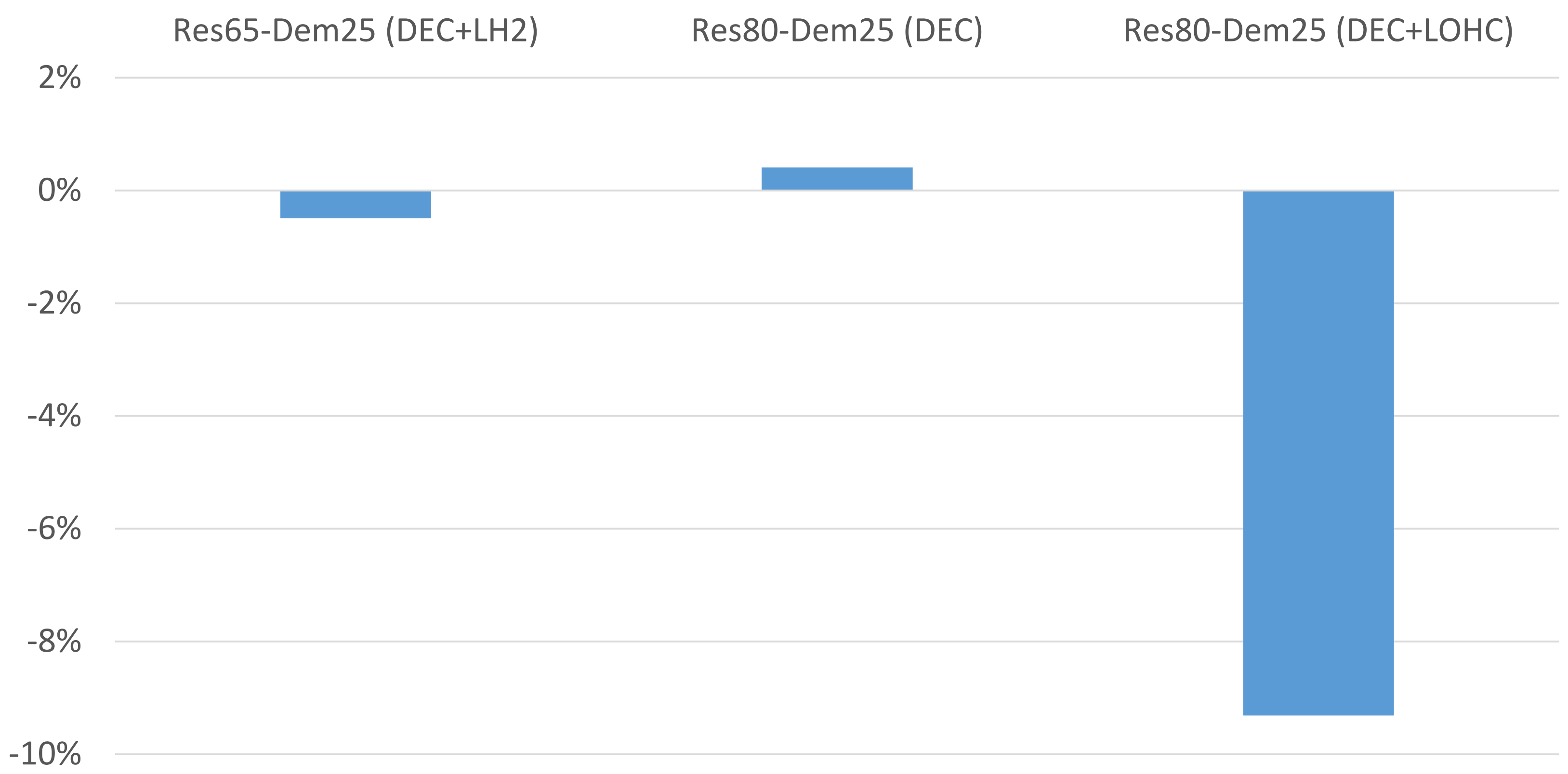
4 Effects on renewable curtailment (vs. respective baseline)



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

4

Effects on system LCOE (without fixed H_2 costs)



→ Clear renewable integration co-benefit of hydrogen in 80% renewables case

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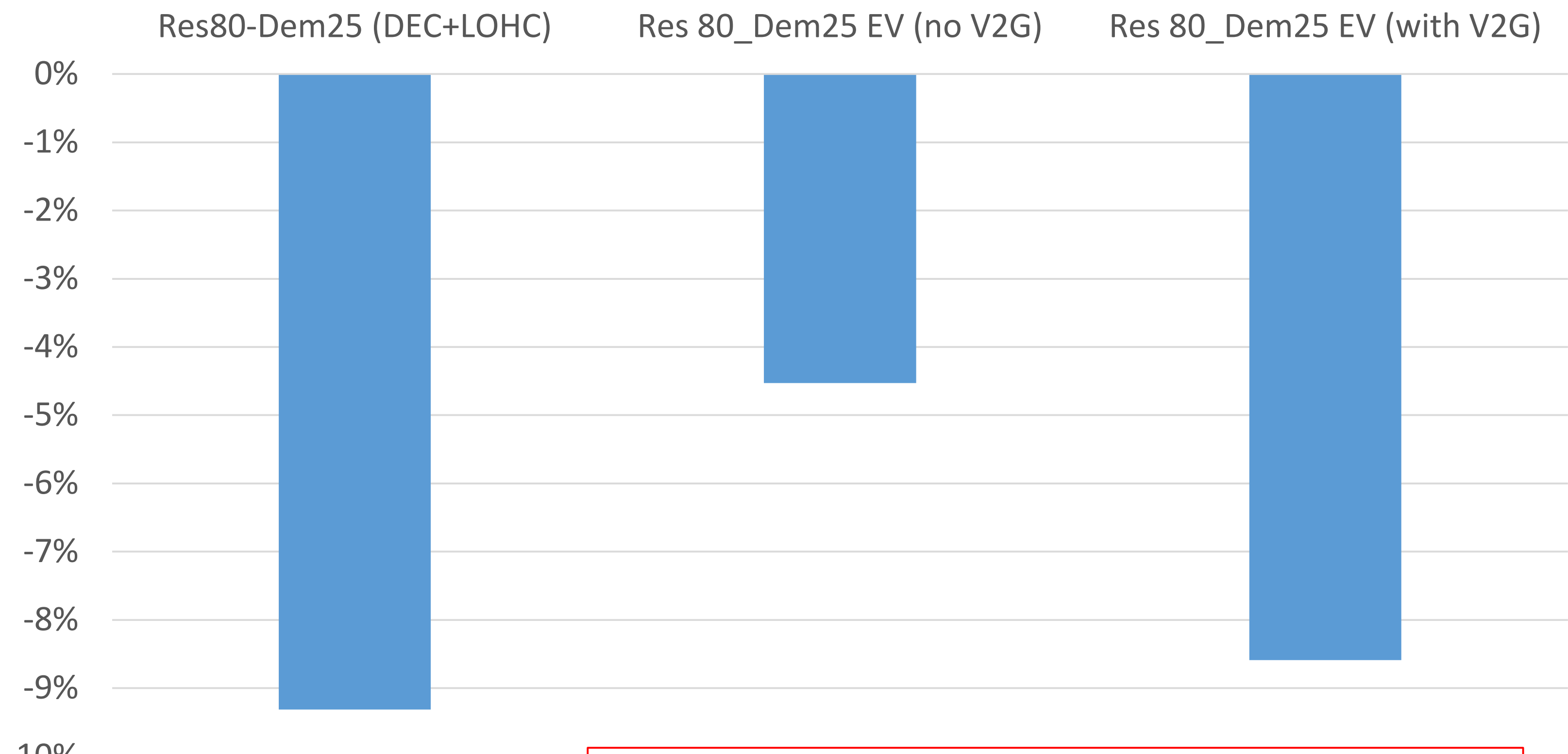
Sneak preview: what about battery-electric vehicles? Effects on system LCOE (without fixed H_2 or BEV-related costs)



→ To be explored in more detail in future work

→ If BEV are used instead of fuel cell H_2 vehicles, also substantial co-benefits

→ …and lower electricity demand, lower deployment of RES, lower overall cost

5 Summary and conclusion

Tradeoff between energy efficiency and temporal flexibility

- Energy-efficient decentral electrolysis optimal for lower shares of variable renewables
- Less energy-efficient centralized electrolysis gains relevance with higher shares of variable renewables because of storage benefits

Optimal choice of H_2 supply chains also needs to consider other factors

- Space requirements
- Technology acceptance
- Perceived / real danger of operations

5

Summary and conclusion

Flexible sector coupling

- …can generate substantial co-benefits for integrating wind and solar energy
  → should be considered in energy models
- …but also requires additional deployment of variable renewables

Limitations

- Results are driven by renewable surplus generation
- Surpluses may be over-estimated, as we do not consider competing options for flexibility and sector coupling
  → More research on energy system implications of massive sector coupling necessary

Future research

- Additional or competing flexibility options in the electricty sector
- Long-term power storage via H_2-to-electricity
- Maybe: how does this compare with Australia?

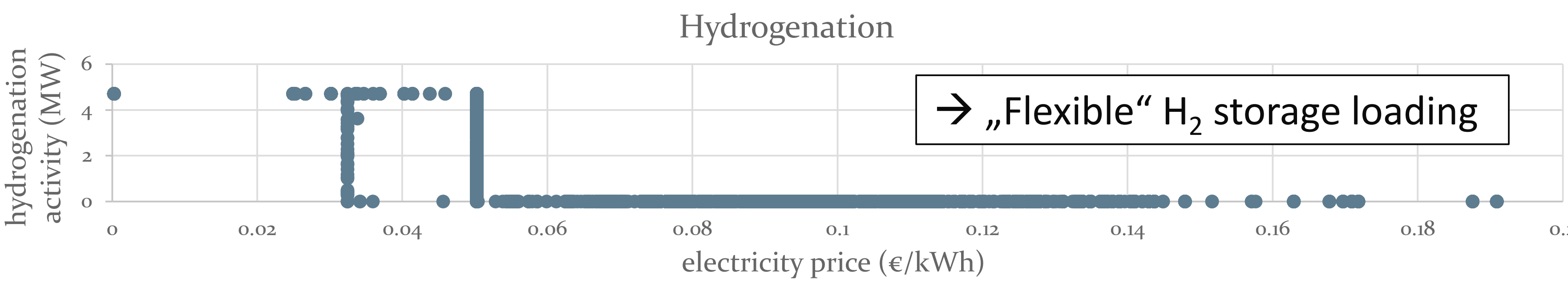
Thank you for listening

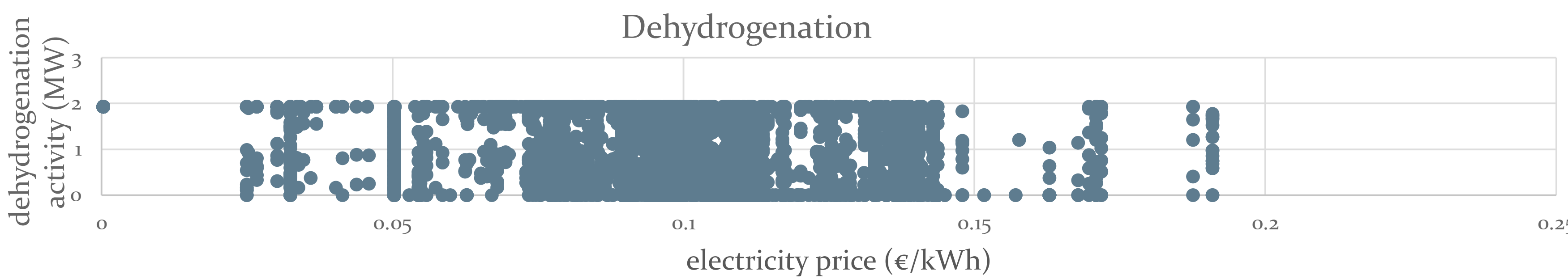
DIW BERLIN

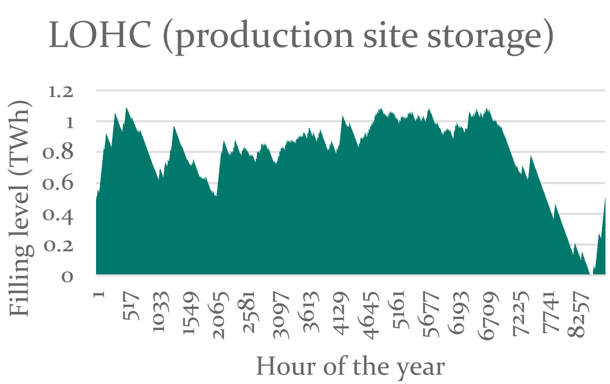
DIW Berlin — Deutsches Institut für Wirtschaftsforschung e.V.
Mohrenstraße 58, 10117 Berlin
www.diw.de

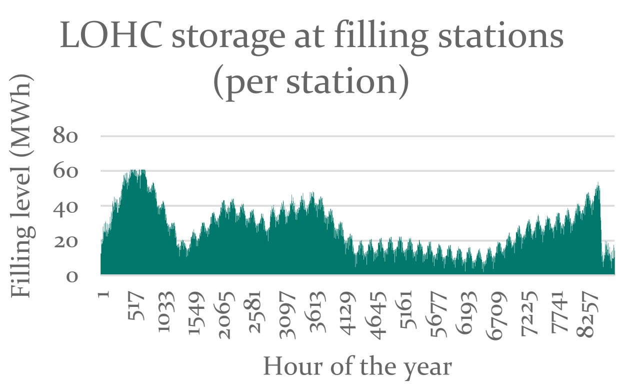
Contact
Dr. Wolf-Peter Schill
wschill@diw.de | @WPSchill

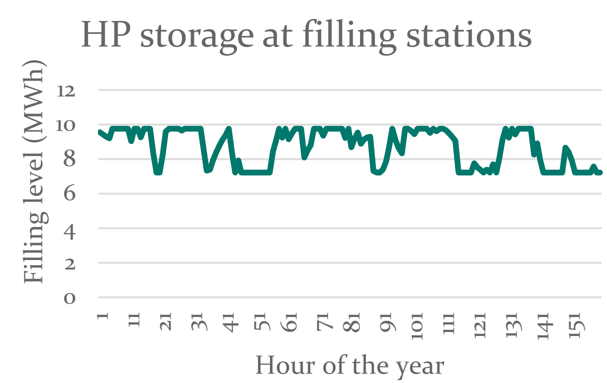
Utilization patterns LOHC (RES75 DEM5)







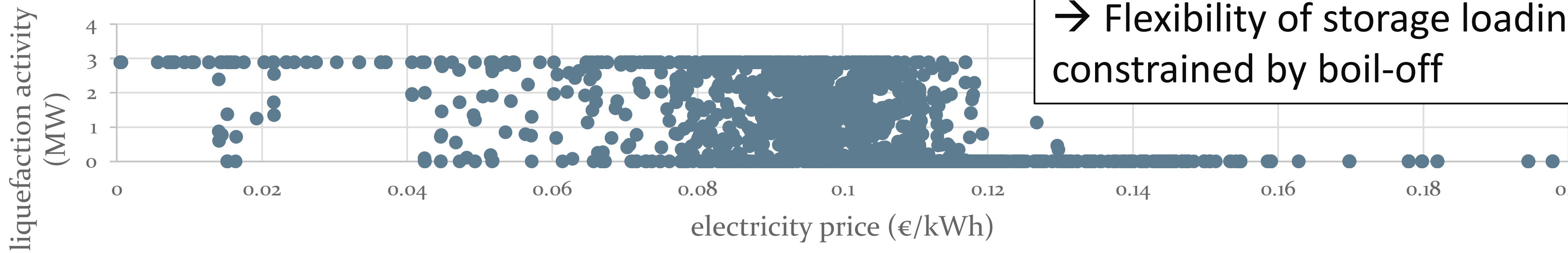




4 Utilization patterns LH_2 (RES75 DEM5)

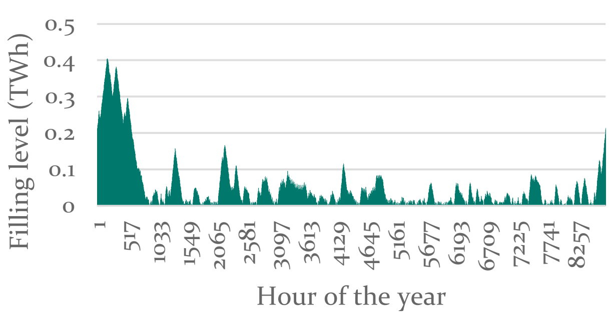
→ Flexibility of storage loading constrained by boil-off

Liquefaction

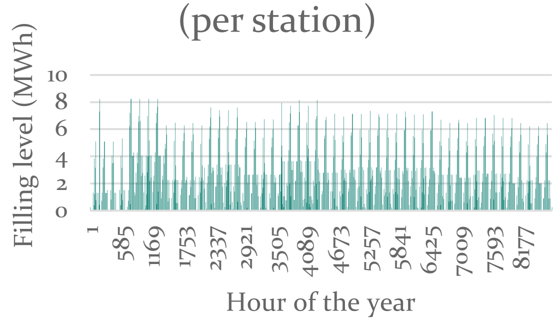


Evaporation

LH_2 (production site storage)



LH_2 storage at filling stations (per station)



HP storage at filling stations