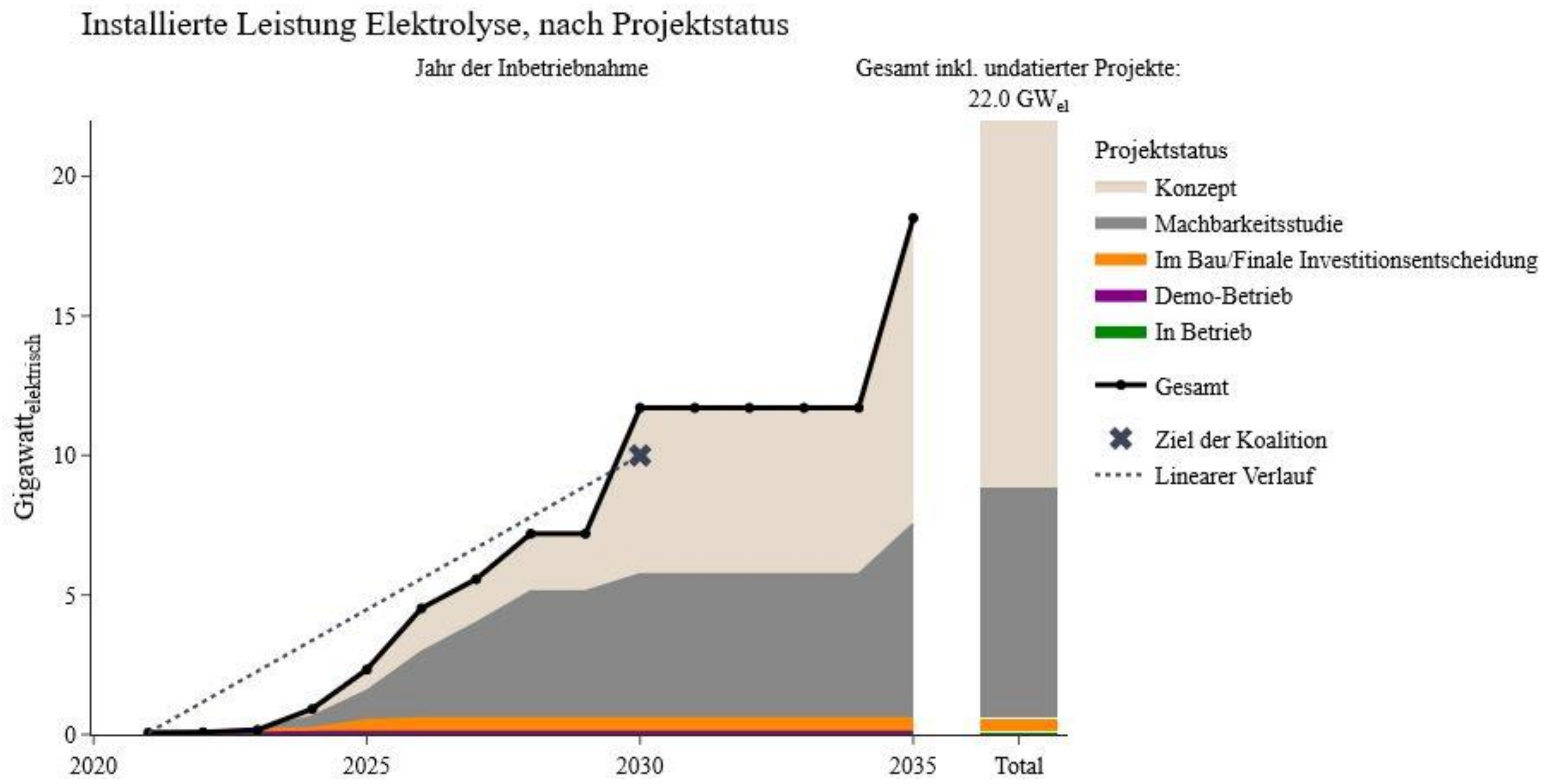
DIW BERLIN

Modezeen Abschlussworkshop 28.11.2023

Stromsektoreffekte grüner Wasserstoffproduktion in Deutschland

Dana Kirchem, Wolf-Peter Schill

Ausgangslage



Forschungsfrage

Welche Auswirkungen hat der Ausbau der heimischen Produktion von grünem Wasserstoff auf den deutschen Stromsektor?

Kapazitäten   Strommix   Systemkosten   Deutschland   2030

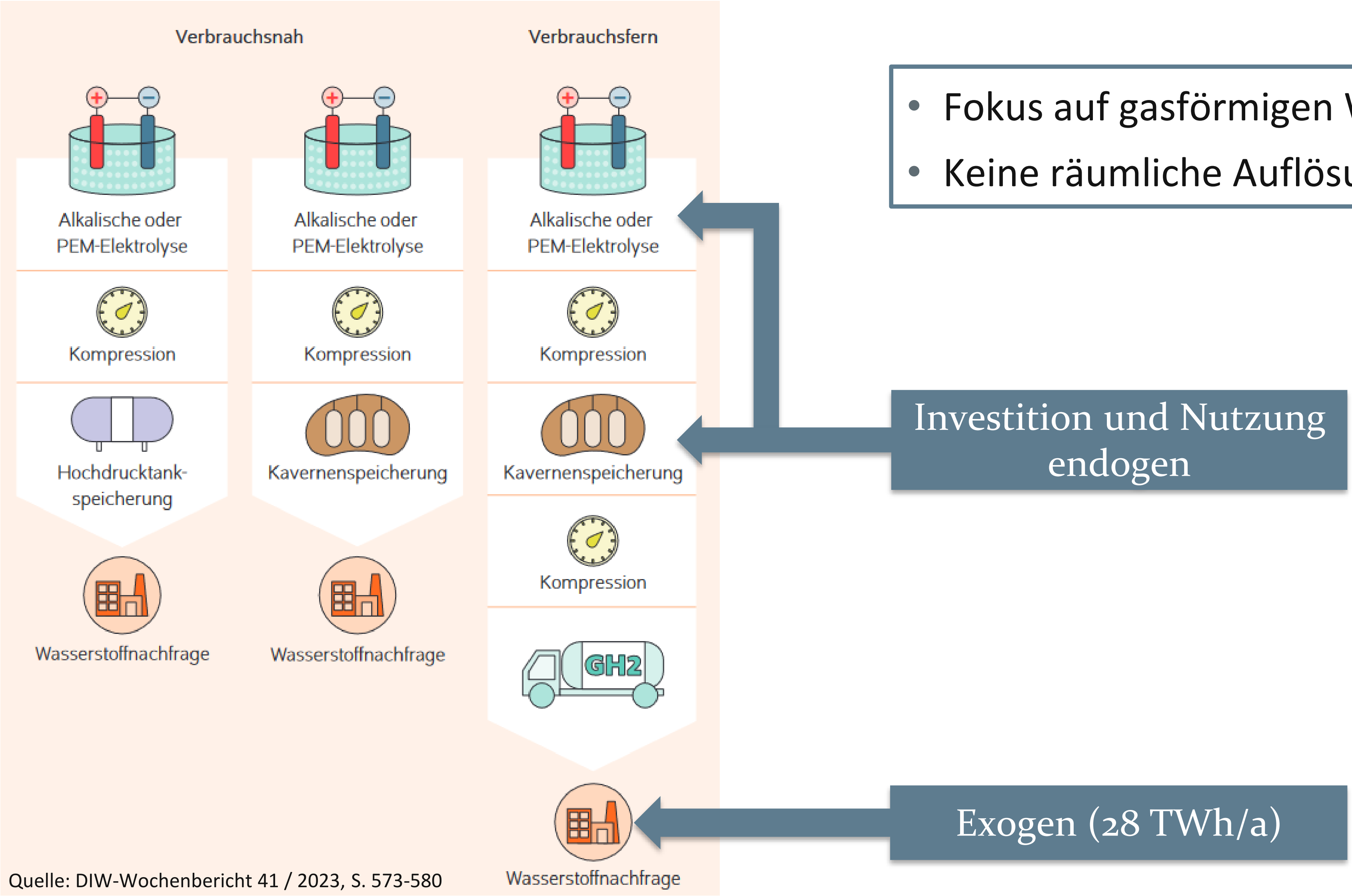
Das Modell DIETER (*Dispatch and Investment Evaluation Tool with Endogenous Renewables*)

- Optimaler Kapazitätsausbau und Energiemix
- Minimierung der Systemkosten
- Lineares Programm
- Gelöst für ein ganzes Jahr in stündlicher Auflösung
- Implementierung in GAMS und Python: DIETERpy (SoftwareX 2021, https://doi.org/10.1016/j.softx.2021.100784)
- Open-source Ansatz: https://gitlab.com/diw-evu/dieter_public
- Verschiedene frühere Anwendungen: Stromspeicherung, Sektorkopplung, Prosumage
- Mehrfach publiziert:

scientific reports

MODEZEEN DIW BERLIN

Wasserstoff-Lieferketten

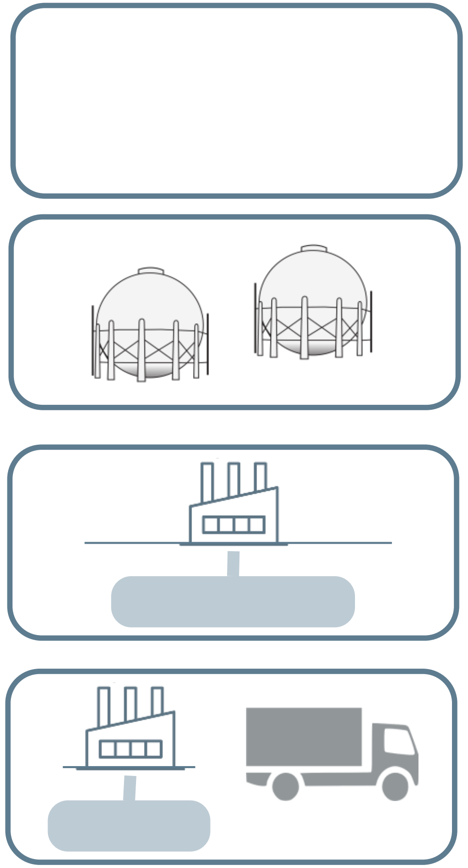


Quelle: DIW-Wochenbericht 41 / 2023, S. 573-580

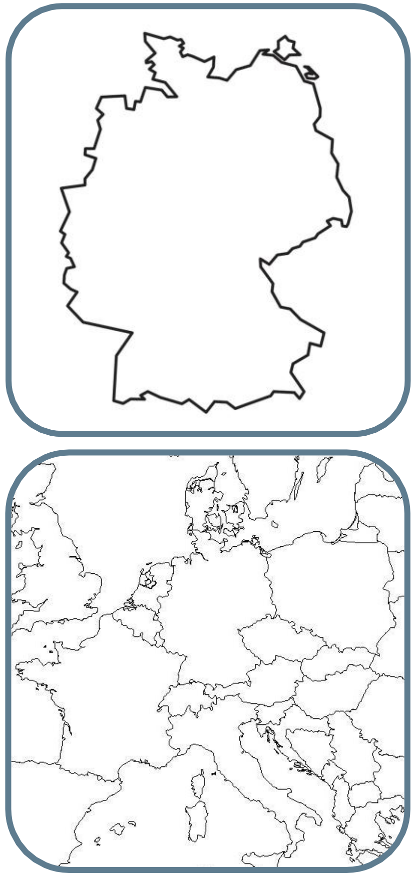
- Fokus auf gasförmigen Wasserstoff
- Keine räumliche Auflösung

Wasserstoff-Szenarien

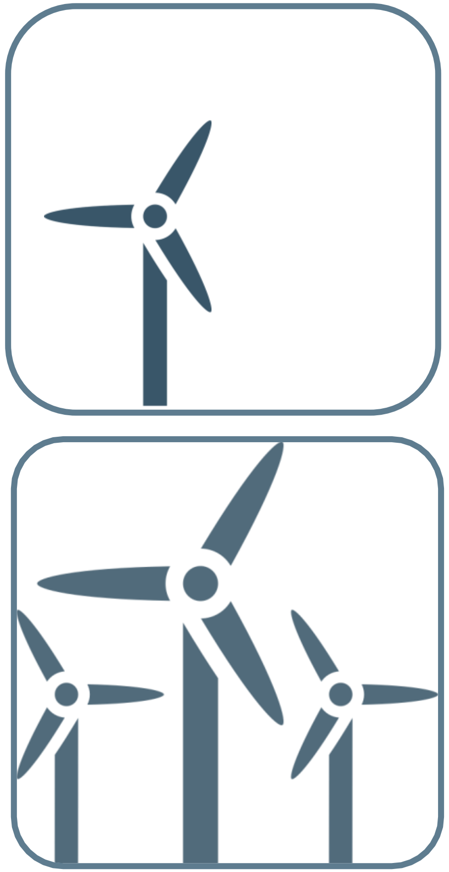
Vier Wasserstoffspeicher-Szenarien



Zwei Geografische Abdeckungen

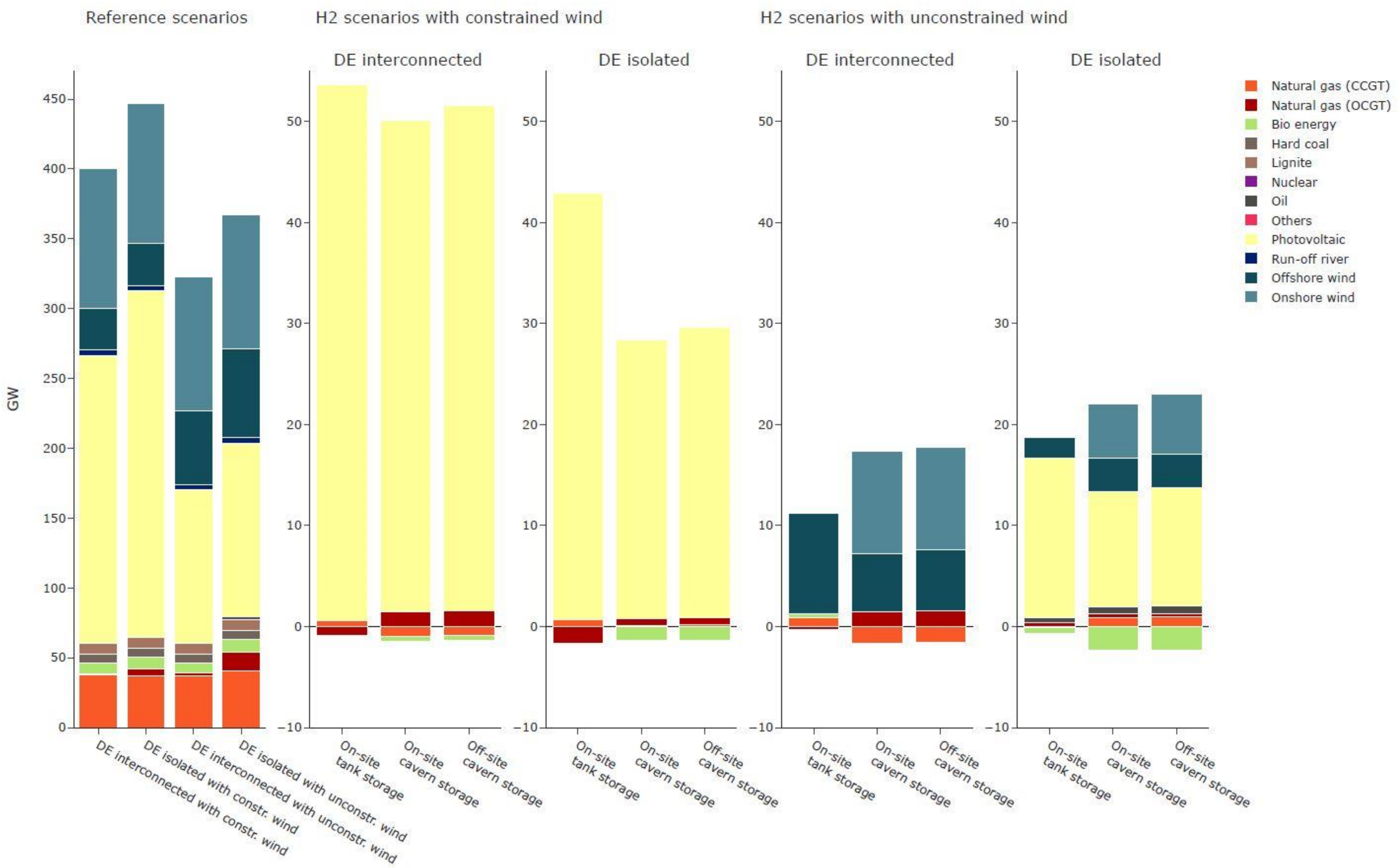


Zwei Annahmen zum Windenergie-Ausbau



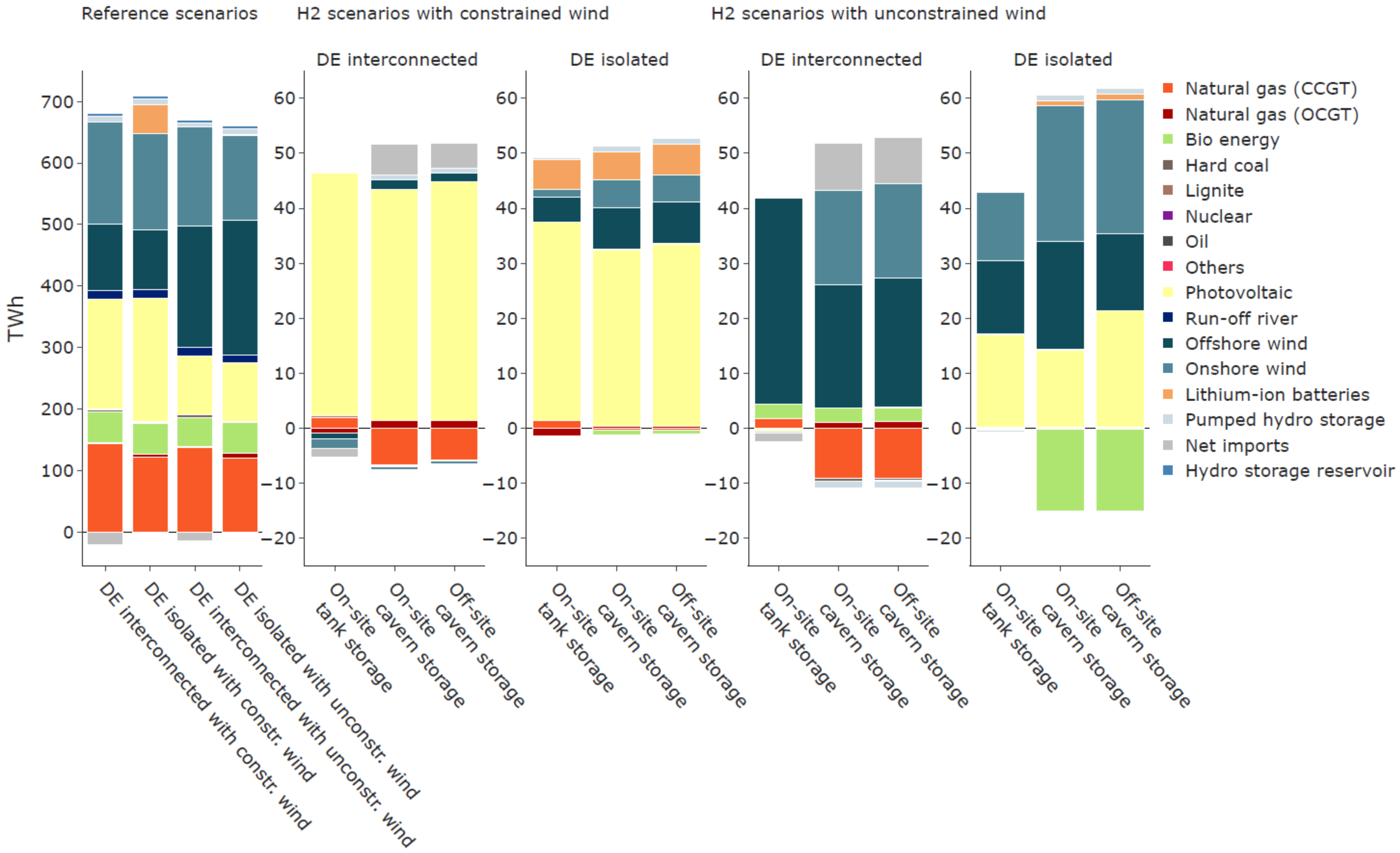
= 16 Modellläufe

Erzeugungskapazitäten



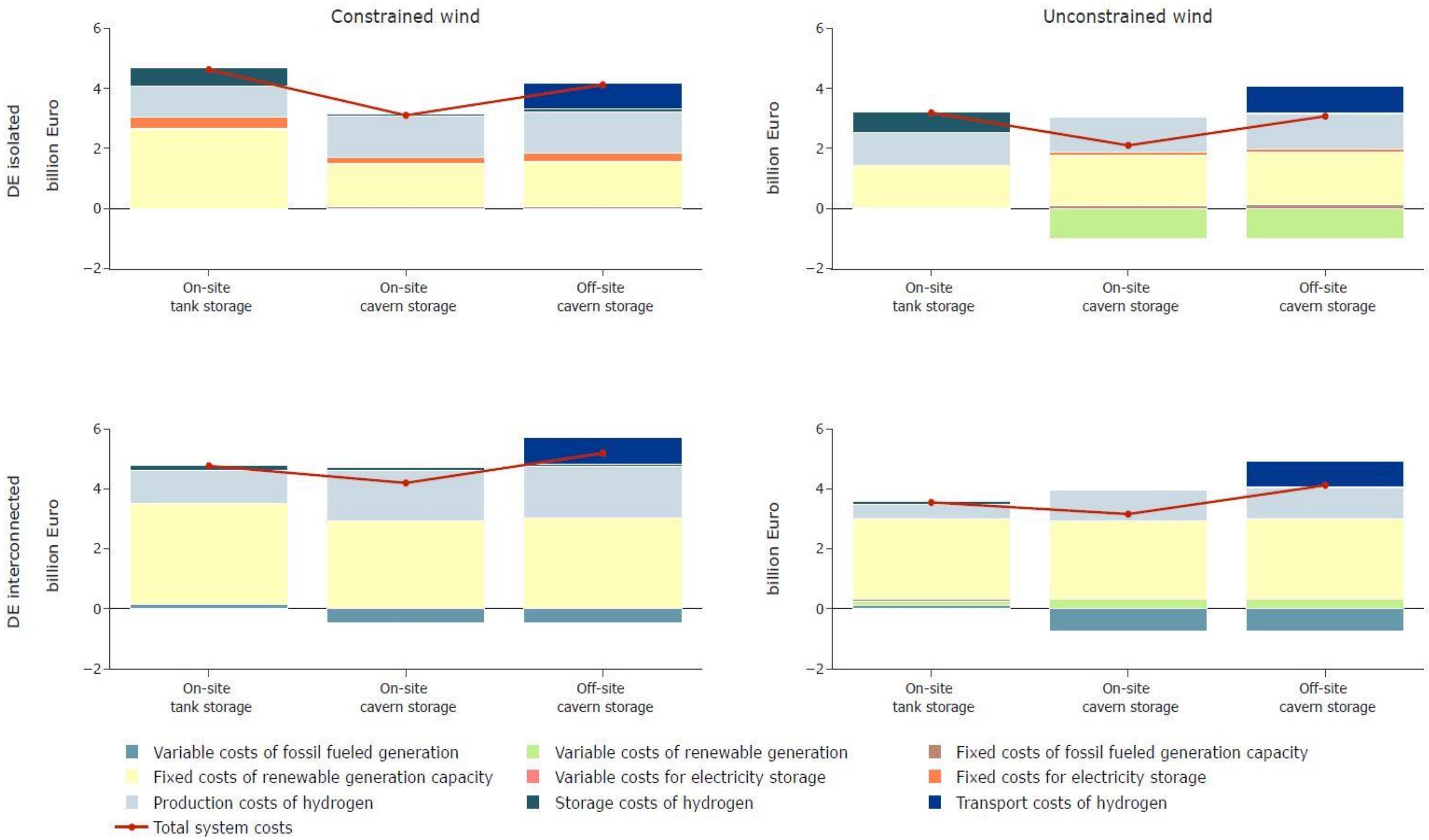
- Wasserstoff führt zu zusätzlichen Kapazitätsinvestitionen
- Eingeschränkte Windkraft: zusätzliche Kapazität ist hauptsächlich Solar-PV
- Höhere Zusatzinvestitionen in PV mit Tankspeichern, da Kavernen saisonaler Schwankungen besser ausgleichen

Strommix



- Zusätzliche PV-Erzeugung, wenn der Windausbau begrenzt
- Weniger Stromexporte mit Kavernenspeicher: Überschüsse aus erneuerbaren Energien können besser im Inland genutzt werden
- Verringerung der fossilen Energieerzeugung
- Ohne Stromverbund: Kurzzeitige Stromspeicherung ist erforderlich, um die Überschüsse aus erneuerbaren Energien auszugleichen, selbst wenn ein großer Kavernenspeicher vorhanden ist.

Zusätzliche Stromsystemkosten



- Wasserstoff verursacht zusätzliche Systemkosten
- Systemkosten am niedrigsten bei verbrauchsnaher Kavernenspeicherung
- Zusätzliche Transportkosten können die Flexibilitätsvorteile der Kavernen aufwiegen
- Kosteneffekte getrieben von Investitionen in Erneuerbare
- Mehr Wasserstoffproduktion bei Kavernenspeicherung
  - höhere Elektrolyseurkapazität
- Kavernenspeicher reduzieren im Stromverbund die variablen Kosten durch fossile Erzeugung

Fazit und Politikempfehlungen

Wir stellen fest, dass

... grüner Wasserstoff die Stromsystemkosten erhöht

... Kavernenspeicher am meisten Flexibilität bieten (aber: Transportkosten)

... Flexibilitätsvorteile der Wasserstoffproduktion von anderen Flexibilitätsoptionen abhängt (z.B. Stromverbund)

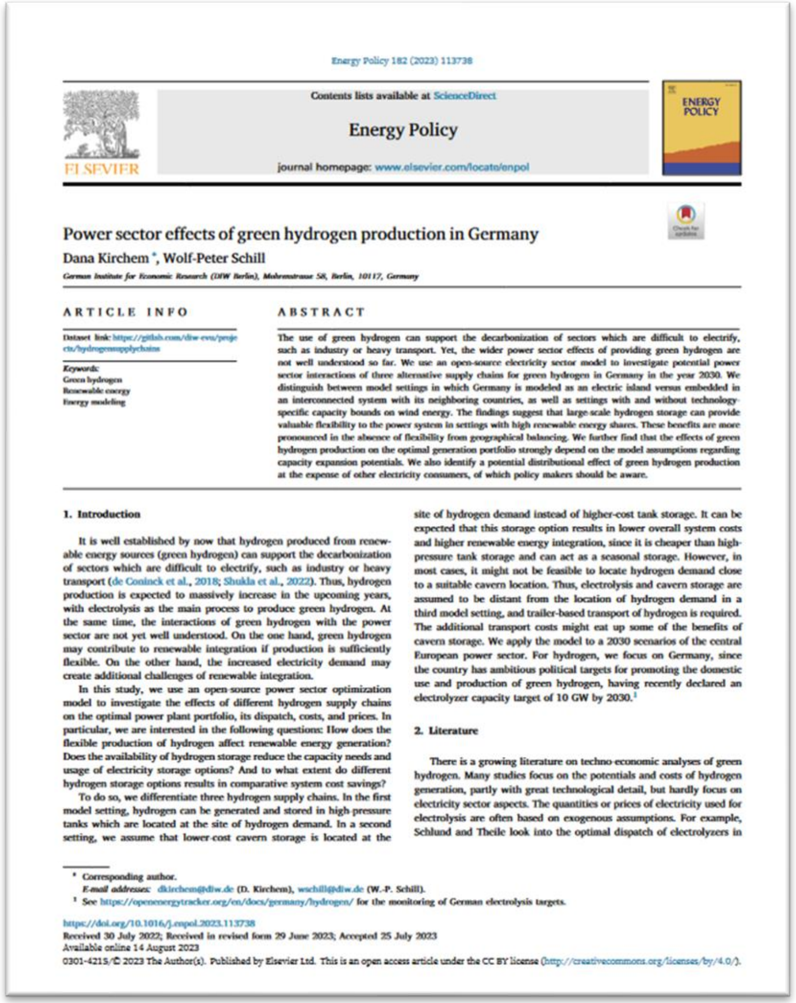
Die Politik sollte

... den EE-Ausbau vorantreiben

... Flexibilität unterstützen (z.B. Kavernenspeicher)

... Transportkosten senken (z. B. Wasserstoffnetz)

Publikationen



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Power sector effects of green hydrogen production in Germany

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ARTICLE INFO

Dataset link: https://gitlab.com/diw-evu/projects/hydrogensupplychains

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ABSTRACT

The use of green hydrogen can support the decarbonization of sectors which are difficult to electrify, such as industry or heavy transport. Yet, the wider power sector effects of providing green hydrogen are not well understood so far. We use an open-source electricity sector model to investigate potential power sector interactions of three alternative supply chains for green hydrogen in Germany in the year 2030. We distinguish between model settings in which Germany is modeled as an electric island versus embedded in an interconnected system with its neighboring countries, as well as settings with and without technology-specific capacity bounds on wind energy. The findings suggest that large-scale hydrogen storage can provide valuable flexibility to the power system in settings with high renewable energy shares. These benefits are more pronounced in the absence of flexibility from geographical balancing. We further find that the effects of green hydrogen production on the optimal generation portfolio strongly depend on the model assumptions regarding capacity expansion potentials. We also identify a potential distributional effect of green hydrogen production at the expense of other electricity consumers, of which policy makers should be aware.

1. Introduction

It is well established by now that hydrogen produced from renewable energy sources (green hydrogen) can support the decarbonization of sectors which are difficult to electrify, such as industry or heavy transport (de Coninck et al., 2018; Shukla et al., 2022). Thus, hydrogen production is expected to massively increase in the upcoming years, with electrolysis as the main process to produce green hydrogen. At the same time, the interactions of green hydrogen with the power sector are not yet well understood. On the one hand, green hydrogen may contribute to renewable integration if production is sufficiently flexible. On the other hand, the increased electricity demand may create additional challenges of renewable integration.

In this study, we use an open-source power sector optimization model to investigate the effects of different hydrogen supply chains on the optimal power plant portfolio, its dispatch, costs, and prices. In particular, we are interested in the following questions: How does the flexible production of hydrogen affect renewable energy generation? Does the availability of hydrogen storage reduce the capacity needs and usage of electricity storage options? And to what extent do different hydrogen storage options results in comparative system cost savings?

To do so, we differentiate three hydrogen supply chains. In the first model setting, hydrogen can be generated and stored in high-pressure tanks which are located at the site of hydrogen demand. In a second setting, we assume that lower-cost cavern storage is located at the site of hydrogen demand instead of higher-cost tank storage. It can be expected that this storage option results in lower overall system costs and higher renewable energy integration, since it is cheaper than high-pressure tank storage and can act as a seasonal storage. However, in most cases, it might not be feasible to locate hydrogen demand close to a suitable cavern location. Thus, electrolysis and cavern storage are assumed to be distant from the location of hydrogen demand in a third model setting, and trailer-based transport of hydrogen is required. The additional transport costs might eat up some of the benefits of cavern storage. We apply the model to a 2030 scenarios of the central European power sector. For hydrogen, we focus on Germany, since the country has ambitious political targets for promoting the domestic use and production of green hydrogen, having recently declared an electrolyzer capacity target of 10 GW by 2030.[1]

2. Literature

There is a growing literature on techno-economic analyses of green hydrogen. Many studies focus on the potentials and costs of hydrogen generation, partly with great technological detail, but hardly focus on electricity sector aspects. The quantities or prices of electricity used for electrolysis are often based on exogenous assumptions. For example, Schlund and Theile look into the optimal dispatch of electrolyzers in

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[1] See https://openenergytracker.org/en/docs/germany/hydrogen/ for the monitoring of German electrolysis targets.

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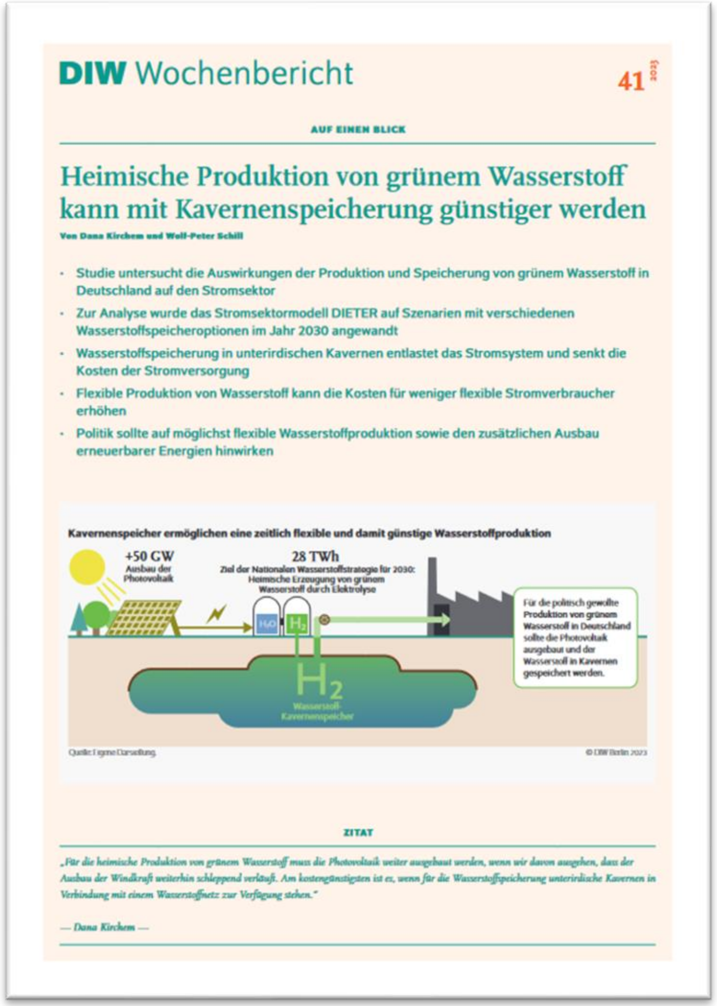

DIW Wochenbericht 41 2023

AUF EINEN BLICK

Heimische Produktion von grünem Wasserstoff kann mit Kavernenspeicherung günstiger werden

Von Dana Kirchem und Wolf-Peter Schill

- Studie untersucht die Auswirkungen der Produktion und Speicherung von grünem Wasserstoff in Deutschland auf den Stromsektor
- Zur Analyse wurde das Stromsektormodell DIETER auf Szenarien mit verschiedenen Wasserstoffspeicheroptionen im Jahr 2030 angewandt
- Wasserstoffspeicherung in unterirdischen Kavernen entlastet das Stromsystem und senkt die Kosten der Stromversorgung
- Flexible Produktion von Wasserstoff kann die Kosten für weniger flexible Stromverbraucher erhöhen
- Politik sollte auf möglichst flexible Wasserstoffproduktion sowie den zusätzlichen Ausbau erneuerbarer Energien hinwirken

Kavernenspeicher ermöglichen eine zeitlich flexible und damit günstige Wasserstoffproduktion

Quelle: Eigene Darstellung.

ZITAT

„Für die heimische Produktion von grünem Wasserstoff muss die Photovoltaik weiter ausgebaut werden, wenn wir davon ausgehen, dass der Ausbau der Windkraft weiterhin schleppend verläuft. Am kostengünstigsten ist es, wenn für die Wasserstoffspeicherung unterirdische Kavernen in Verbindung mit einem Wasserstoffnetz zur Verfügung stehen."

— Dana Kirchem —

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Vielen Dank für die Aufmerksamkeit.

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MODEZEEN

Modellierung (De-)Zentraler Energiewenden: Wechselwirkungen, Koordination und Lösungsansätze aus systemorientierter Perspektive

Das DIETER Modell

Input

Techno-ökonomische Parameter

- (EE) Erzeugung
- Speicher
- BEV, Wärmepumpen, H2

Stündl. Zeitreihendaten auf Länderebene

- EE Verfügbarkeit (Wetter)
- Stromnachfrage
    - Industrie, Haushalte, Wärme, Mobilität

NTCs

→

Modell

Systemkosten → MIN

- Investitionskosten (annualized)
- Fixe und variable Kosten

Nebenbedingungen

- Mindest-EE Anteil
- Betriebsbeschränkungen
- Flexibilitätsoptionen (Stromverbund, Speicher)

→

Output

Investitionsentscheidungen (Kapazitäten) UND Stündlicher Betrieb (Energie) Für:

- Stromerzeugung
- Flexibilitätsoptionen
    - BEV, Wärmepumpen, H2

Stromflüsse

Preise & Systemkosten

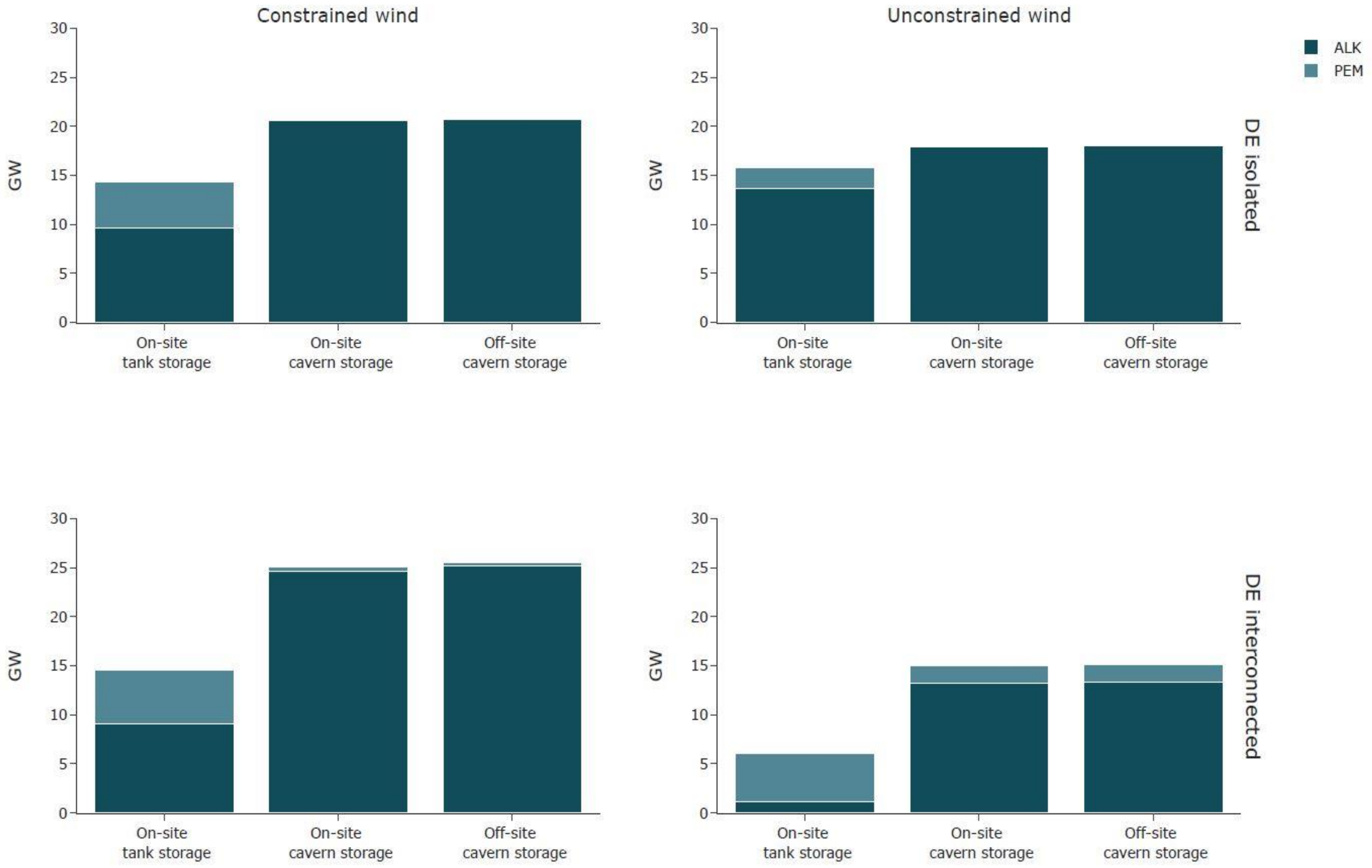
- Marktwerte

Inputdaten

Parameter	Value	Source
Nachfrage grüner Wasserstoff	28 TWh/a	Based on the target of the German government to install 10 GW of electrolyser capacity in 2030
Zeitreihendaten EE Verfügbarkeit		Open Power System Data Platform
Zeitreihendaten Stromnachfrage		ENTSOE TYNDP 2020 scenario 'Distributed Energy'
Mindest-EE Anteil (an Stromnachfrage)	≥80 %	Eigene Annahme
Brennstoffpreise		World Energy Outlook 2020
CO_2 Preis	130 €/t	Eigene Annahme
NTCs		ENTSOE TYNDP 2020 scenario 'Distributed Energy'
Kapazitäts-Ausbaugrenzen in DE		NEP 2030 and Government targets
Erzeugungskapazitäten im Ausland		ENTSOE TYNDP 2020 scenario 'Distributed Energy'

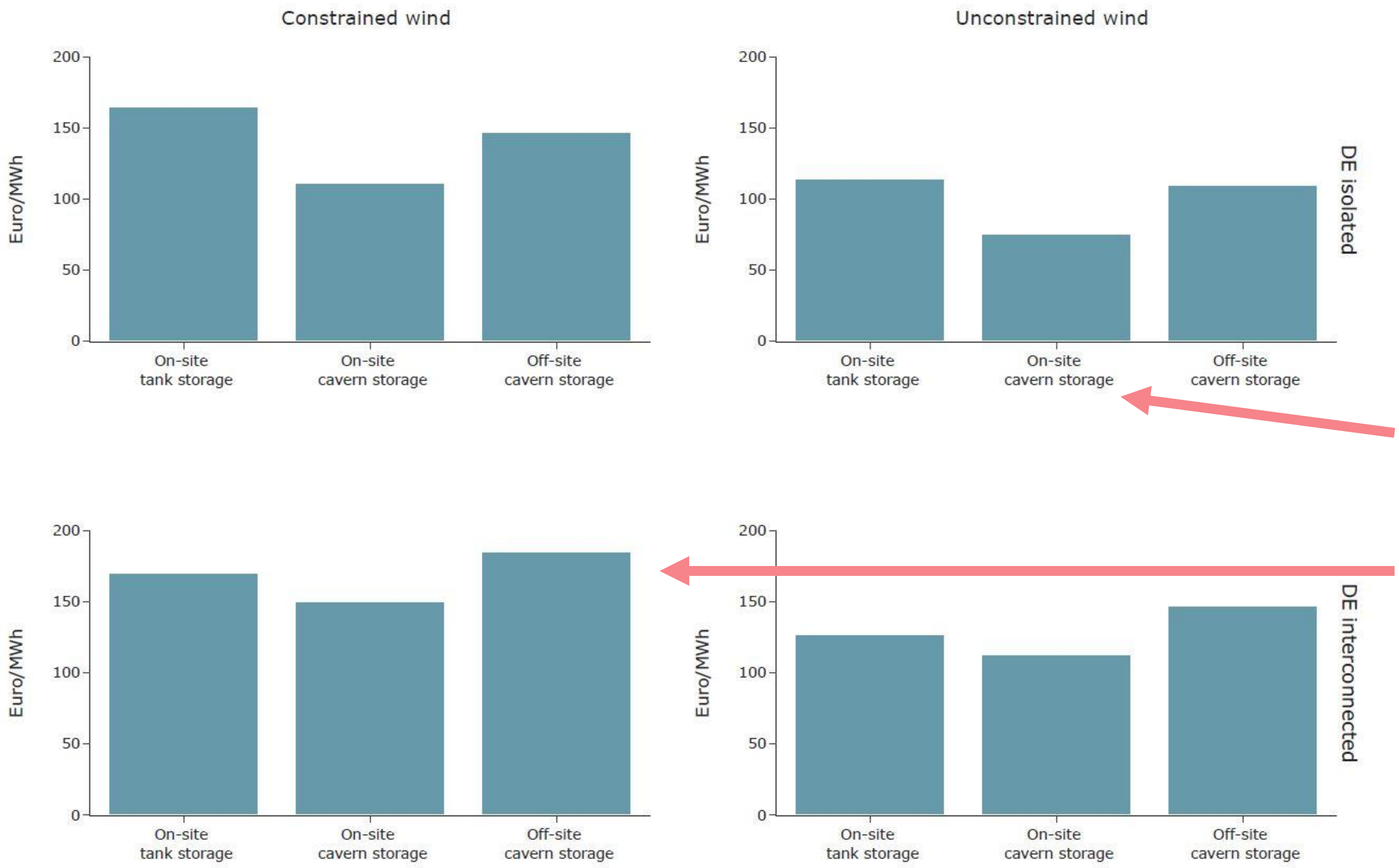
4

Results: Installed electrolyzer capacity



- More investments in ALK than in (more efficient) PEM
  - renewable electricity is relatively cheap here: electricity costs matter less than investment costs
- Electrolyzer capacity is higher with cavern storage
  - caverns enable electrolysis to draw more electricity from the grid in hours of high renewable availability (low prices)
- Electrolyzer capacity is higher if wind power expansion is constrained
  - higher PV capacity, with large temporal renewable surplus generation around midday

Results: Additional System Costs of Hydrogen (ASCH)

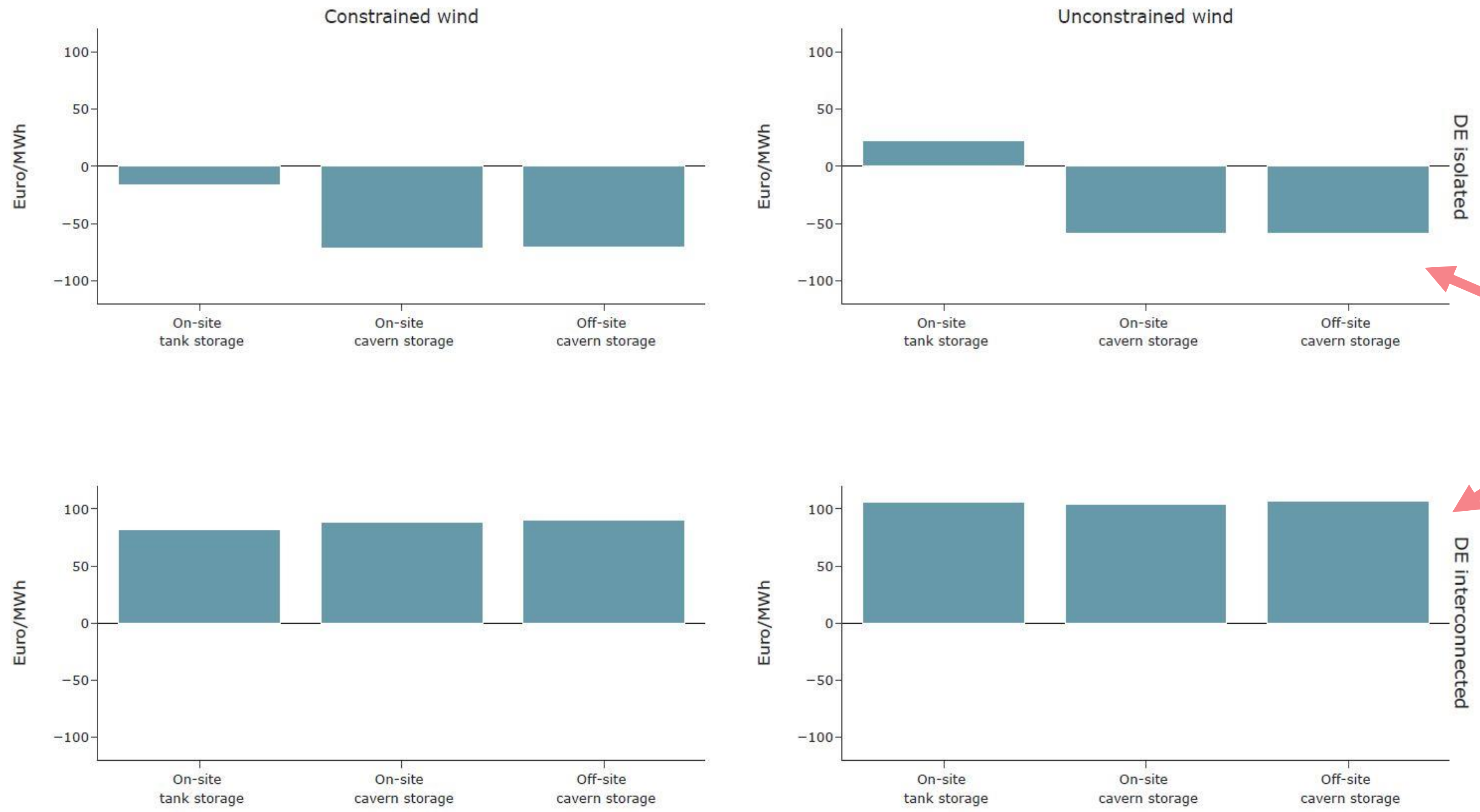


ASCH = total additional power system costs related to amount of green hydrogen generated

Lowest ASCH: electrolyzers can make use of high renewable surpluses

Highest ASCH: much less renewable surplus energy, and transport costs outweigh the flexibility benefits of cavern storage.

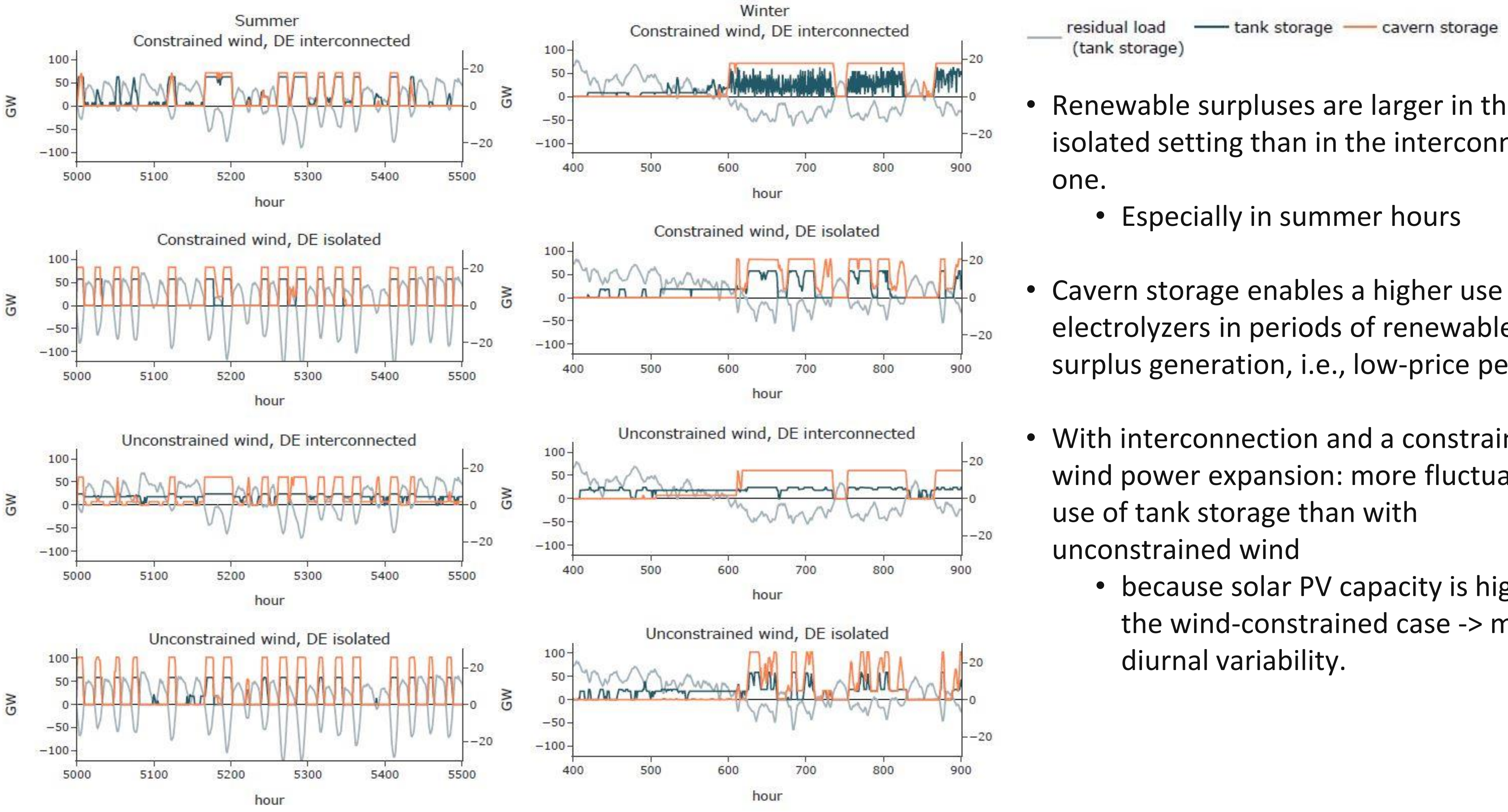
Results: Average Provision Costs of Hydrogen (APCH)



- APCH = sum of fixed and variable costs related to electrolysis, hydrogen storage and transport, plus the energy bill faced by operators of electrolyzers and compressors. (hydrogen producer perspective)
- Negative, because electrolyzers can use renewable surpluses at negative prices
- Positive, but still lower than ASCH.

- Indicates that hydrogen producers may not internalize the full costs that they cause in the power sector.

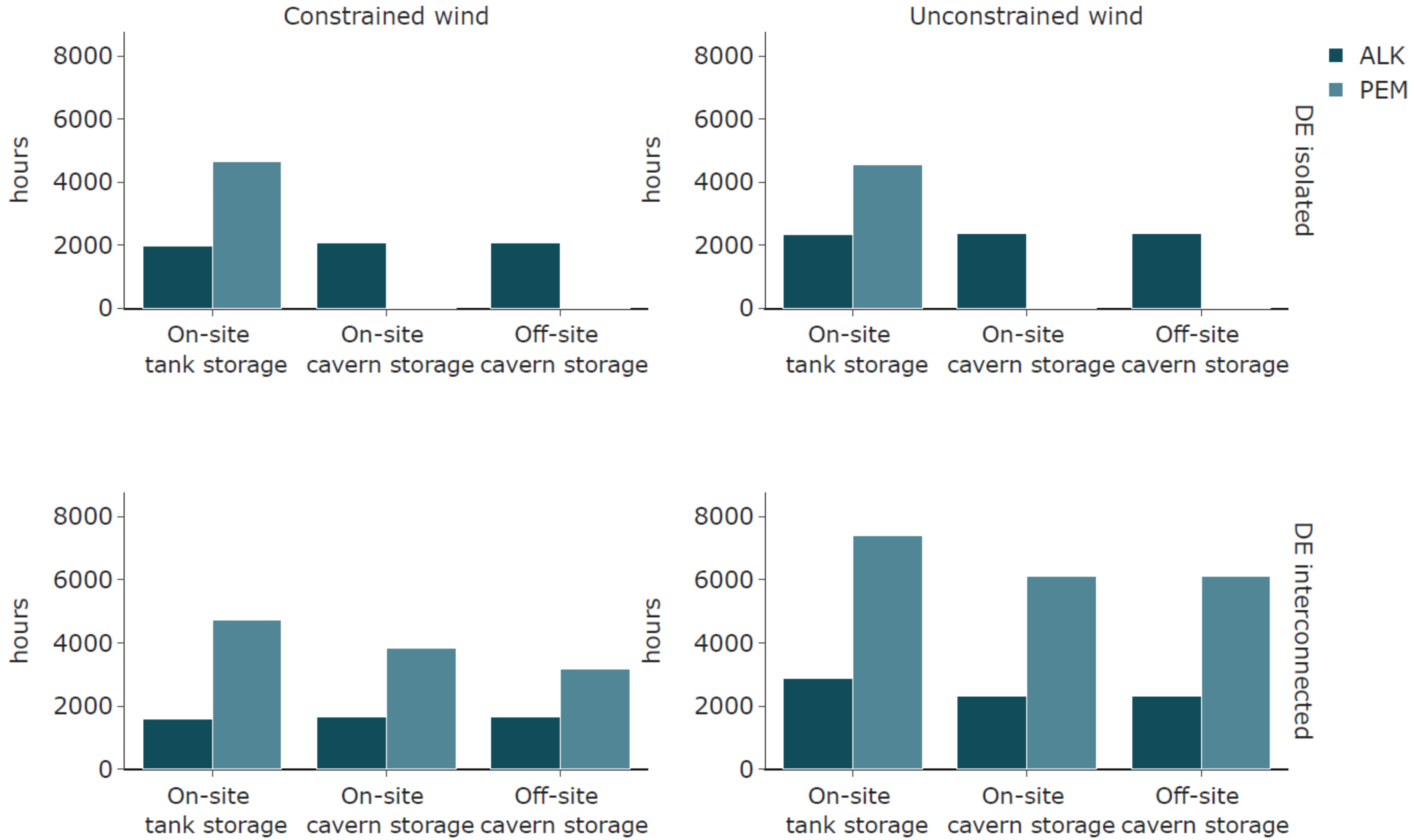
Results: Electricity consumption by electrolyzers



- Renewable surpluses are larger in the isolated setting than in the interconnected one.
  - Especially in summer hours
- Cavern storage enables a higher use of electrolyzers in periods of renewable surplus generation, i.e., low-price periods
- With interconnection and a constrained wind power expansion: more fluctuating use of tank storage than with unconstrained wind
  - because solar PV capacity is higher in the wind-constrained case -> more diurnal variability.

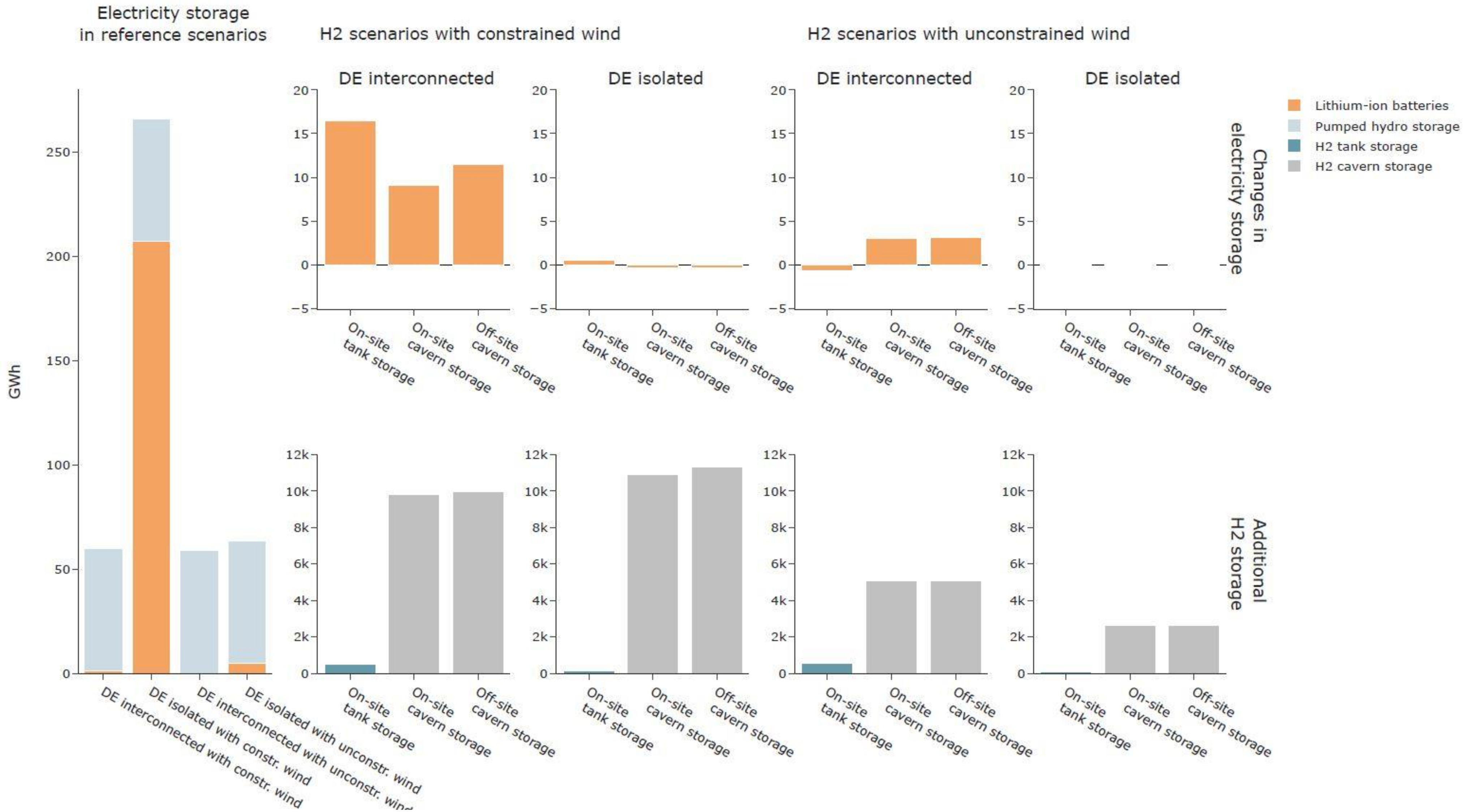
4

Results: Full-load hours of electrolyzers

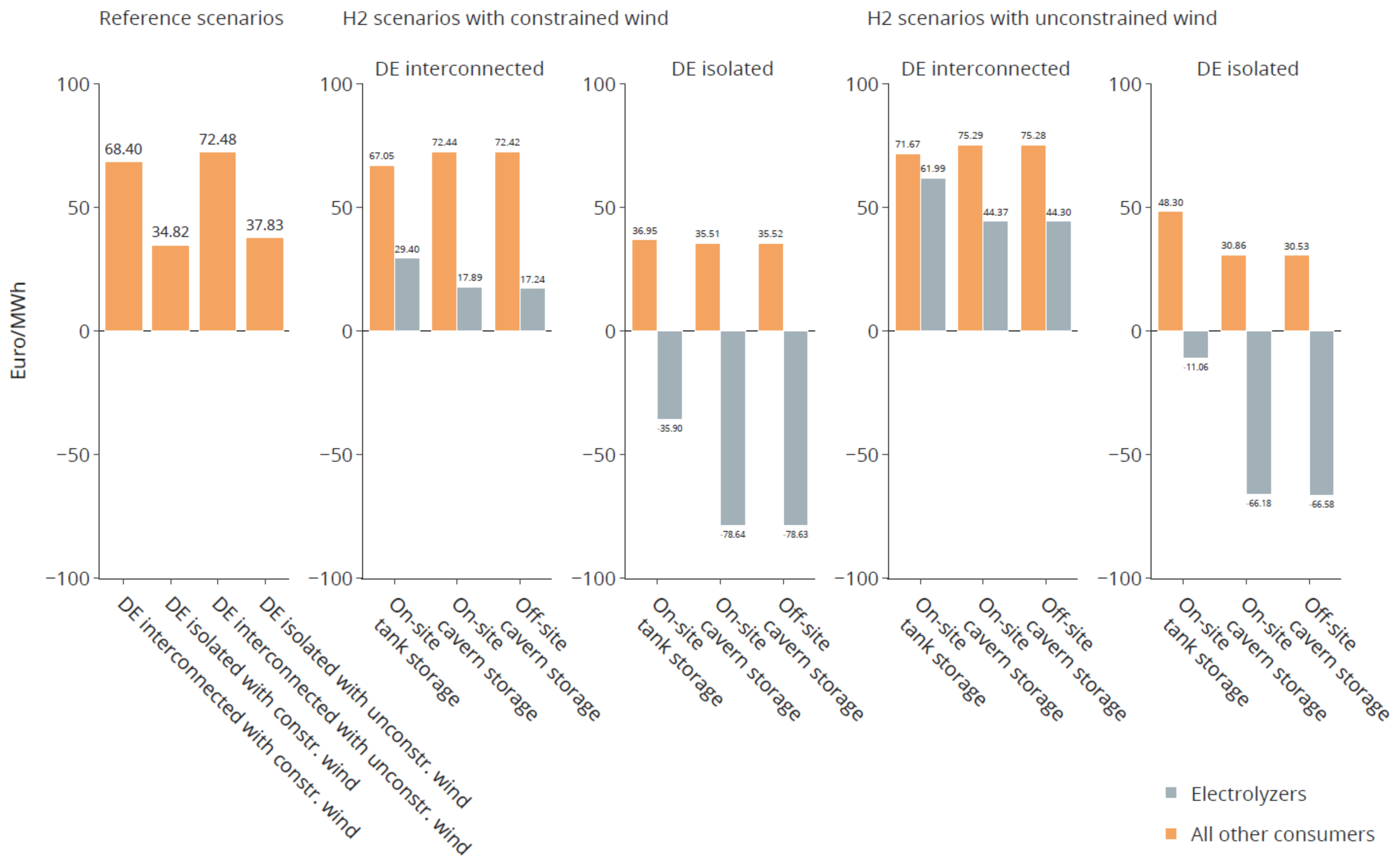


- FLH lower with cavern storage: electrolyzer capacities are higher
- ALK already recovers ist lower investment costs with less full-load hours; PEM needs more to recover costs
- Because of large renewable surpluses: investment costs outweigh efficiency as decision factor

Results: Installed electricity storage capacities (storage energy) in Germany



4 Results: Load-weighted average electricity prices (absolute values)



- In reference cases: lower average prices if Germany is modeled in isolation
  - More renewable capacity needed to meet RES constraint
  - higher renewable surpluses and more hours with very low prices.
- Green hydrogen producers can exploit periods with low prices.
  - to a higher degree if low-cost caverns can be built
- Average electricity prices of electrolyzers even negative in “DE isolated”
  - Electrolyzers are paid for the electricity they consume.
  - Depends on the binding RE target
  - Interpretation: energy-based support payment for generators to achieve zero profits in equilibrium
- With interconnection and a lot of temporal flexibility: negative average prices vanish

4 Results: Yearly renewable curtailment