

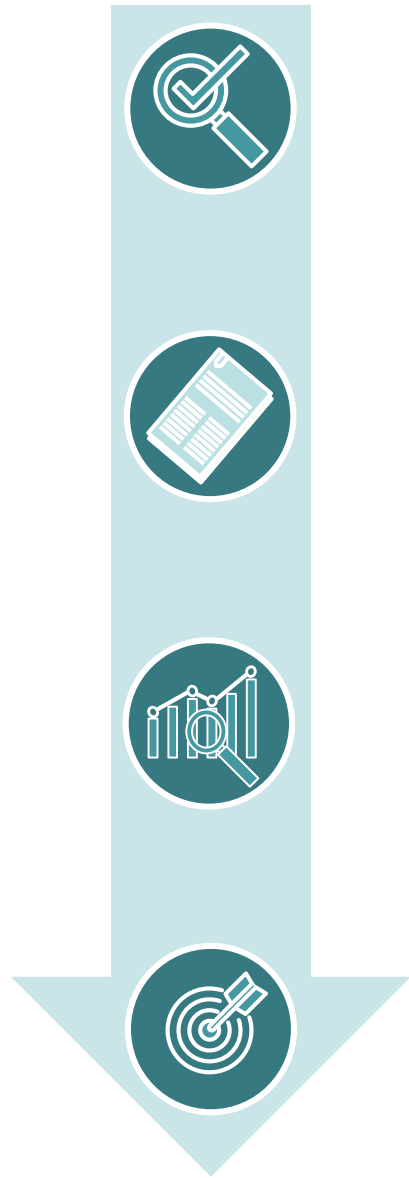


CODAHEA – Hydrogen Talk
28.02.2023

Cost Optimized Hydrogen Production by Wind Power & Photovoltaics

– Cost & Potential in the European Catchment Area –

Lucas Sens, Martin Kaltschmitt



1. Background

2. System Definition

3. Results

4. Key Conclusions



Green hydrogen in a future energy system

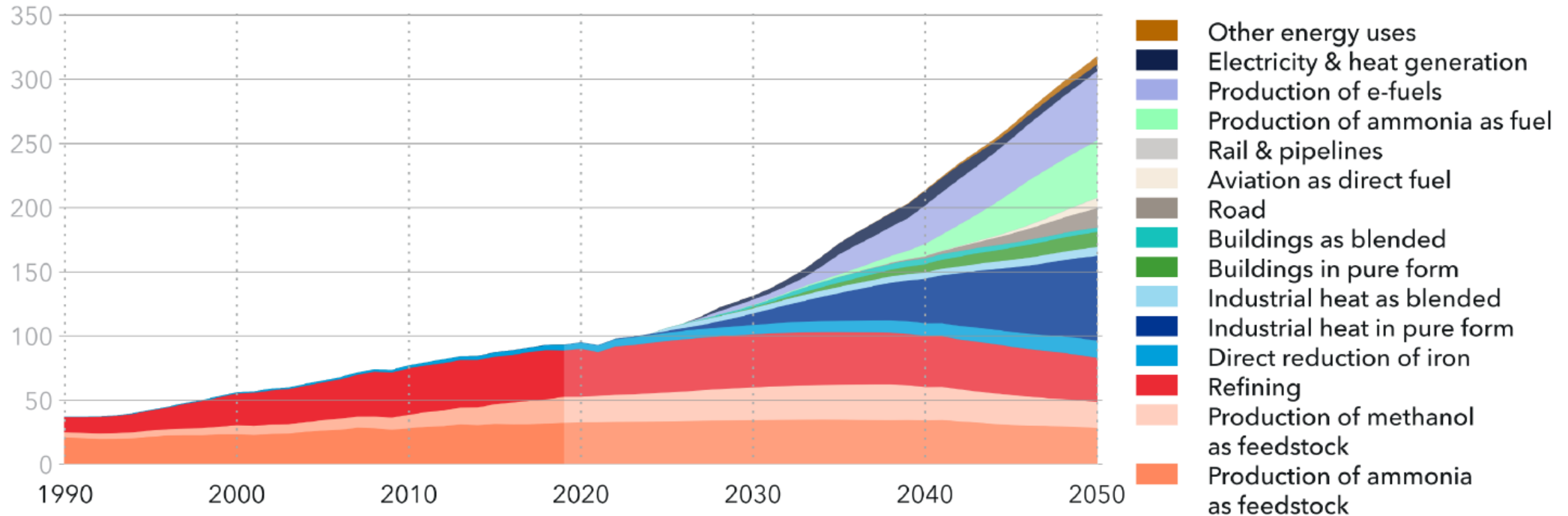
1. Background



Hydrogen Demand Projections

Global hydrogen demand by sector

Units: MtH₂/yr



Does not include hydrogen use in residual form from industrial processes. Historical data sources: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021), USGS Mineral Commodity Summaries (1990-2022), IFA (2022)



1. Are hydrogen costs below $2 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ realistic in the future?
2. Which regions are most favorable for a hydrogen supply to Germany?
3. What is the influence of the implementation of salt caverns as a hydrogen storage?
4. Is the domestic production potential enough for a self-sufficient hydrogen supply in Germany?

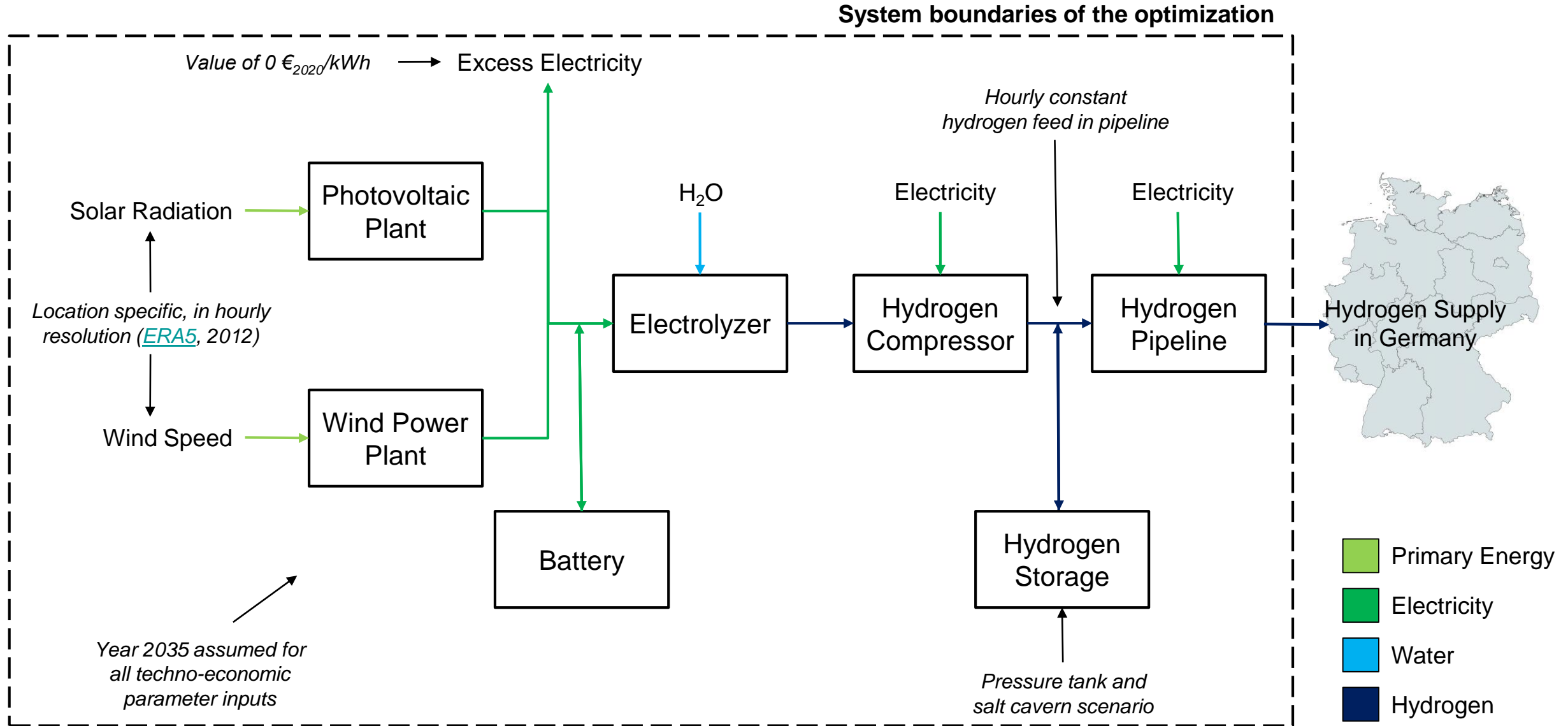


Modelling & Assumptions

2. System Definition

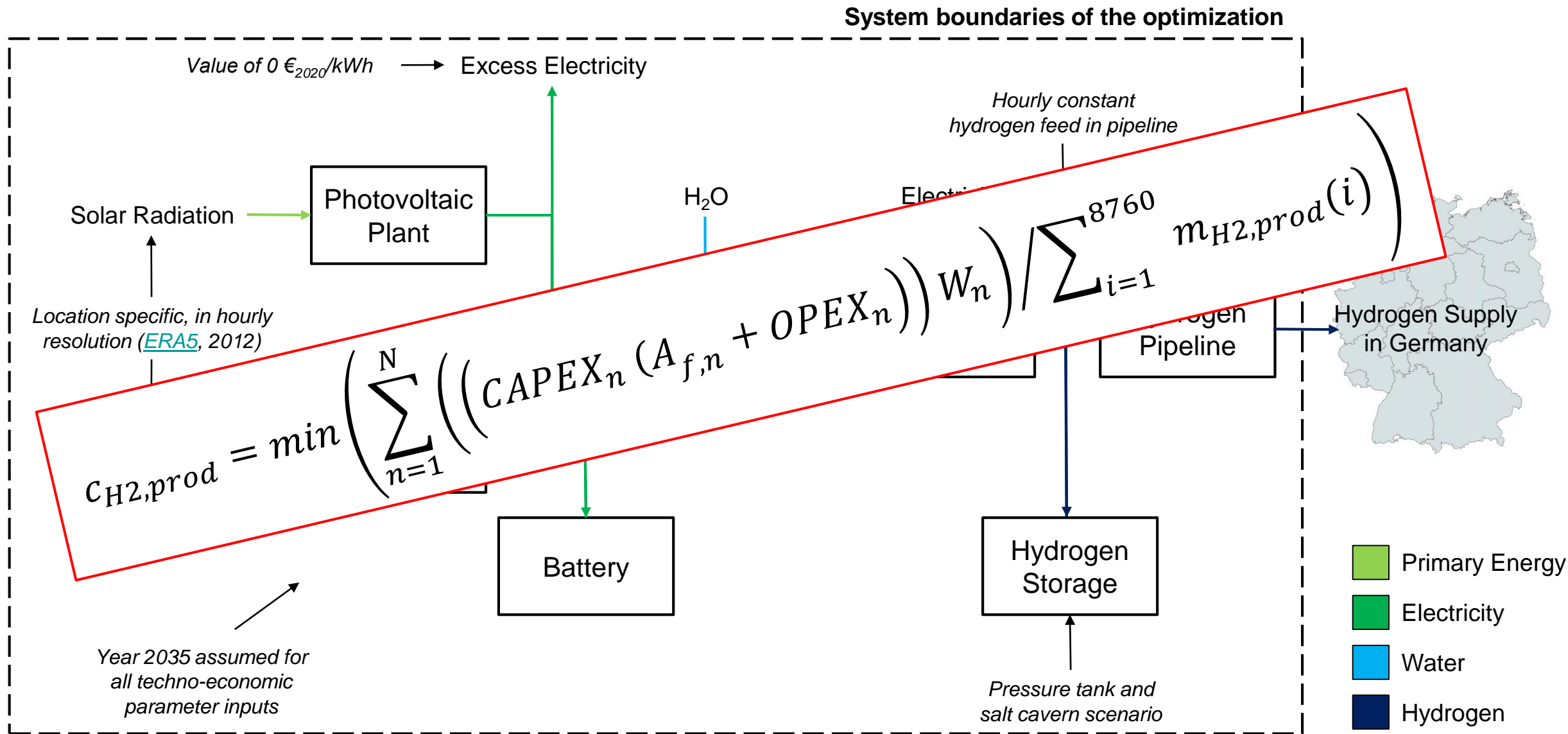


Hydrogen Production System



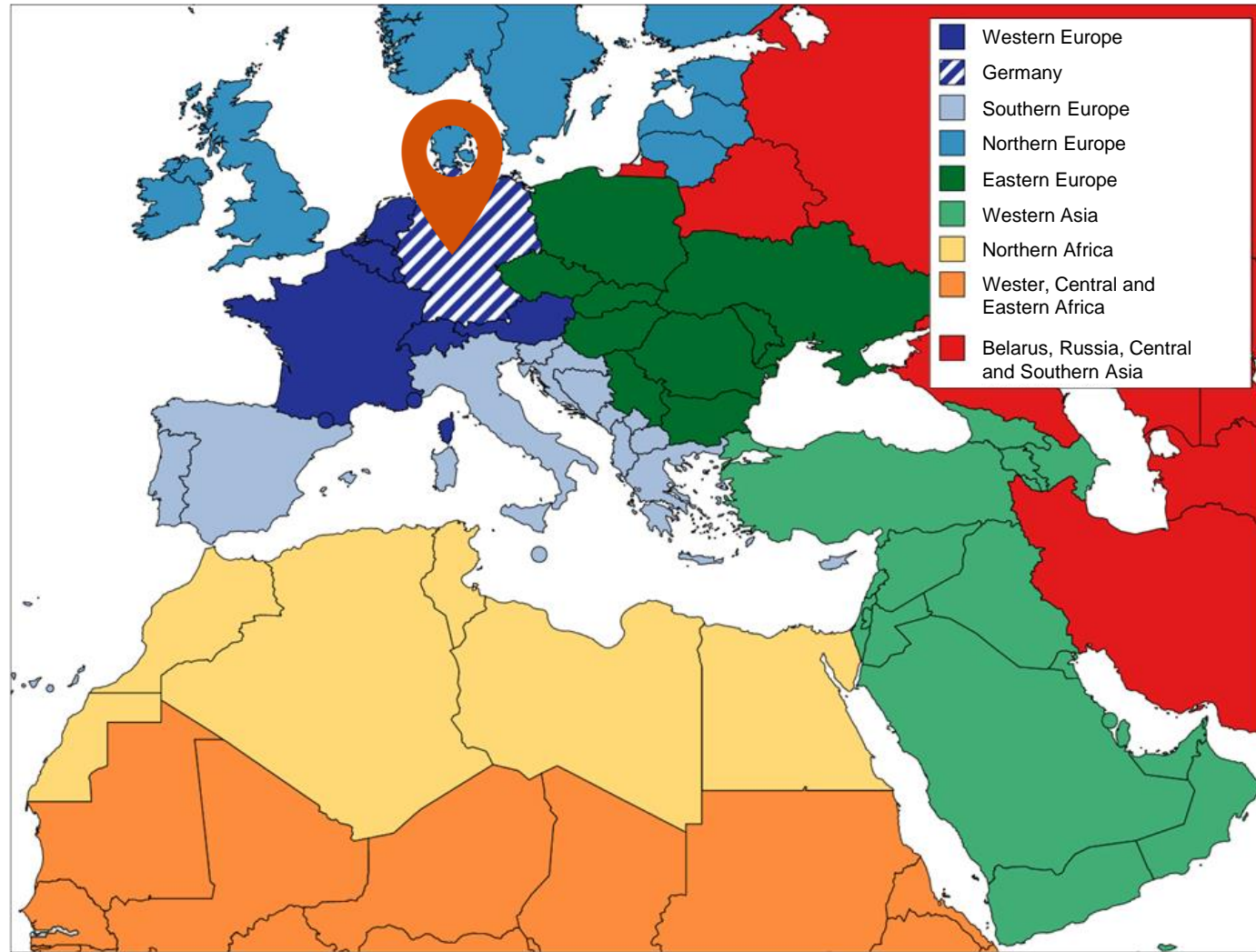


Hydrogen Production System





Catchment Area



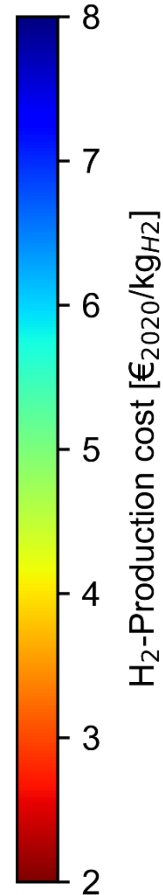
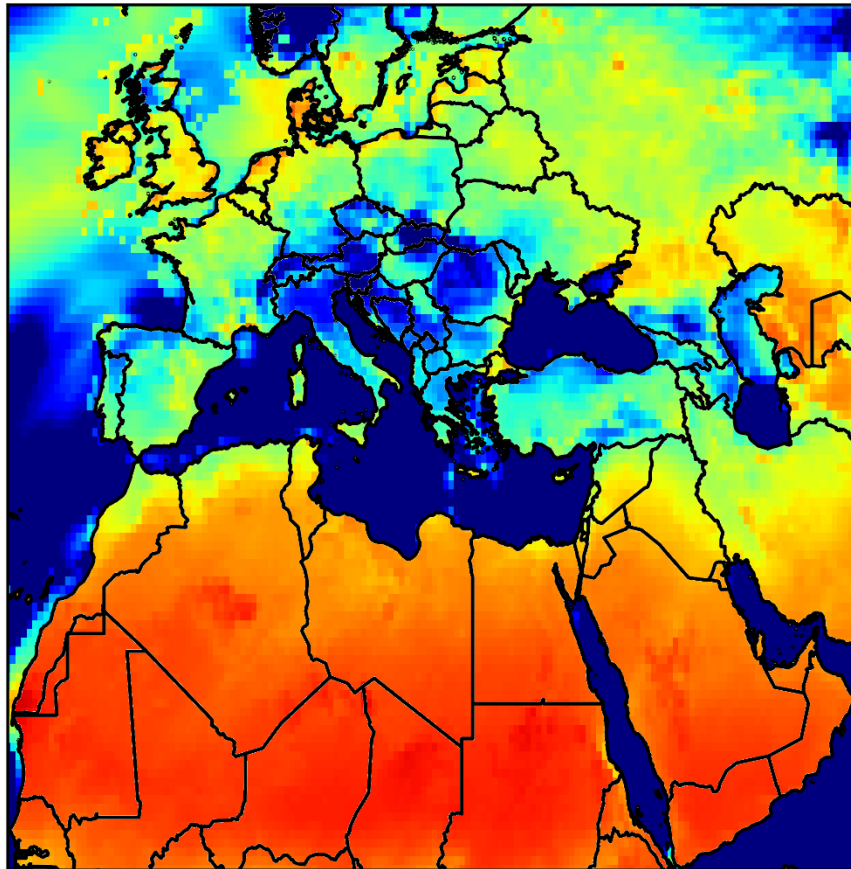


Costs and Potentials

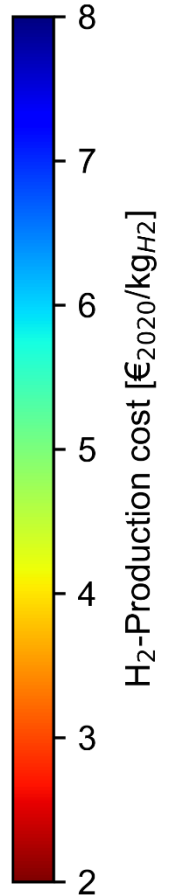
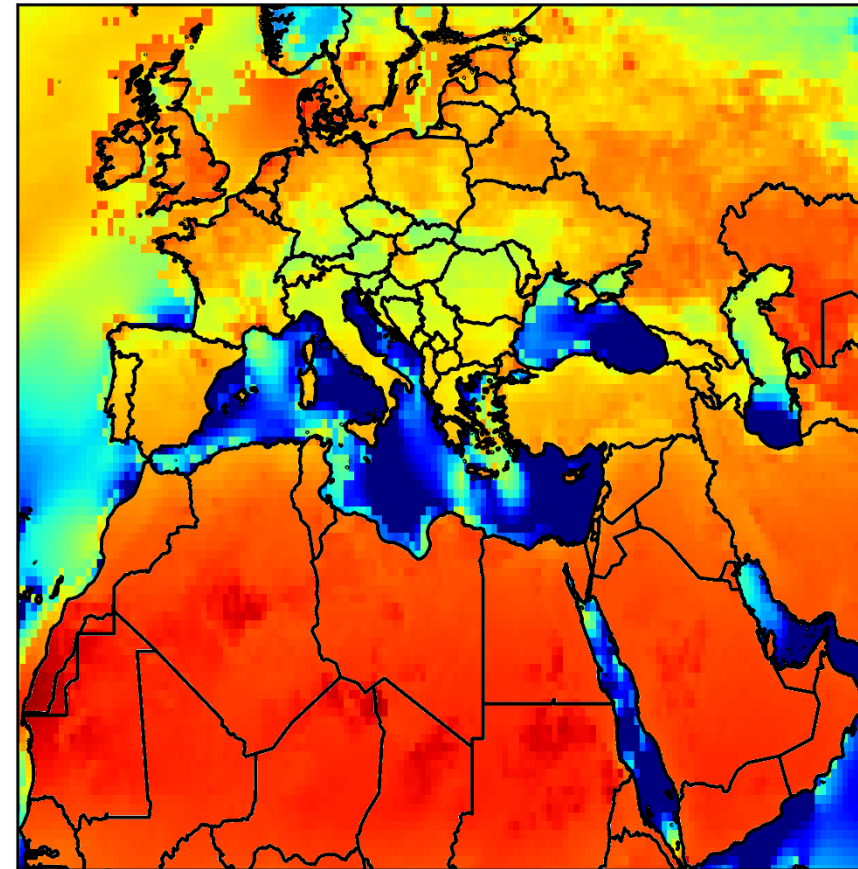
3. Results



Pressure Tank Scenario

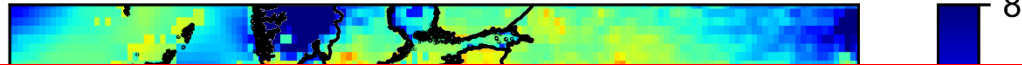


Salt Cavern Scenario





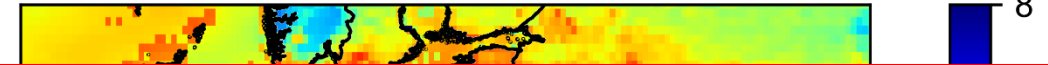
Pressure Tank Scenario



1. In the case of a **pressure tank** use:
 - Lowest hydrogen production cost reached in Africa and parts of Western Asia due to high solar radiation combined with low seasonal fluctuation leading to low needed electricity generation and storage capacities
 - Similar costs can be reached for costal locations (with high mean wind speeds) in Europe due to a hybrid photovoltaics wind power electricity generation system, covering the seasonal fluctuations of the solar radiation and wind speed each
 - In countries like Italy or Spain hydrogen production costs are relatively high due to the high seasonal fluctuation of the solar radiation, even so the LCOE of photovoltaics are low, combined with low wind speeds, leading to high electricity generation and storage capacities
2. In the case of a **salt cavern** use:
 - Hydrogen production cost decrease significantly, especially in regions with a high seasonality of the solar radiation and wind speed, due to cheaper storage possibilities and therefore less excess electricity
 - Many regions obtain low and very similar costs



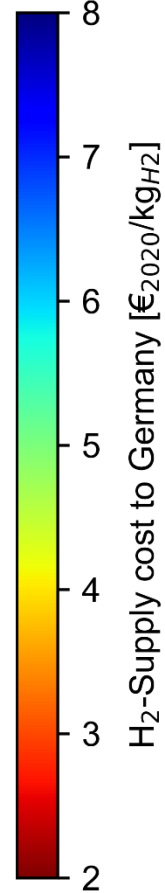
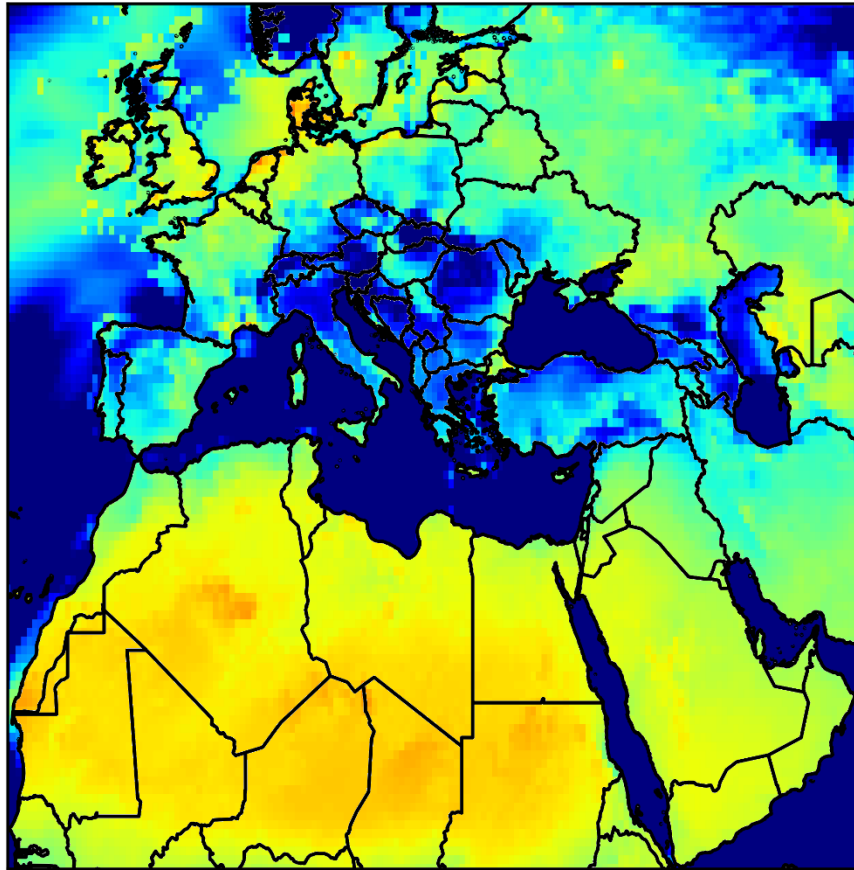
Salt Cavern Scenario



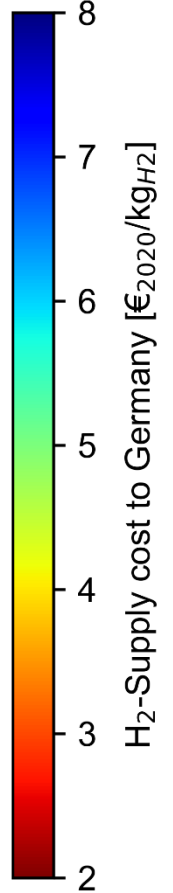
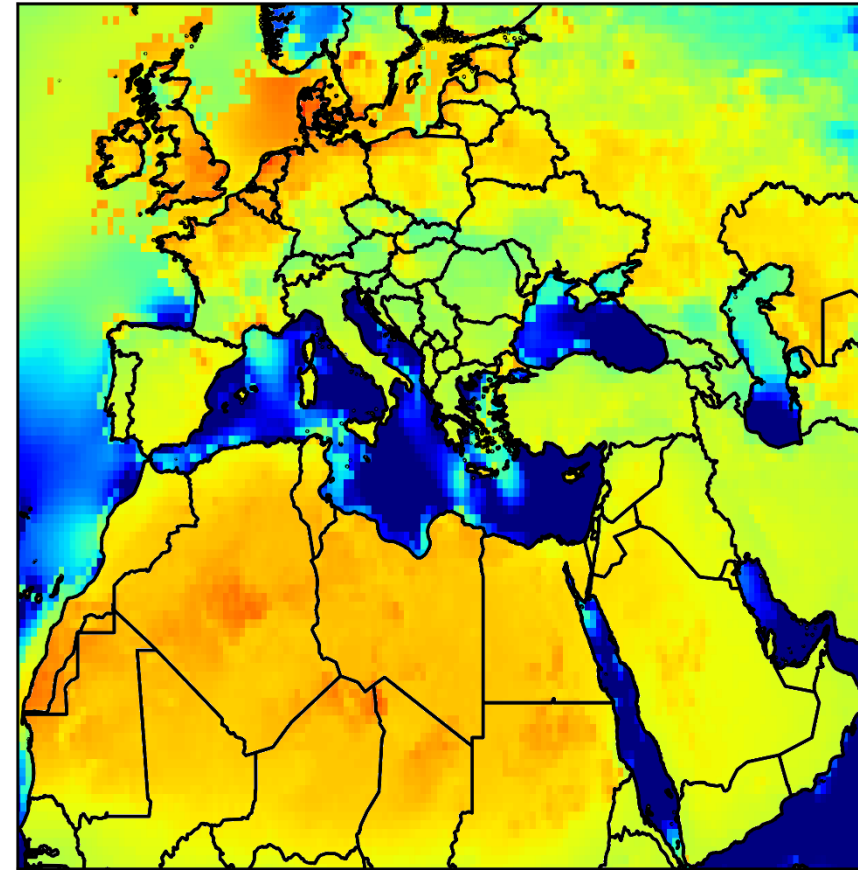


Hydrogen Supply Cost to Germany*

Pressure Tank Scenario

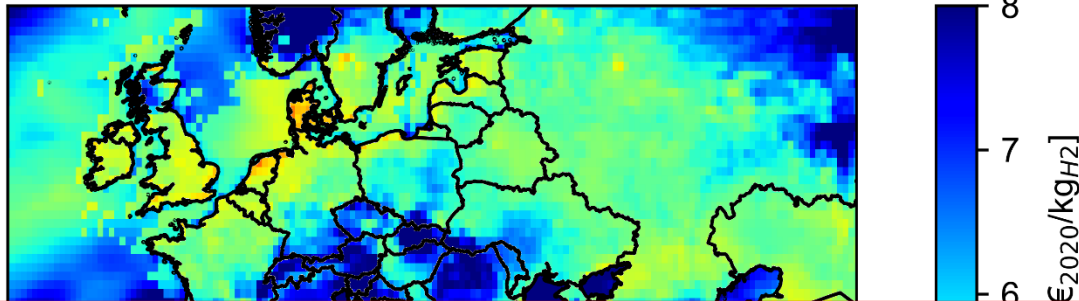


Salt Cavern Scenario

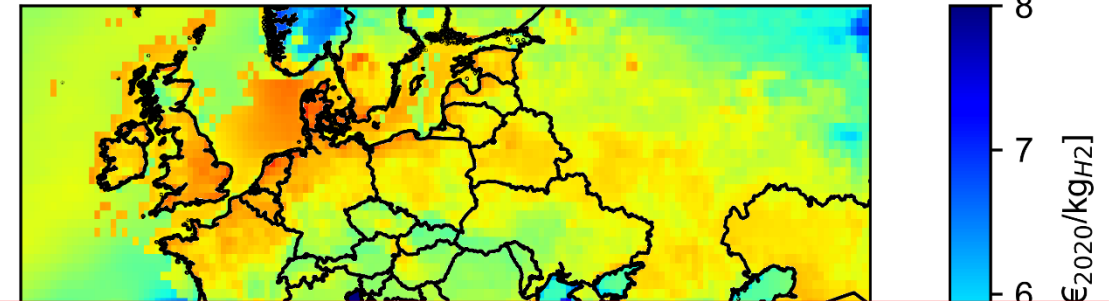




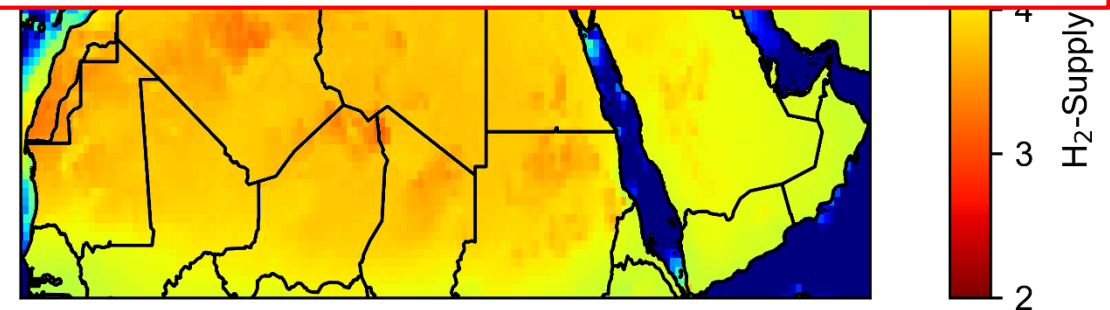
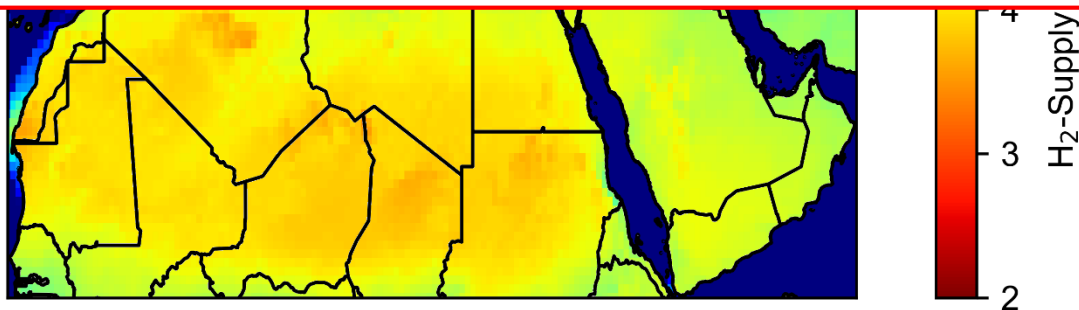
Pressure Tank Scenario



Salt Cavern Scenario

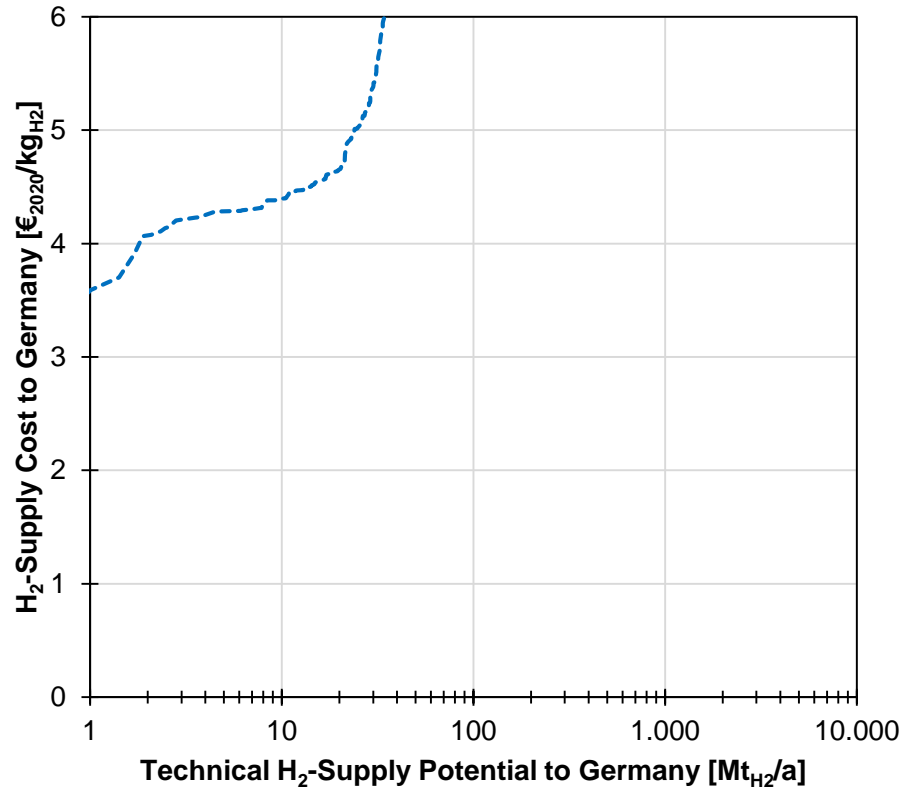


1. In the case of a **pressure tank** use, locations in Western Sahara and Algeria obtain the lowest hydrogen supply cost to Germany. In Europe only costal locations around the North Sea reach similar cost level.
2. For the use of **salt caverns** the hydrogen supply costs to Germany are for many costal locations in Northern Europe (including offshore locations in the North Sea) at the same cost level as the best locations in Africa.

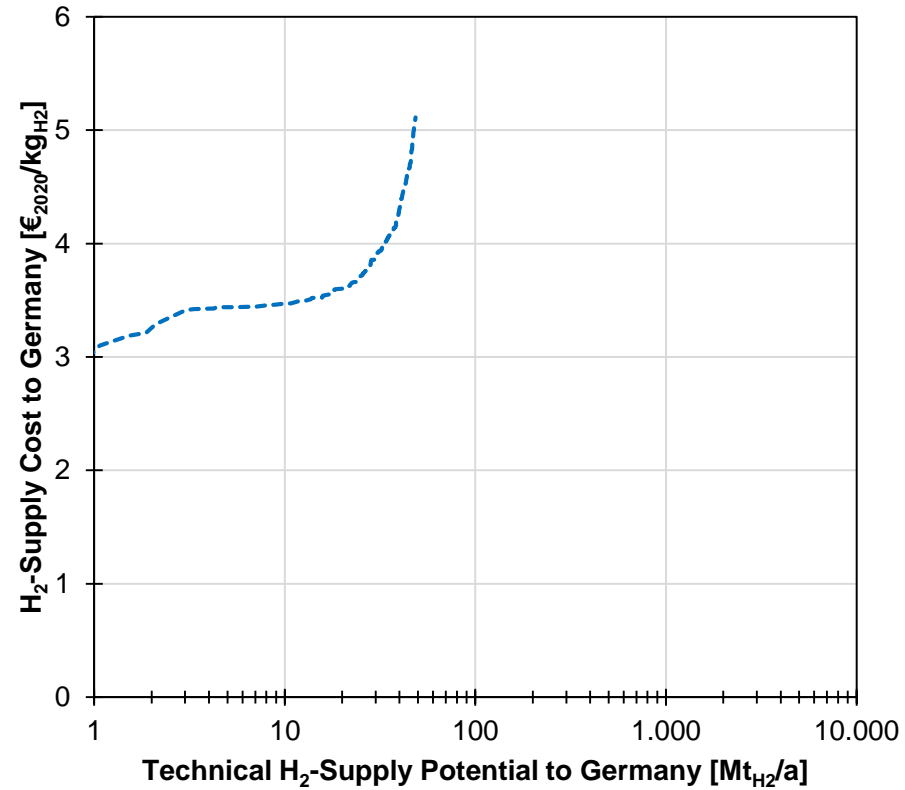




Pressure Tank Scenario



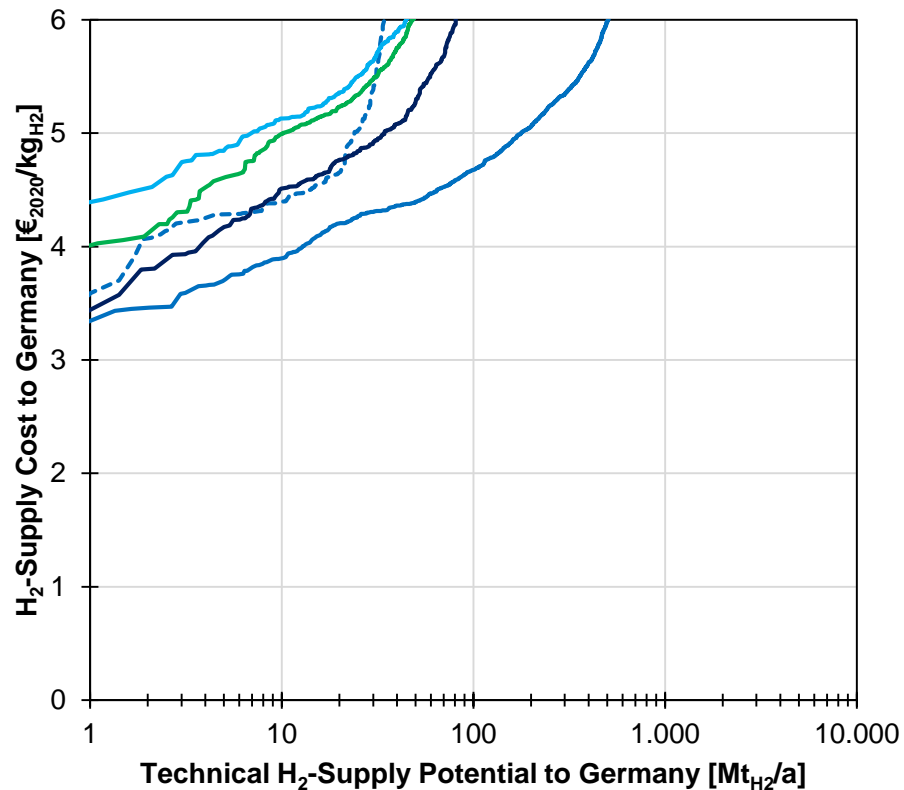
Salt Cavern Scenario



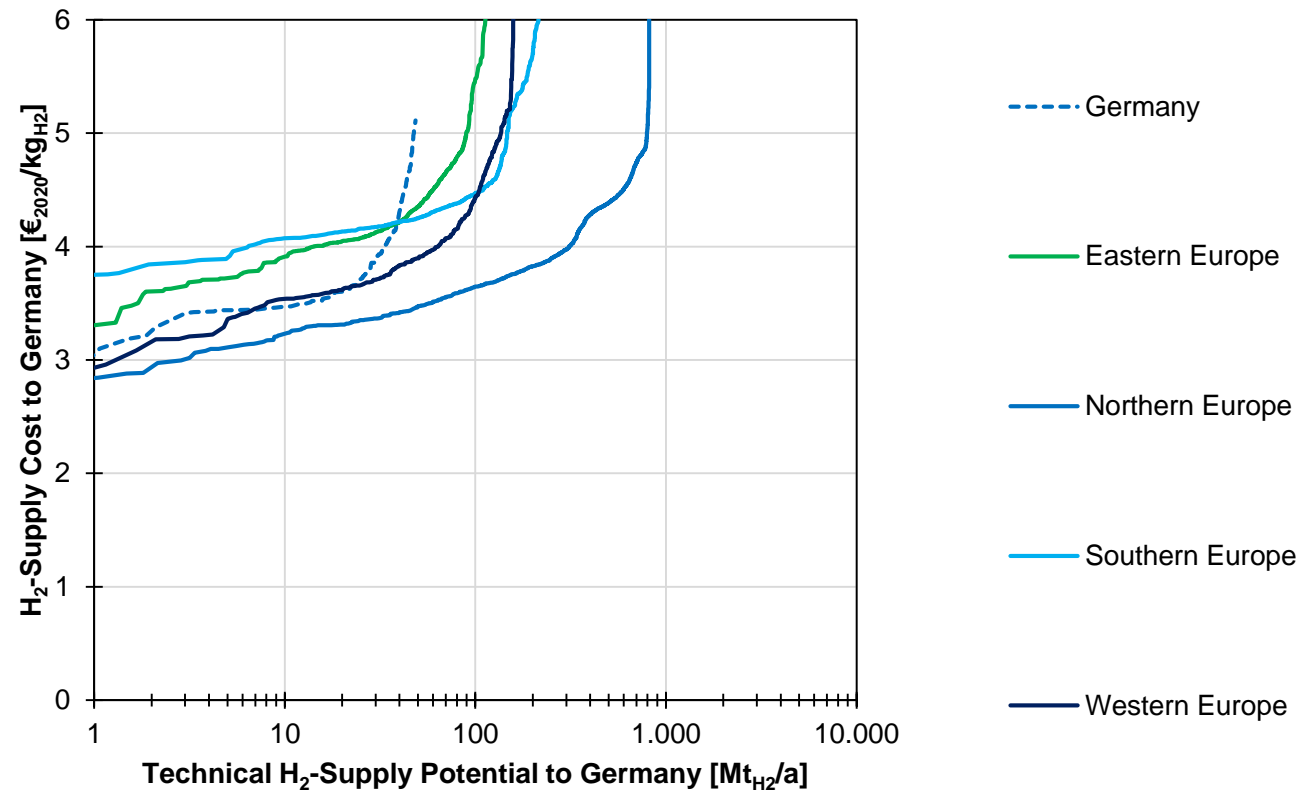
--- Germany



Pressure Tank Scenario

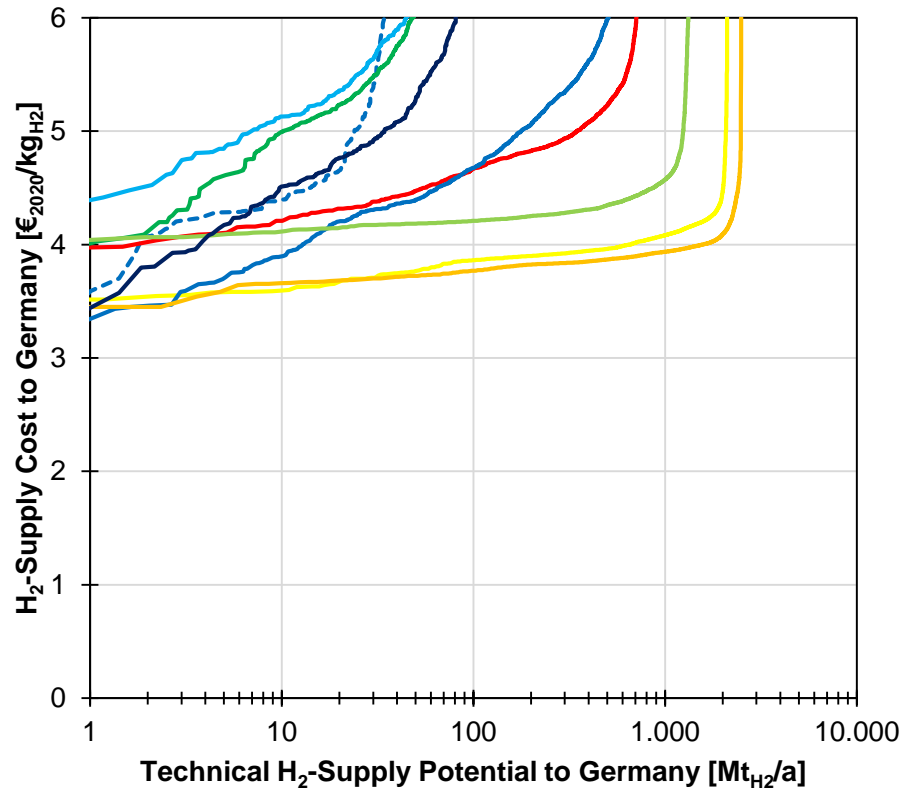


Salt Cavern Scenario

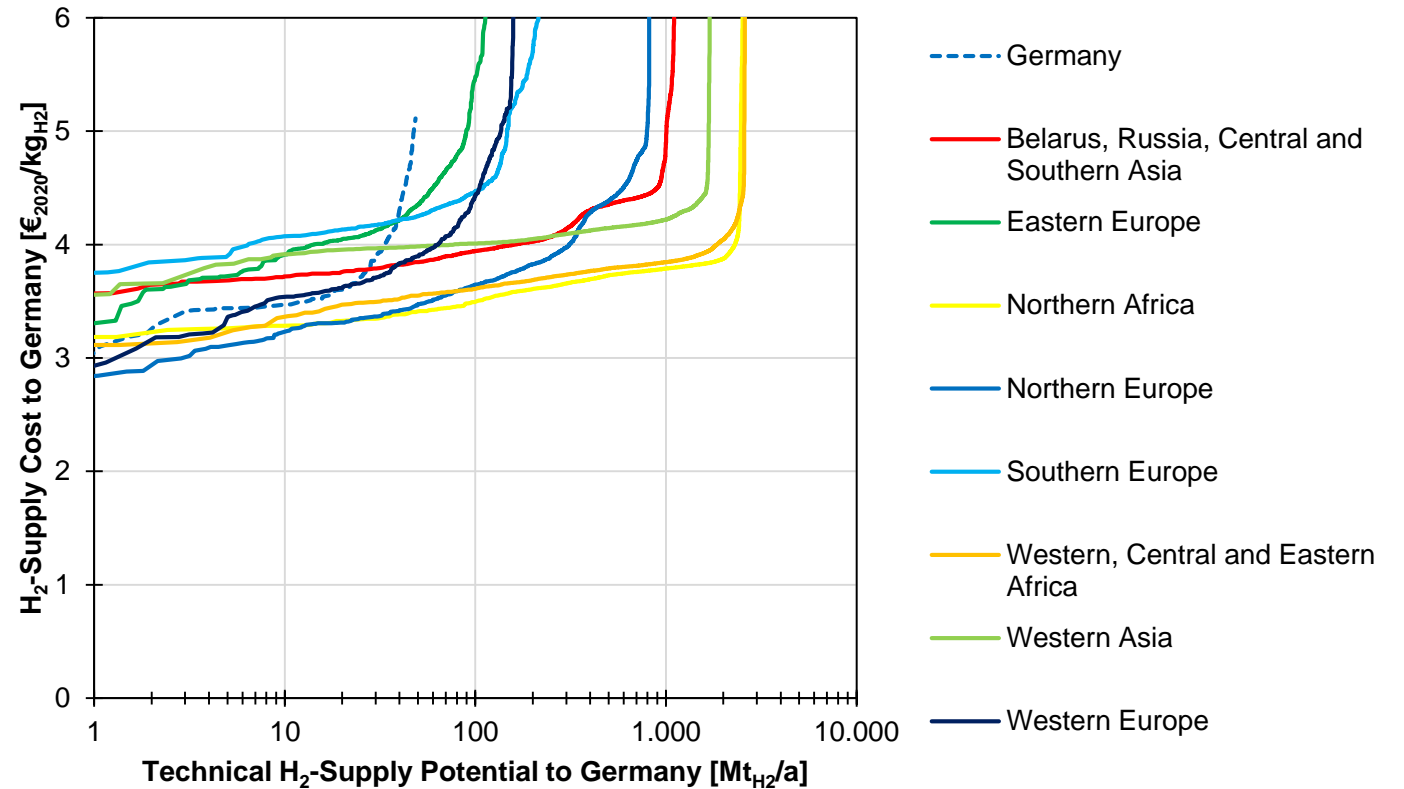




Pressure Tank Scenario



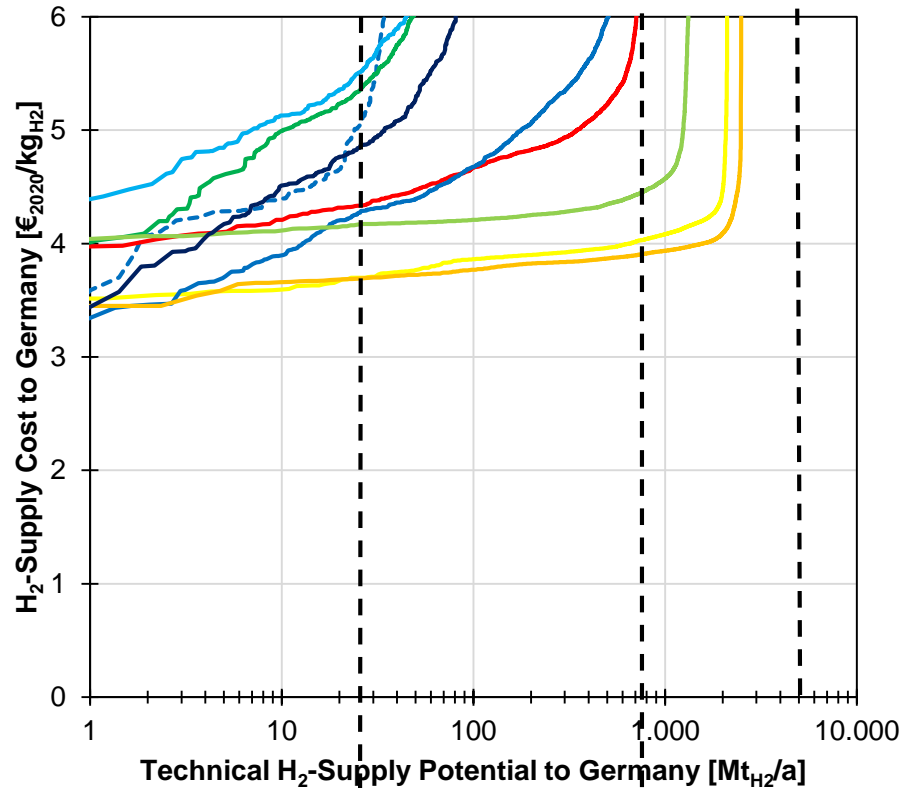
Salt Cavern Scenario





Pressure Tank Scenario

Primary energy demand worldwide in 2021

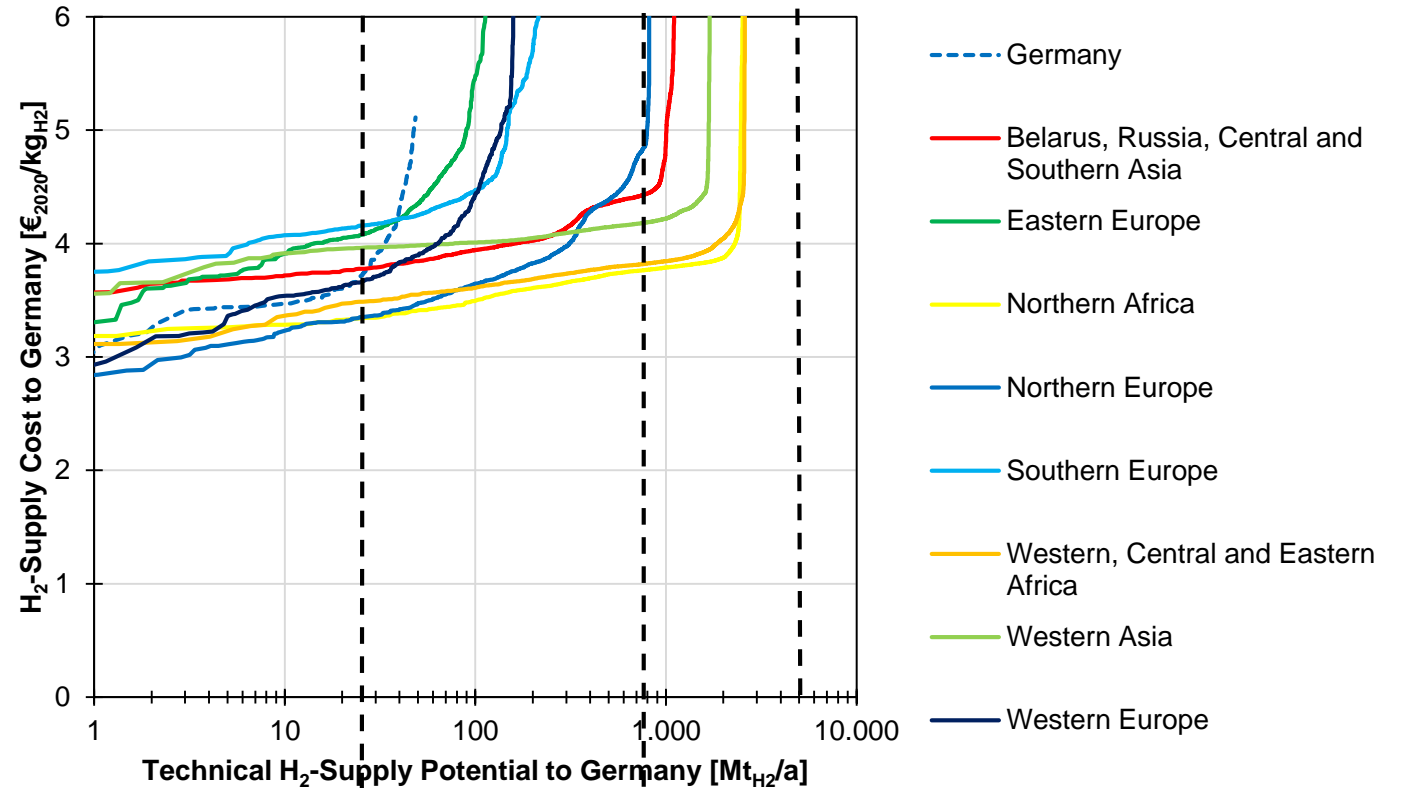


Max. projected hydrogen demand in Germany in 2050

Max. projected hydrogen demand worldwide in 2050

Salt Cavern Scenario

Primary energy demand worldwide in 2021



Max. projected hydrogen demand in Germany in 2050

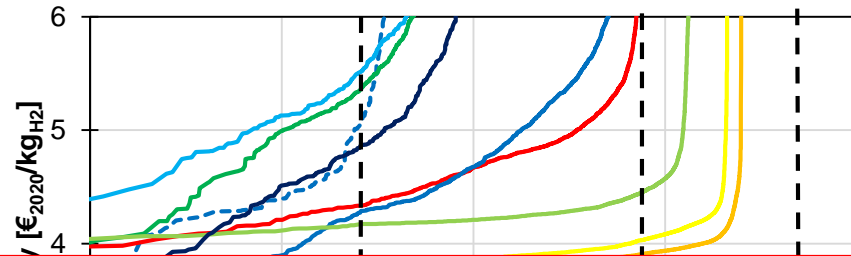
Max. projected hydrogen demand worldwide in 2050

- Germany
- Belarus, Russia, Central and Southern Asia
- Eastern Europe
- Northern Africa
- Northern Europe
- Southern Europe
- Western, Central and Eastern Africa
- Western Asia
- Western Europe



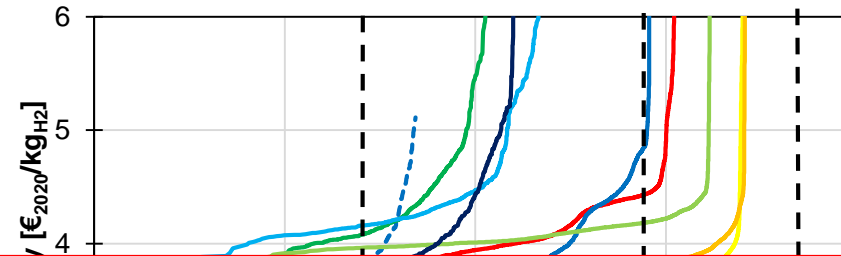
Pressure Tank Scenario

Primary energy demand worldwide in 2021



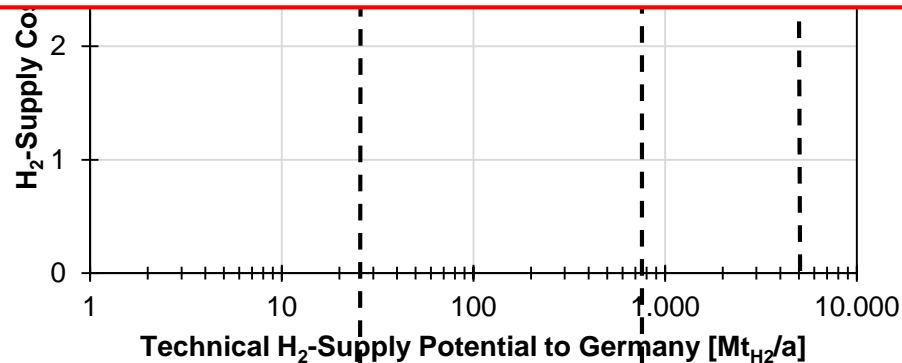
Salt Cavern Scenario

Primary energy demand worldwide in 2021



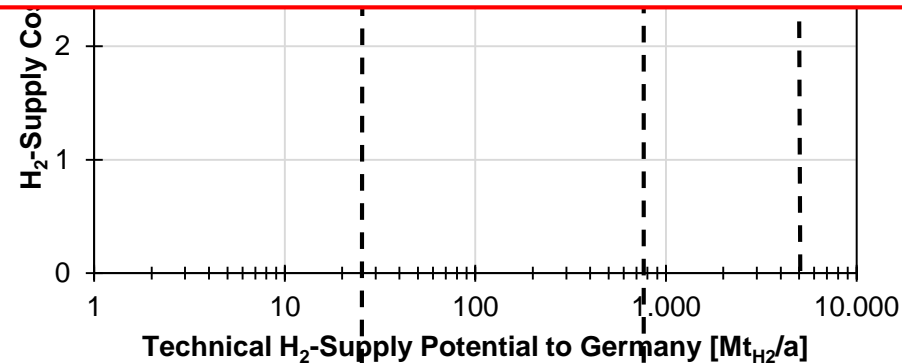
- Germany
- Belarus, Russia, Central and Southern Asia
- Eastern Europe

Assuming additional space demand for further technologies (e.g. domestic electricity power generation for direct use) the sustainable hydrogen supply potential in Germany seems to be not self sufficient. However, additional hydrogen imports at low costs could be even realized from other European regions.



Max. projected hydrogen demand in Germany in 2050

Max. projected hydrogen demand worldwide in 2050



Max. projected hydrogen demand in Germany in 2050

Max. projected hydrogen demand worldwide in 2050



4. Key Conclusions



1. Are hydrogen costs below $2 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ realistic in the future?
 - Hydrogen production cost of $2 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ can be reached in the best locations (e.g. Western Sahara) in 2035. However, taking a subsequent transport to Germany into account costs are at likely to be around $3 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$
2. Which regions are most favorable for a hydrogen supply to Germany?
 - Locations in **Western Sahara**, **Central Algeria** and at the **North Sea** (Onshore and Offshore) show the lowest hydrogen supply costs to Germany
3. What is the influence of the implementation of salt caverns as a hydrogen storage?
 - The use of salt caverns leads especially in regions with a high seasonality of the solar radiation and low wind speeds (e.g. Italy) to a significant **reduction** of the hydrogen production costs up to **50%**
4. Is the domestic production potential enough for a self-sufficient hydrogen supply in Germany?
 - Considering the demand for the “additional” direct electricity use a self-sufficient hydrogen supply in Germany seems **questionable** and **imports are likely**

Thank you for your Attention!

Questions and Discussion

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