Global Green Hydrogen Supply: Good Renewable Energy Potentials & Demand Proximity is not Enough

Heidi U. Heinrichs, Detlef Stolten et al.

h.heinrichs@fz-juelich.de

Symposium on International Cooperation for Green Hydrogen

Challenges for a hydrogen-based economy: Storage and transport

DWIH New Delhi online

07th December 2022

IEK-3: Institute of Techno-Economic Systems Analysis

IEK-3: Techno-Economic Systems Analysis – Mission, Resources & Projects

Mission

Independent and **unbiased** investigations on **technologies**, **energy pathways**, **value chains**, **market introduction** and **scale up** for future energy systems from **regional to global scale**

Action knowledge

Resources

- **Interdisciplinary team**: engineers (mechanical, energy, process, environment, material, industrial, electrical), chemist, physicist, geologist (~43 staff; full time equivalent)
- **Computer cluster** w/ 1200 cores; 440 TB storage capacity, particularly for geographic data and weather data

Selected Projects

- **H2 Mobility study:** comparison of battery and fuel cell vehicle infrastructure
- **H2 Atlas Africa:** Green H_2 potentials in selected regions in Africa
- **THG45 study**: German energy transition to greenhouse gas neutrality in 2045
- **LOCALIZED**: EU energy transition on NUTS3 level
- **HyUsPRe**: European porous hydrogen underground storage
- And many more

Our IEK-3 team

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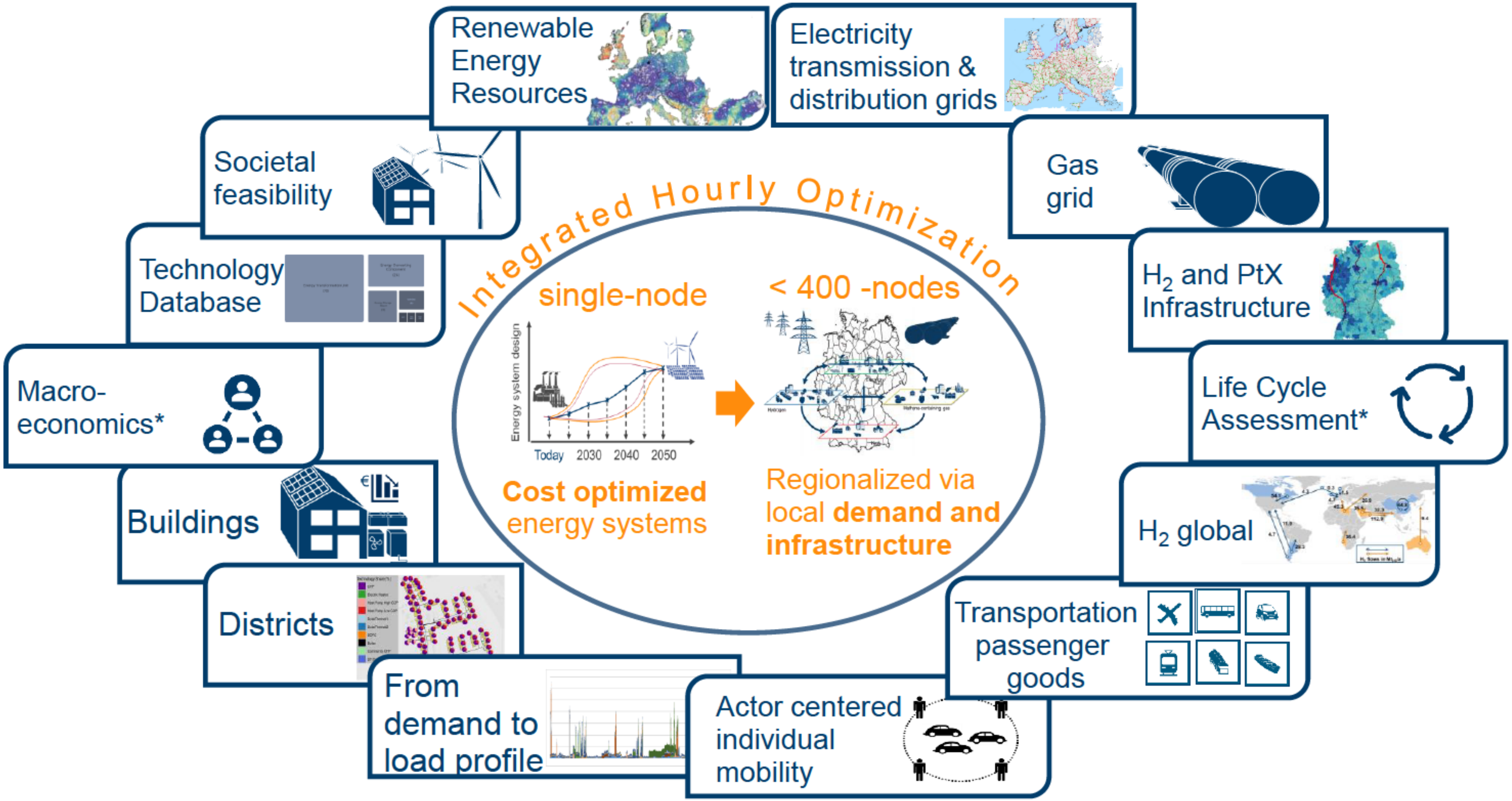
ETHOS: Energy Transformation PatHway Optimization Suite



*with IEK-STE

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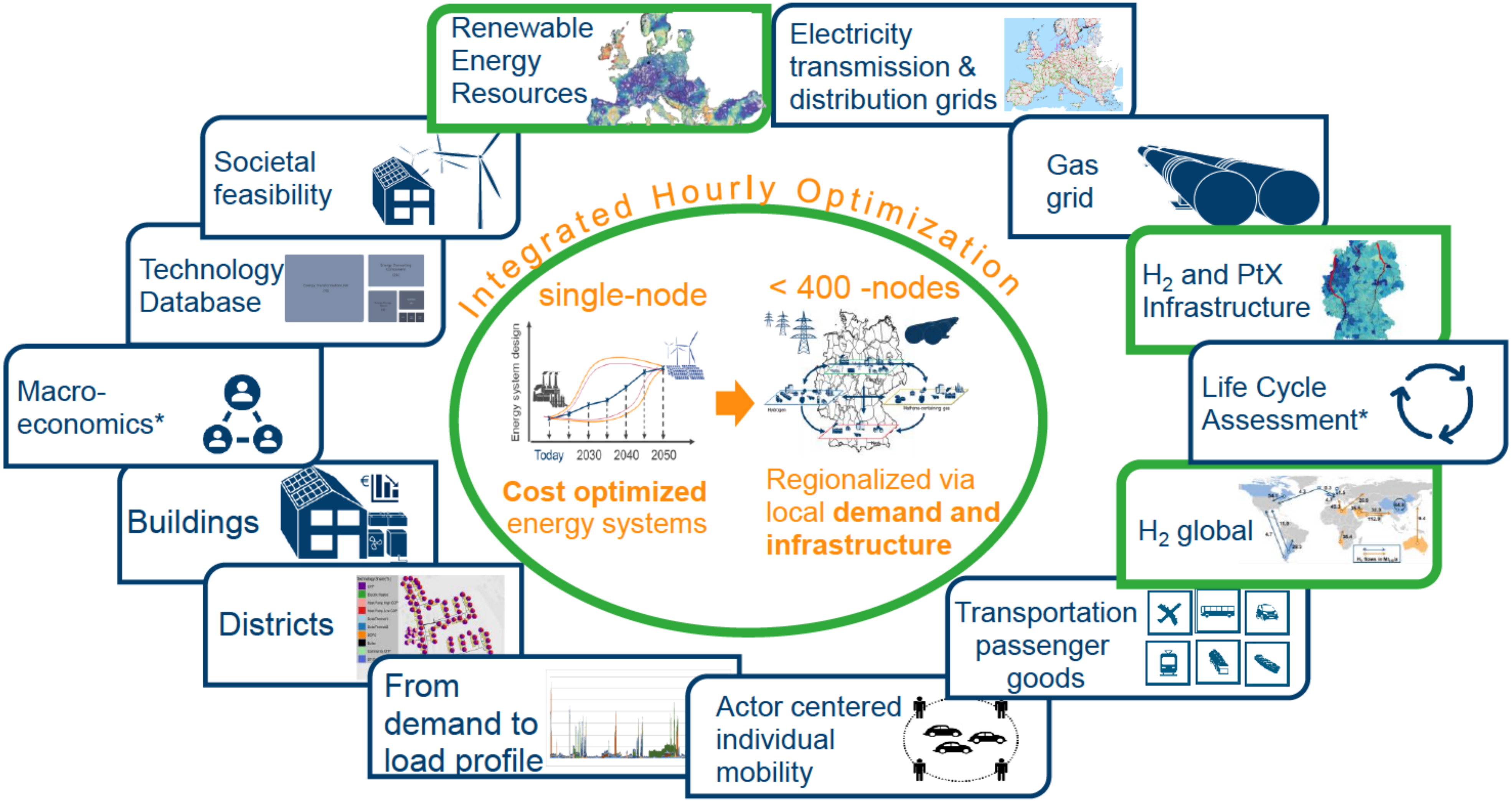

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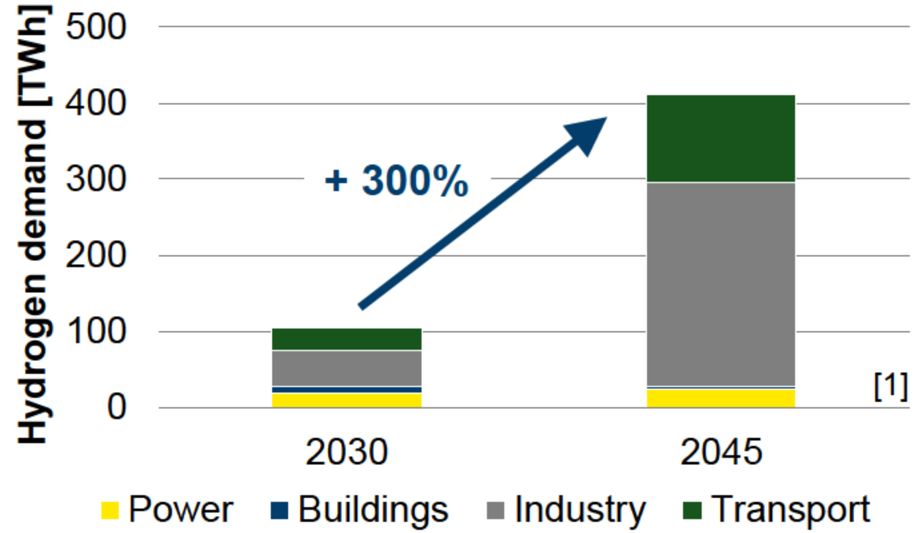
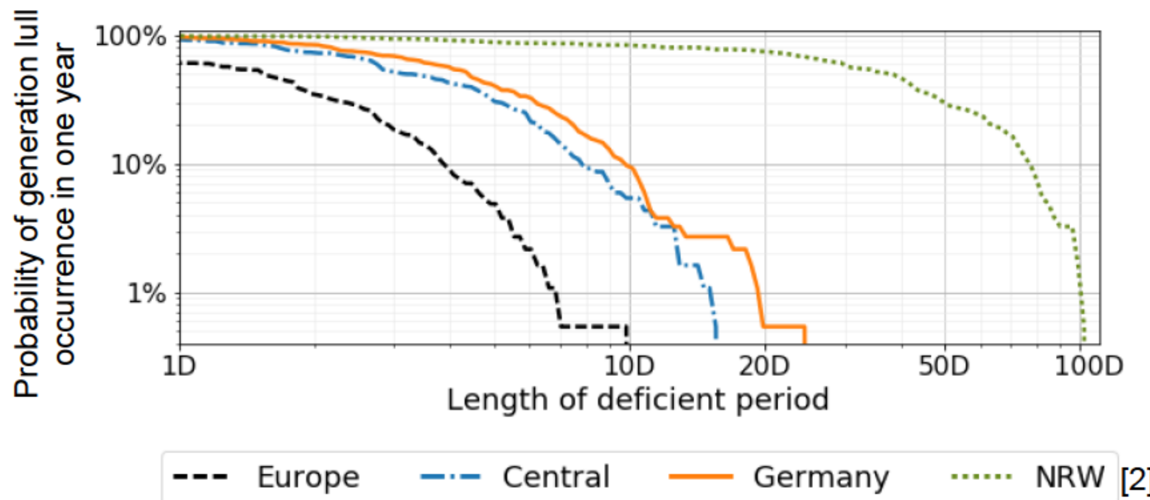
Greenhouse Gas Neutral Energy Systems Favor Green Hydrogen

- Green hydrogen **pillar for greenhouse gas neutrality** in Germany [1]
- **Later shifts** in transformation goals can induce **higher cost (path dependencies)**
- Production of green hydrogen needs **additional expansion of renewable energy technologies**
- Germany will need **hydrogen imports** (~50% of H_2 demand [1])

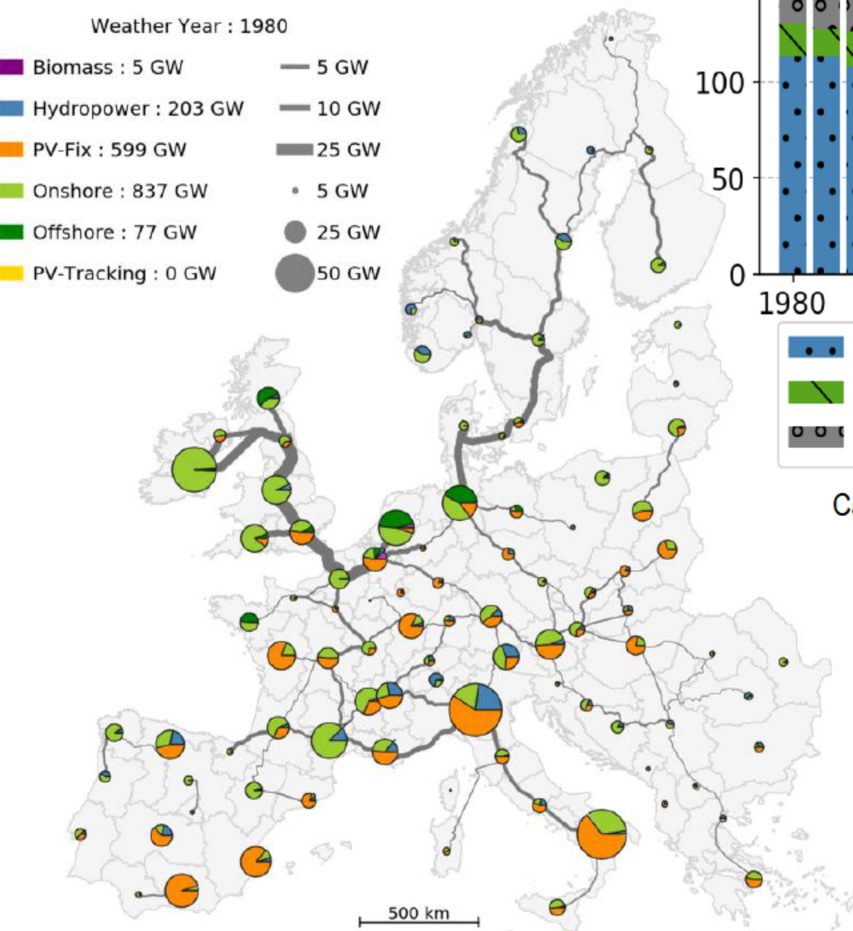


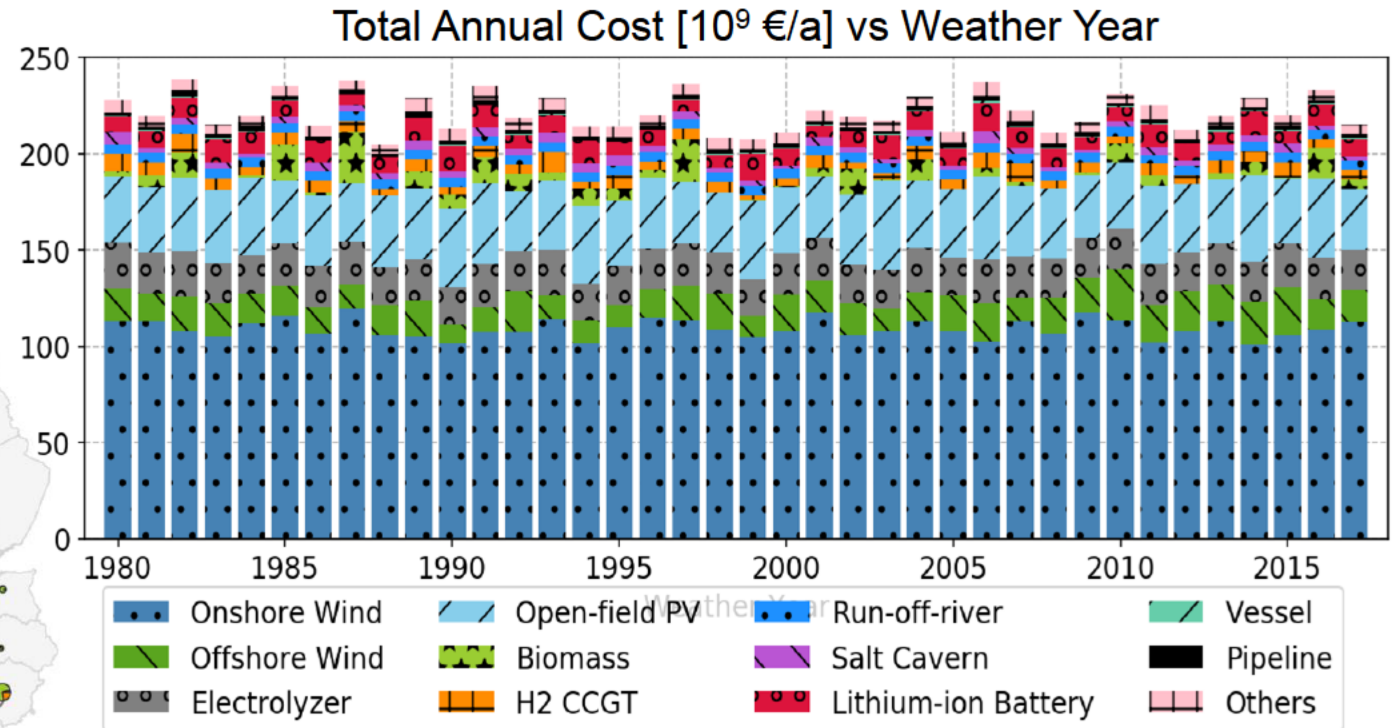
- **100% renewable** energy systems **need bulk storage** even across large interconnected regions like Europe
- **Green hydrogen** especially combined with salt caverns provide **promising storage option** required for greenhouse gas neutral energy systems



[1] D. Stolten et al. (021): Strategien für eine treibhausgasneutrale Energieversorgung bis zum Jahr 2045. [2] Ryberg et al. (2019): Occurrence of variable renewable energy system generation lulls in a future European capacity scenario. In proceedings of the International Conference on Applied Energy (ICAE) 2019, Västeras, Sweden.

Weather Years Impact Energy Systems Design





Caglayan et al. *Int. J. Hydrogen Energy*, 2019, **44**, 25442–25456. doi:10.1016/j.ijhydene.2019.08.032

Designing energy systems for future green energy imports has to **account for different weather years to provide robust solutions**.

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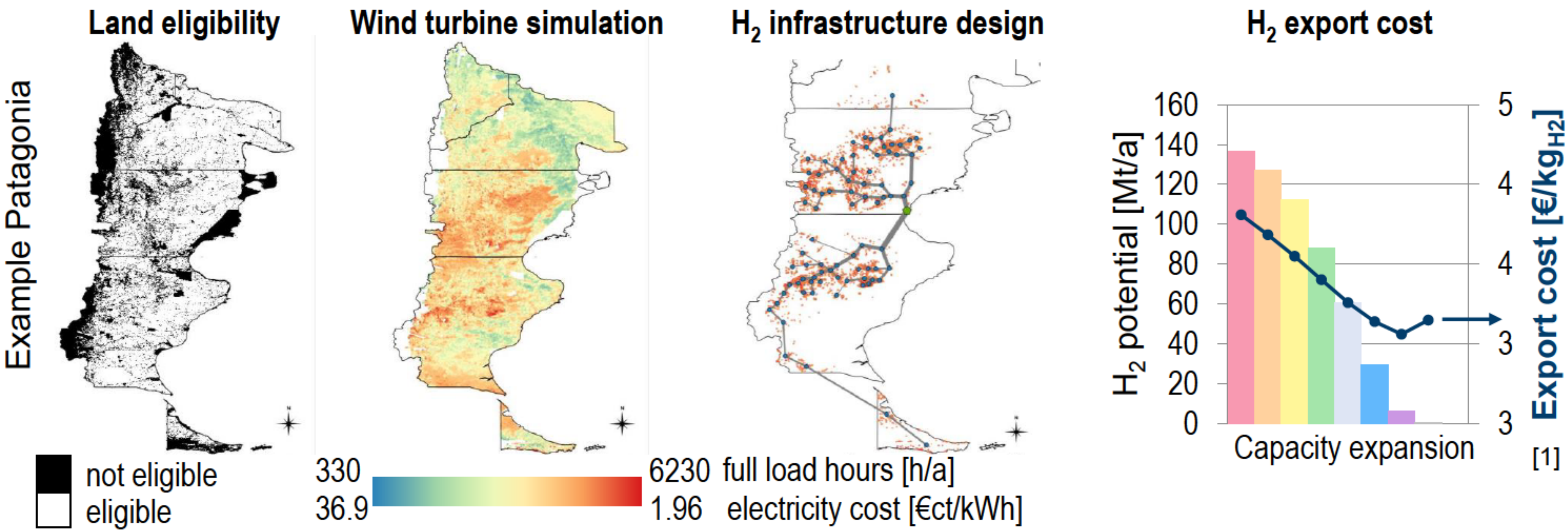
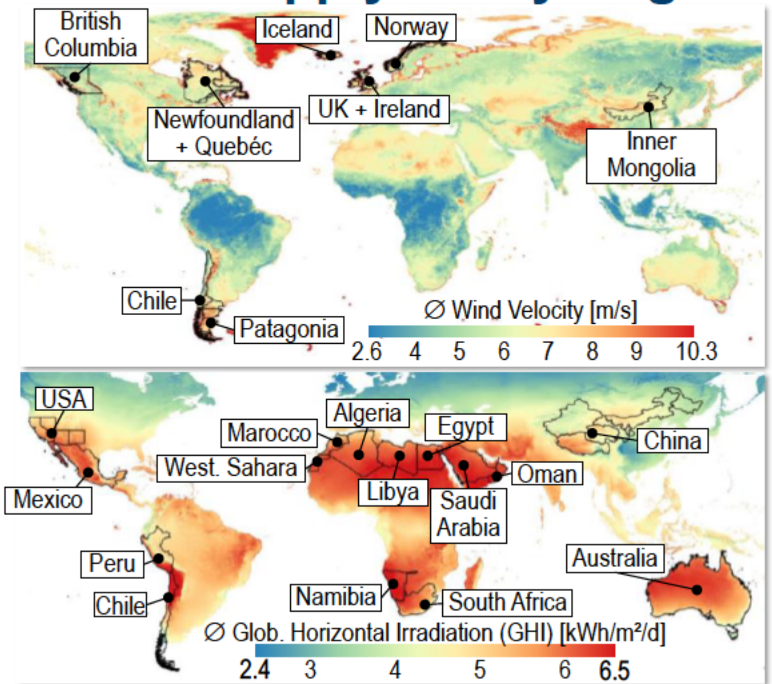
Potential Synergies & Competition of Land & Energy Resources



- **Required land** should **not affect** well-being & economic development of **local population**
  ➔ dozens of **eligibility criteria** applied & mostly **only best 5% of locations** allowed
- **Sufficient** renewable energy **potential** to supply both local demand & H_2 export
  ➔ **synergies of infrastructures** possible
- Sun-rich regions with **stable electricity generation cost** mostly **independent of PV expansion**
  ➔ **low competition** for best locations

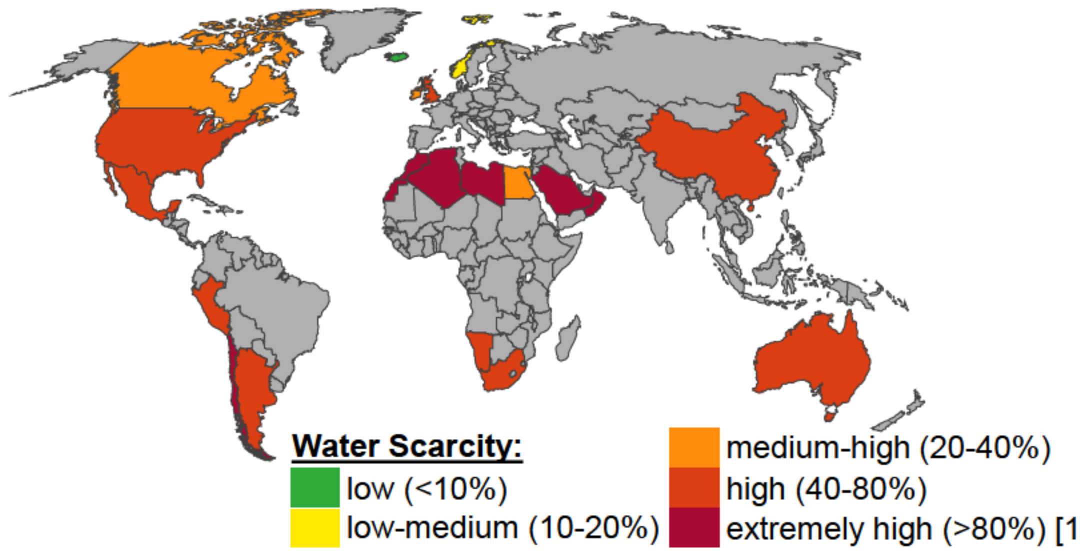
[1] P.-M. Heuser et al. (2019): Techno-economic analysis of a potential energy trading link between Patagonia and Japan based on CO_2 free hydrogen, Int. J. of Hydrogen Energy, 44, 12733-12747.

Water Supply for Hydrogen Production via Water Electrolysis



[2]

- 25 exemplary renewable-rich regions with coastal access
- Only some countries have enough fresh water + beneficial locations for renewable energy technologies



Solution: Seawater desalination

- Only **minor impact on hydrogen cost** (+0.9 – 1.4 €ct/kg_{H2} ➔ 0.2 – 0.5% of LCOH) [3]
- **Suitable for market ramp up** as **fully scalable** from in-house applications to industrial scale (<1m³/d – hundreds of thousands of m³/d) [4]
- Potential **co-benefit for local water supply** by utilizing economy of scale

[1] T. Luo et al. (2015) Aqueduct projected water stress country rankings" World Resources Institute, Washington. [2] P.-M. Heuser et al. (2020) Worldwide Hydrogen Provision Scheme Based on Renewable Energy. [3] L. Gao et al. (2017) An Economic Assessment of the Global Potential for Seawater Desalination to 2050. In Water 9 (10), p. 763. [4] Kyriakarakos et al. (2019) Is Small Scale Desalination Coupled with Renewable Energy a Cost-Effective Solution? Appl. Sci. 2021, 11, 5419.

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Sustainable Groundwater not Sufficient for Green Hydrogen

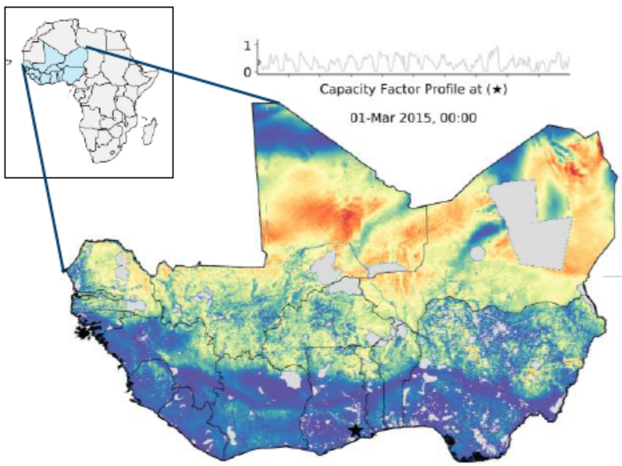
Preliminary Results of Green Hydrogen Potential for West Africa

Renewable Energy Potential

- ✓ wind & solar energy
- ✓ unit-specific placement
- ✓ newest weather data
- ✓ open source & data

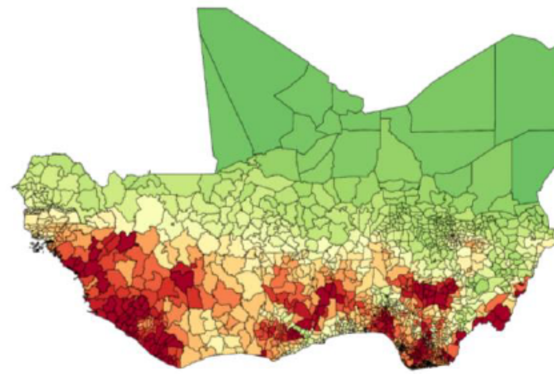
Green Hydrogen Potential

- ✓ optimal wind & solar mix
- ✓ sustainable water supply
- ✓ optimal system design
- ✓ open source & data



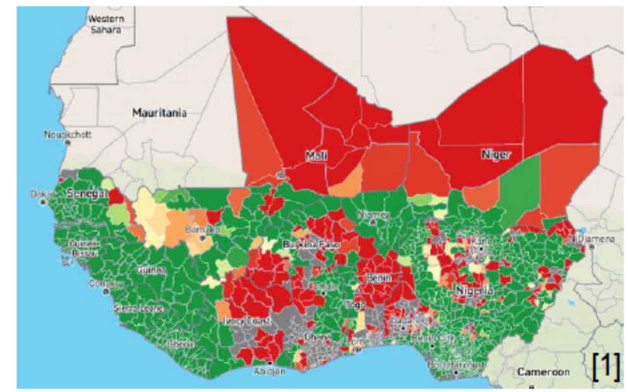
\> 5 million eligible onshore wind locations

0 2 4 6 8
Available onshore wind generation [MWh km^{-2} h^{-1}]



\> 90 PWh local green hydrogen potential

0 2 4 6 8 10
Local Cost of Hydrogen for 2020 (50% of potential) [EUR/kg]



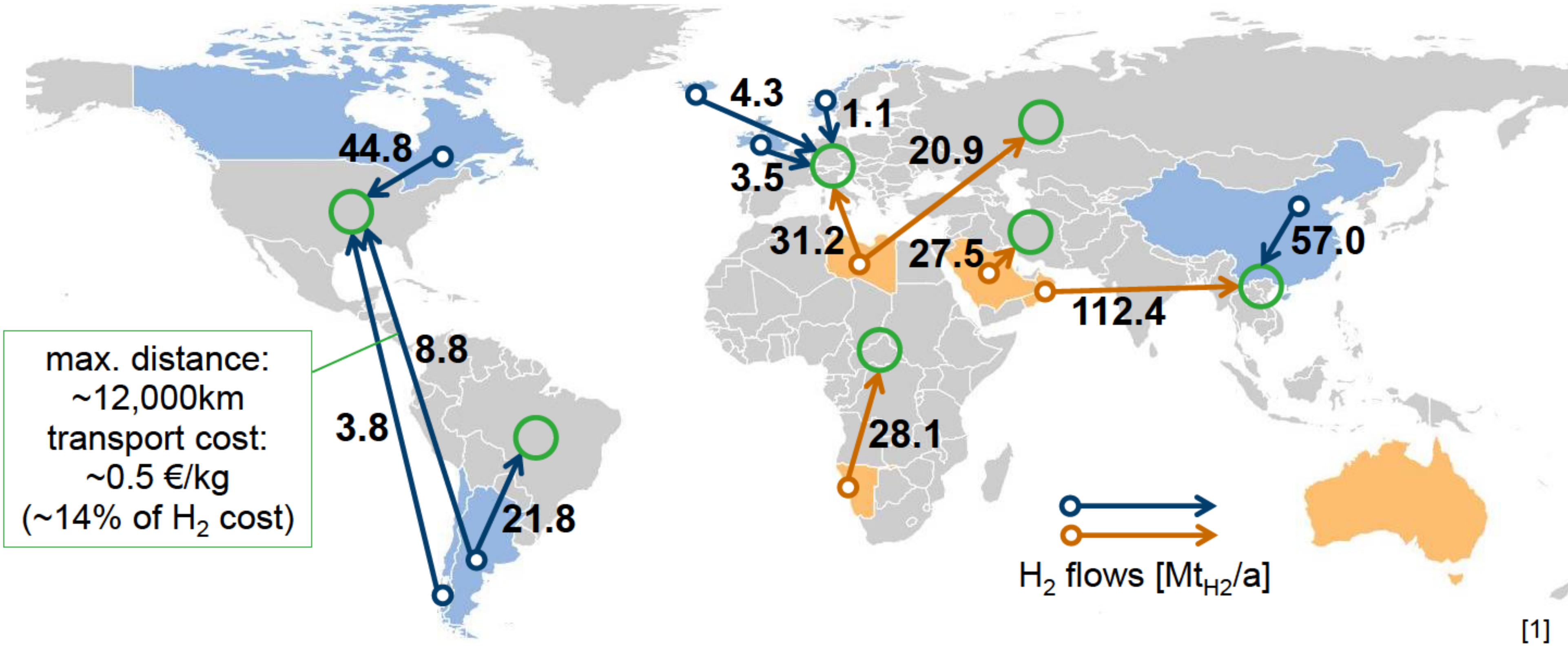
~ 35% of green H_2 potential producible from local sustainable groundwater

100 80 60 40 20 0
Share of green H_2 from sustainable groundwater [%]

Groundwater not sufficient for global green hydrogen production

[1] B. Bayat et al.: Groundwater Layer: Available Groundwater, https://africa.h2atlas.de/ecowas.

Global Green Hydrogen Supply More Regionalized



- **Very long transport** mostly **not cost-minimal** & not required
- **Green transport options** required (e.g. green hydrogen driven ships)

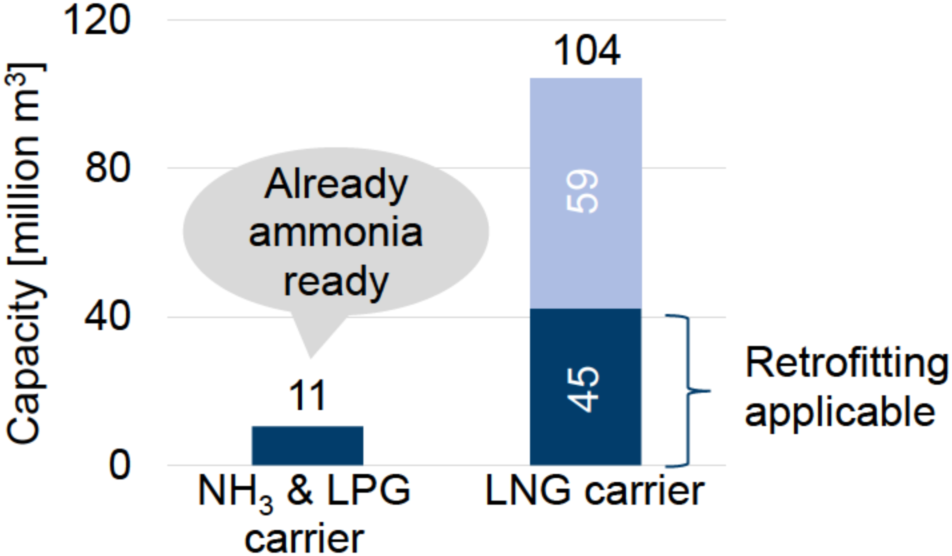
  ➔ **CO_2 savings** of up to **$800Mt_{CO2}/a$** possible compared to marine diesel oil

- Nearly **1000 LH_2 ships** required **until 2050** for green hydrogen demand of ~360 Mt_{H2}/a

[1] P.-M. Heuser et al. (2020) Worldwide Hydrogen Provision Scheme Based on Renewable Energy.

Maritime Infrastructure Transition Towards Renewable Energy Carriers

Global vessel capacities 2022 [1]



Global hydrogen vessel 2022 [2]

1 prototype: 1,250 m³ global capacity

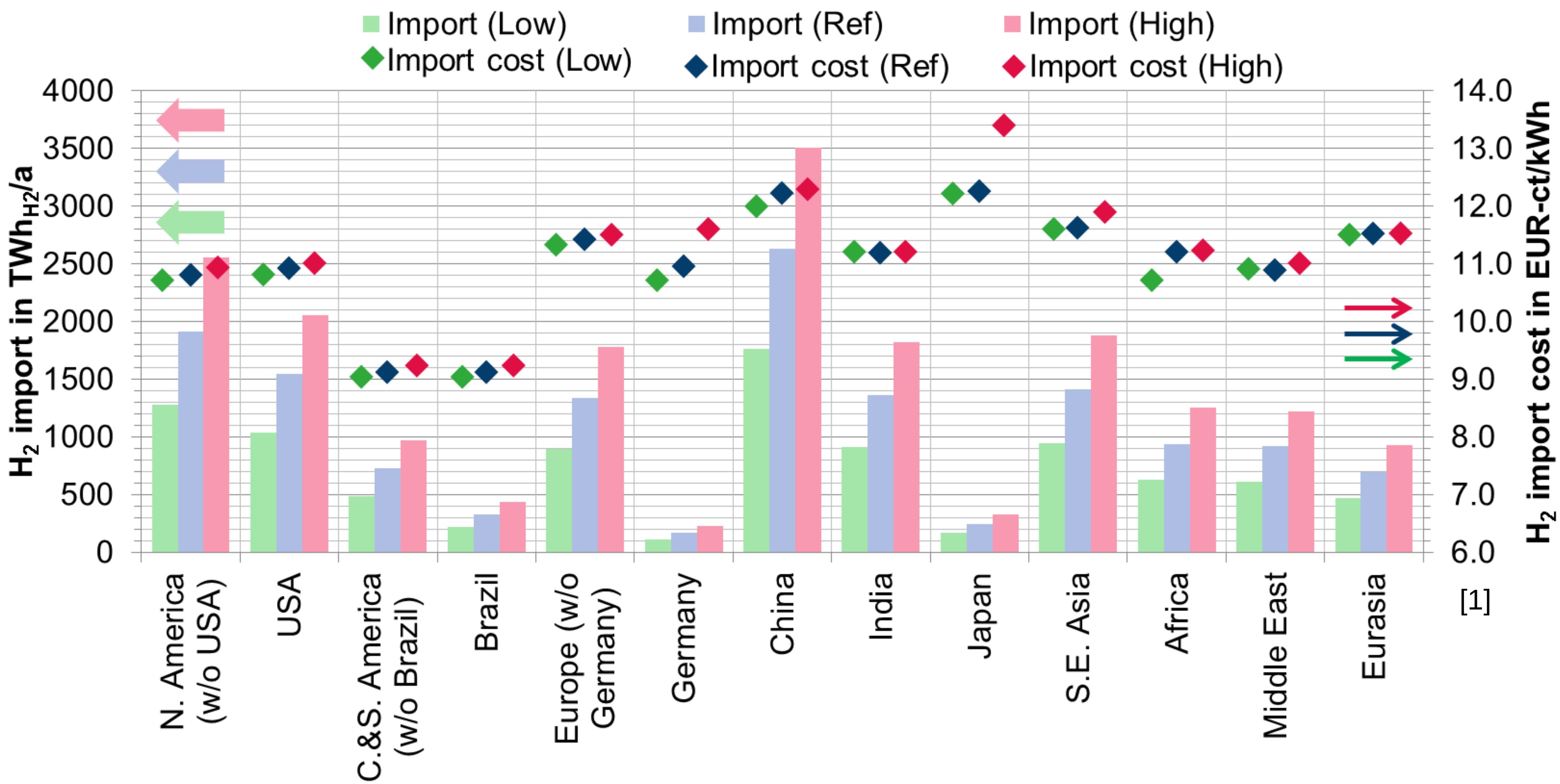
- Properties of energy carriers determine vessel characteristics
- Current maritime infrastructure not sufficient for global hydrogen market
- Ammonia requires additional energy supply in importing country

- 67 new LNG vessels in 2021 [1a]
- LNG shipyards mainly in Asia (China, South Korea, Japan) [1a]

➔ **Ramp-up of maritime infrastructure required**

[1] own estimations based on: [1a] GIIGNL (2022), Annual report 2022. [1b] Lloyd’s List (2021), Ammonia hype builds in shipping market. [2] Kawasaki (2019): World’s fist Liquefied H2 Carrier Suiso Frontier.

Diversity of Potential Export Countries Support Low Market Power



- **Import cost** of green hydrogen could range between **~3 and ~4.4 €/kg$_{H_2}$**
- **Import cost relative stable** in case of increasing demand or shortfall of strong export countries

[1] P.-M. Heuser et al. (2020) Worldwide Hydrogen Provision Scheme Based on Renewable Energy.

Key Take Away Messages

- Clear pathway towards **climate neutrality** beneficial and **green hydrogen** represents **a pillar**
- Potential **synergies and competition of** land and energy **resources** have to be considered
- **Preferable** water supply for hydrogen production via water electrolysis is **seawater desalination**
- Differences in green hydrogen cost most often do **not balance very long transport distances**
- Global green hydrogen supply requires **green transport options** and the **maritime infrastructure** needs a substantial **ramp-up**
- Diversity of potential export countries support **low market power**

Thank you for your attention!

For further questions, please contact:

Dr. Heidi U. Heinrichs
h.heinrichs@fz-juelich.de

Prof. Dr. Detlef Stolten
d.stolten@fz-juelich.de

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GHG net zero scenario
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Project DaceStorE
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H2 Atlas Africa
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