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ORCID: https://orcid.org/0000-0001-6300-4218

TUHH IUE

The Dawn of the Hydrogen Economy? – Recent Developments and Activities
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Cost Optimized Hydrogen Production by Wind Power & Photovoltaics

– Cost & Potential in the European Catchment Area –

Lucas Sens, Martin Kaltschmitt

[1] [2] [3] [4] [5] [6]

Hamburg University of Technology (TUHH), Institute of Environmental Technology and Energy Economics (IUE)

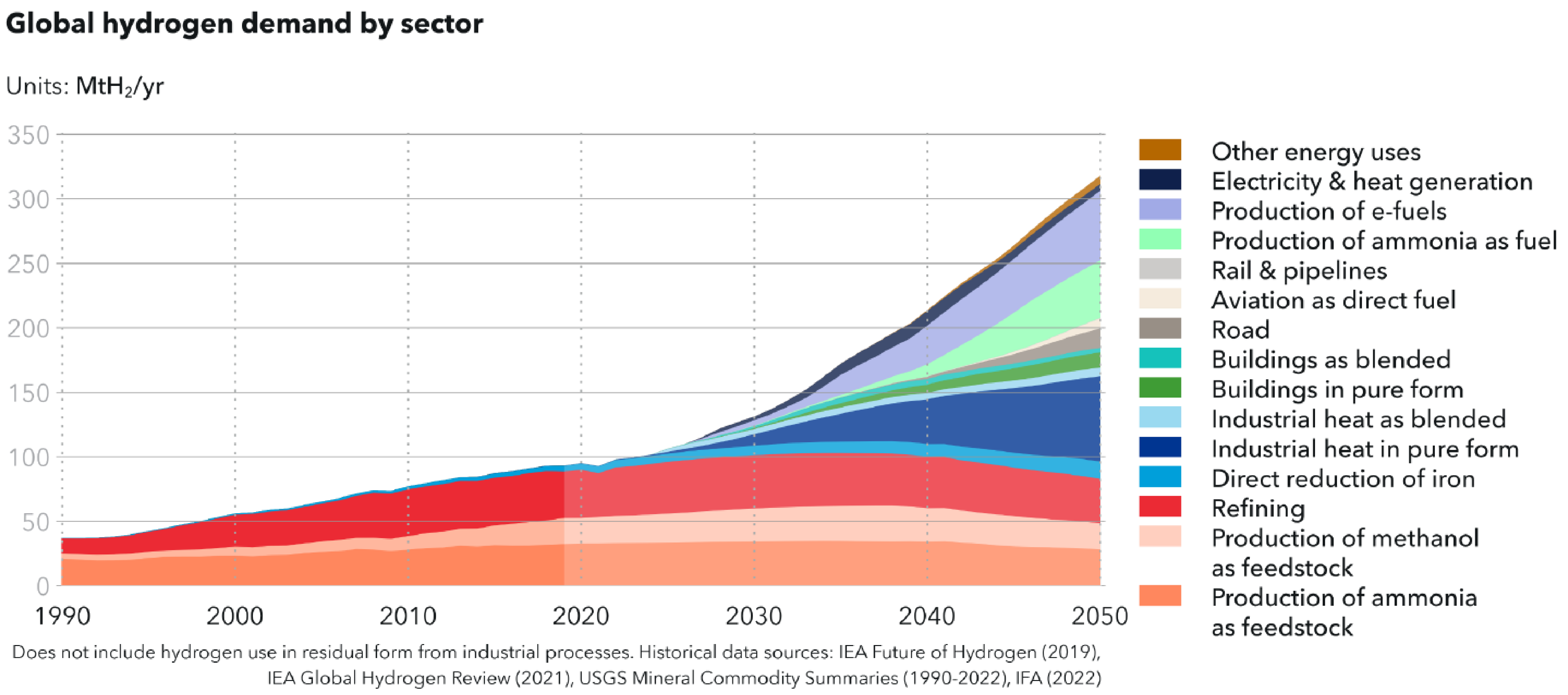
Outline

1. Background
2. System Definition
3. Results
4. Key Conclusions

Green hydrogen in a future energy system

1. Background

Hydrogen Demand Projections



Source: DNV 2022

Research Questions

1. Are hydrogen costs below 2 $€_{2020}/kg_{H2}$ realistic in the future?

2. Which regions are most favorable for a hydrogen supply to Germany?

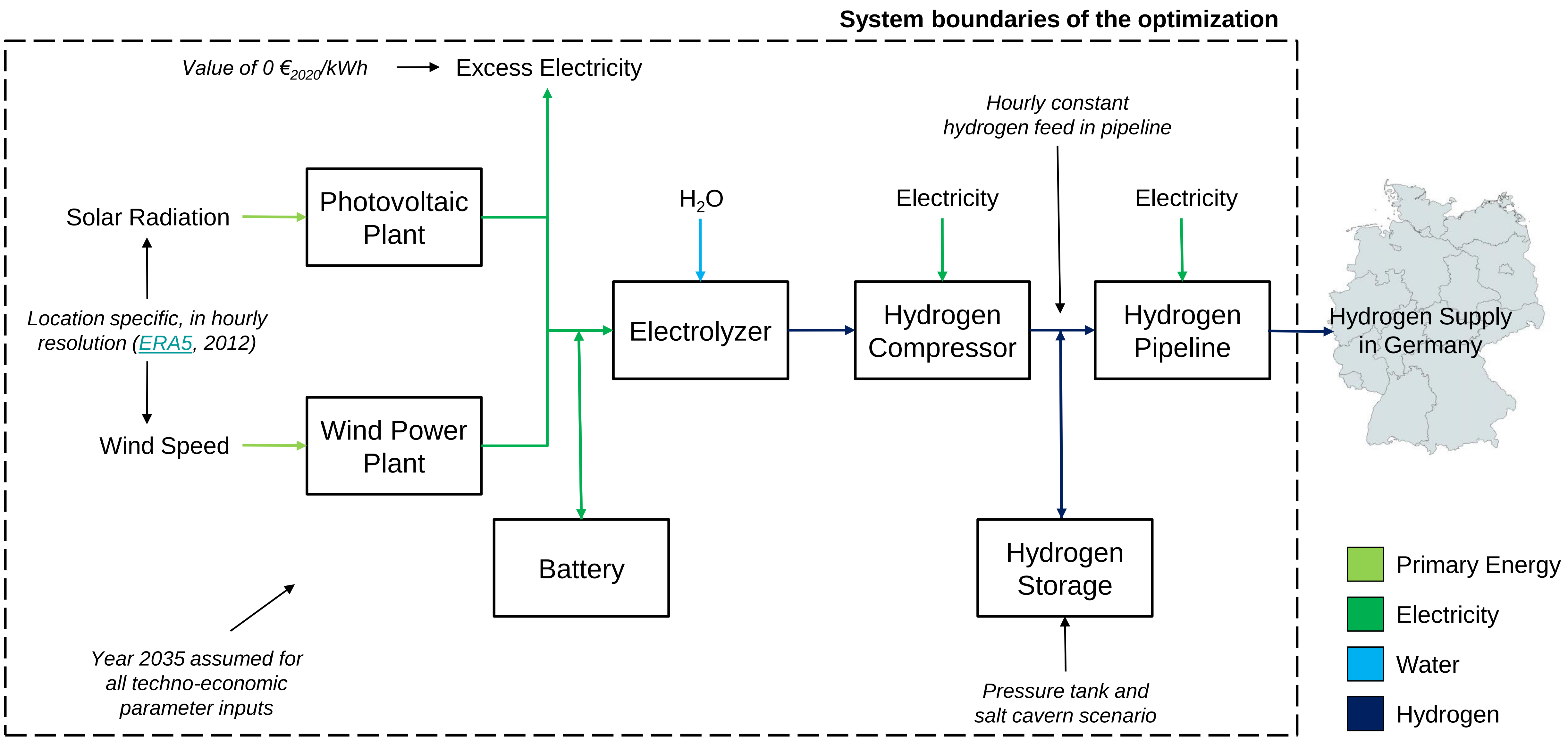
3. What is the influence of the implementation of salt caverns as a hydrogen storage?

4. Is the domestic production potential enough for a self-sufficient hydrogen supply in Germany?

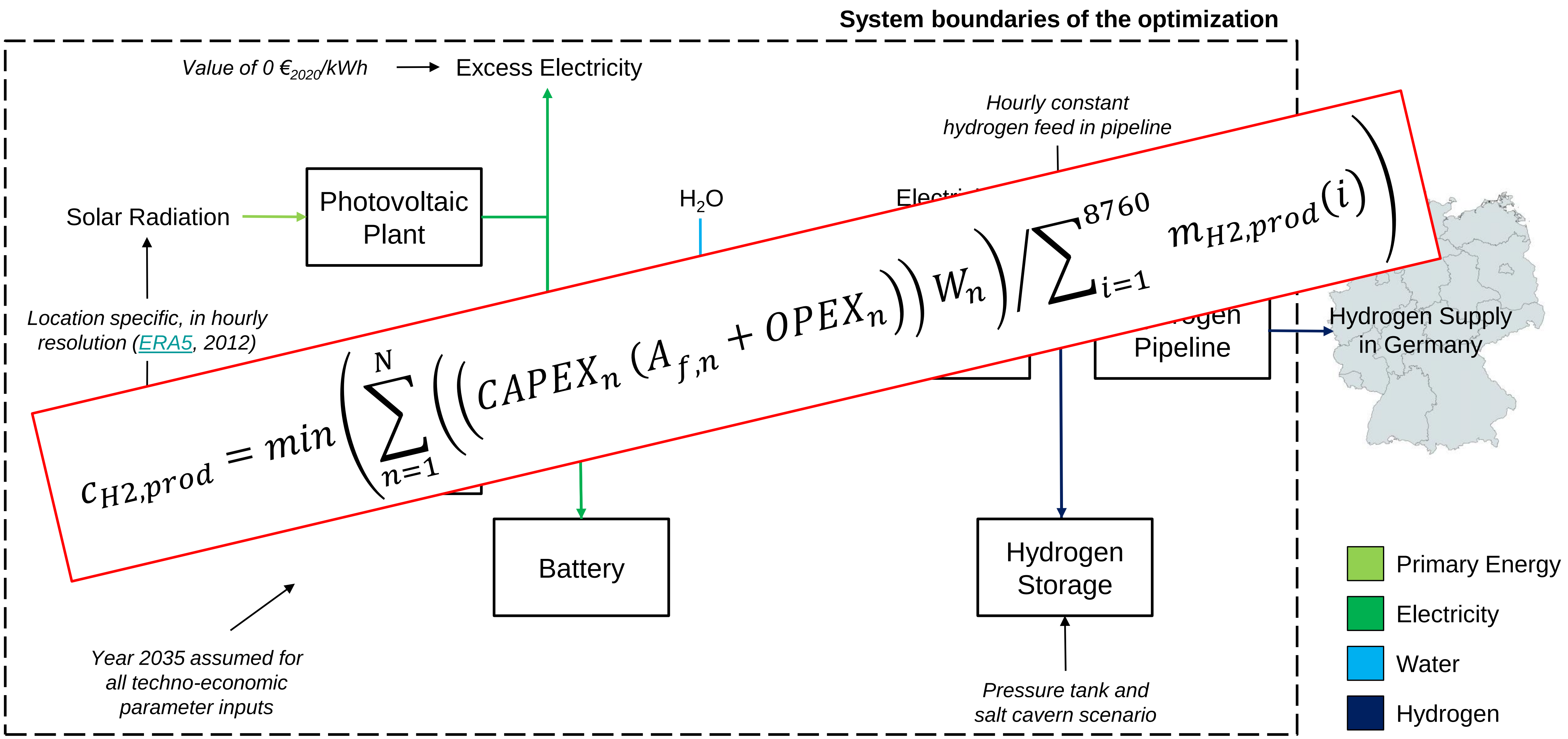
Modelling & Assumptions

2. System Definition

Hydrogen Production System

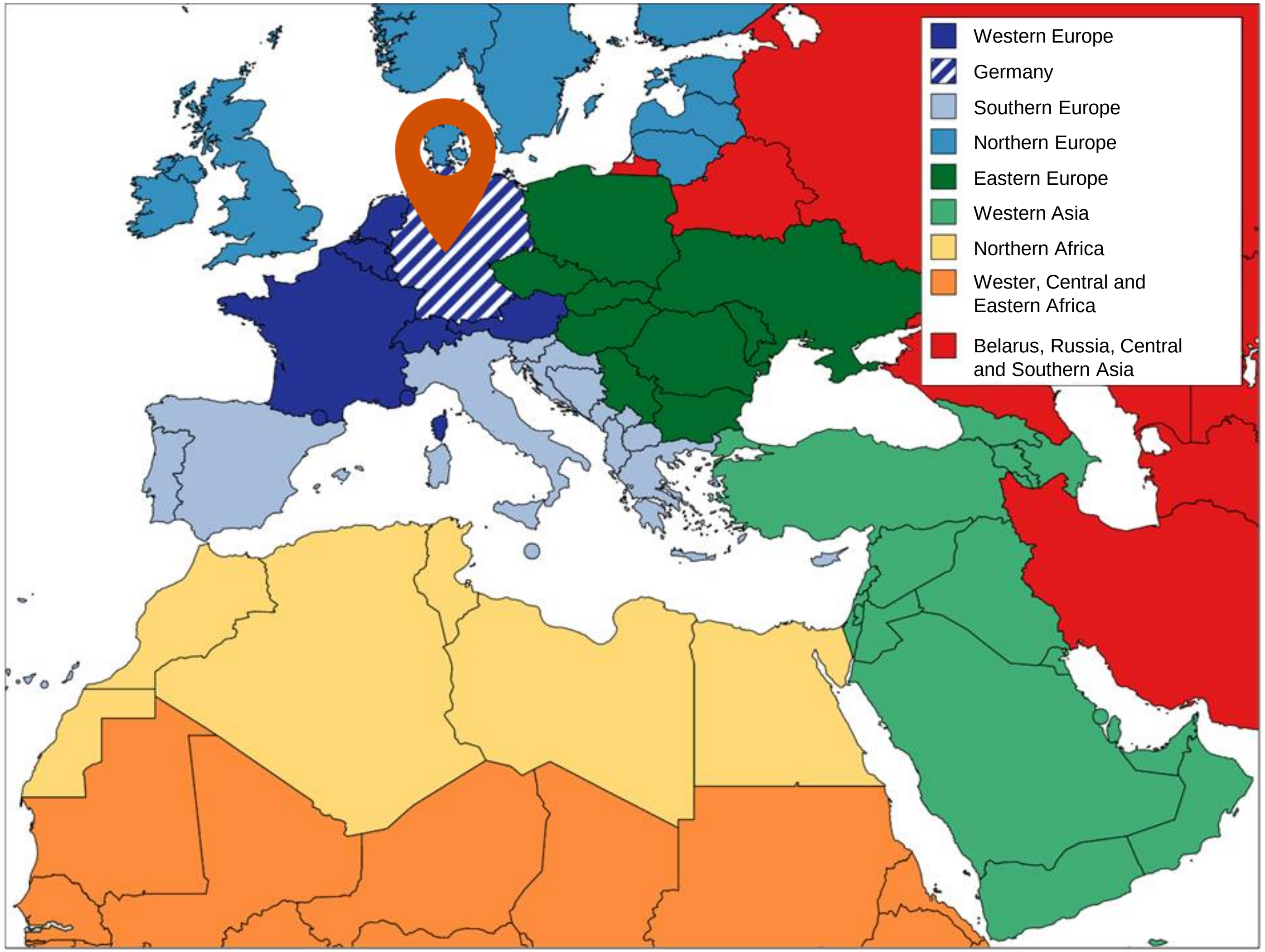


Hydrogen Production System



$$c_{H2,prod} = min\left(\sum_{n=1}^{N}\left(\left(CAPEX_n\left(A_{f,n} + OPEX_n\right)\right)W_n\right) / \sum_{i=1}^{8760} m_{H2,prod}(i)\right)$$

Catchment Area

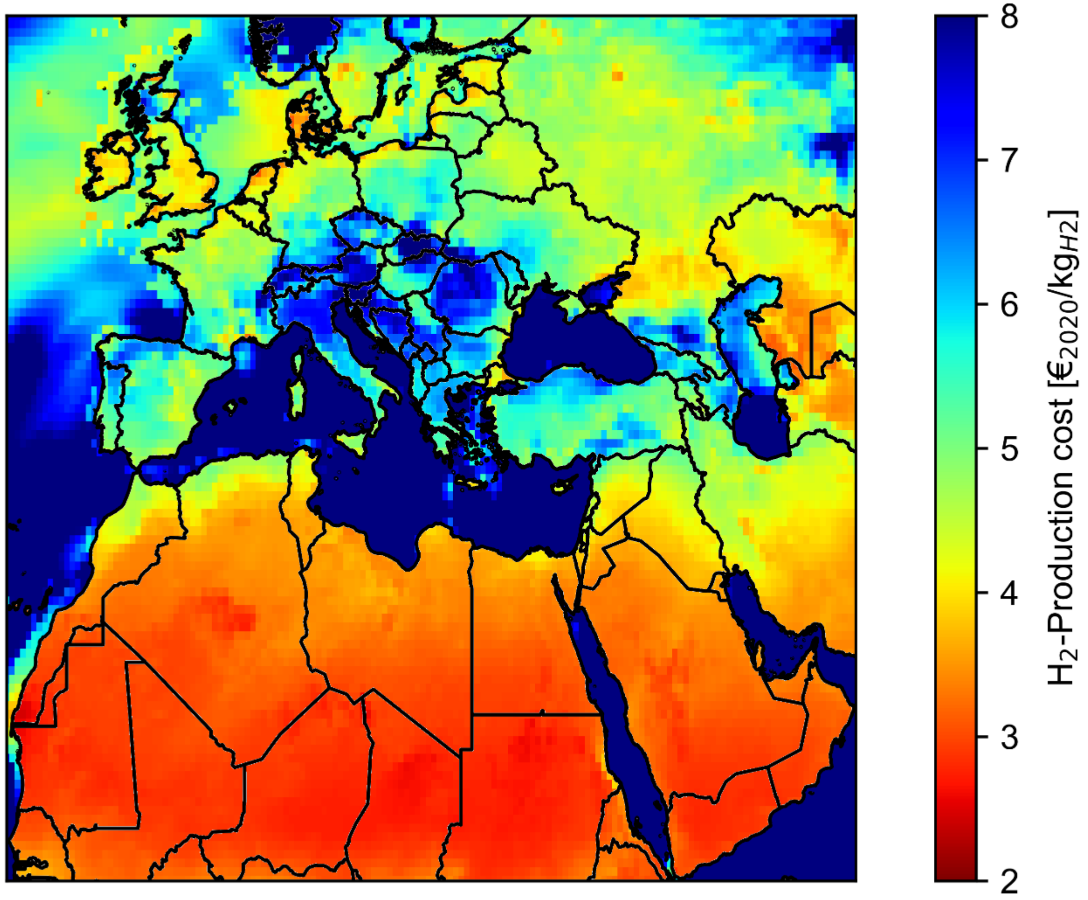


Costs and Potentials

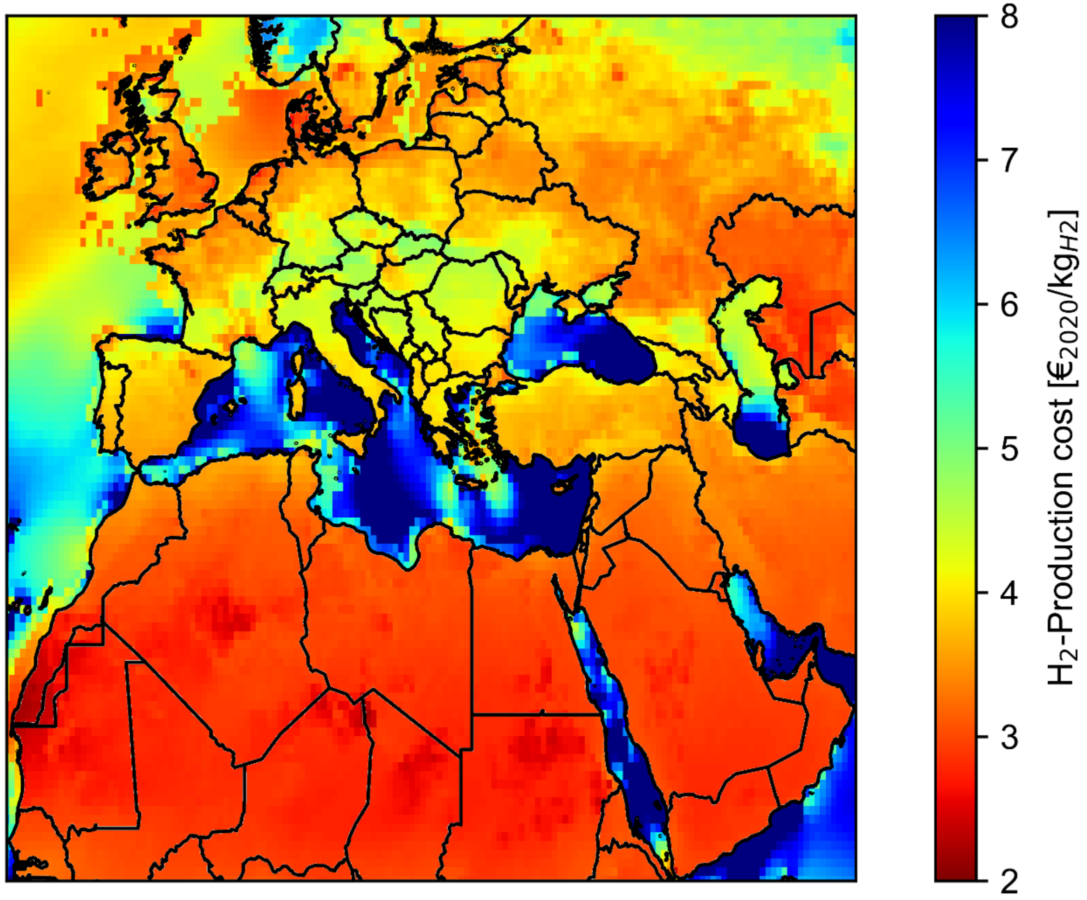
3. Results

Hydrogen Production Cost*

Pressure Tank Scenario



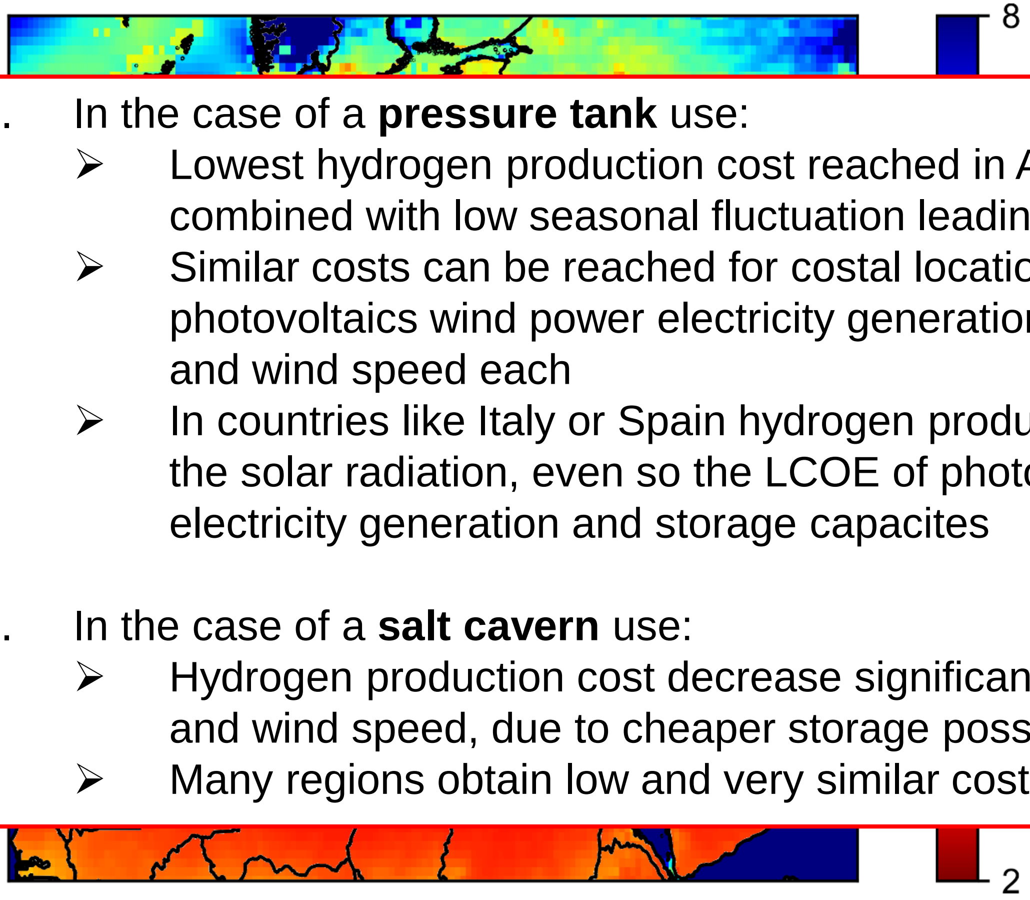
Salt Cavern Scenario



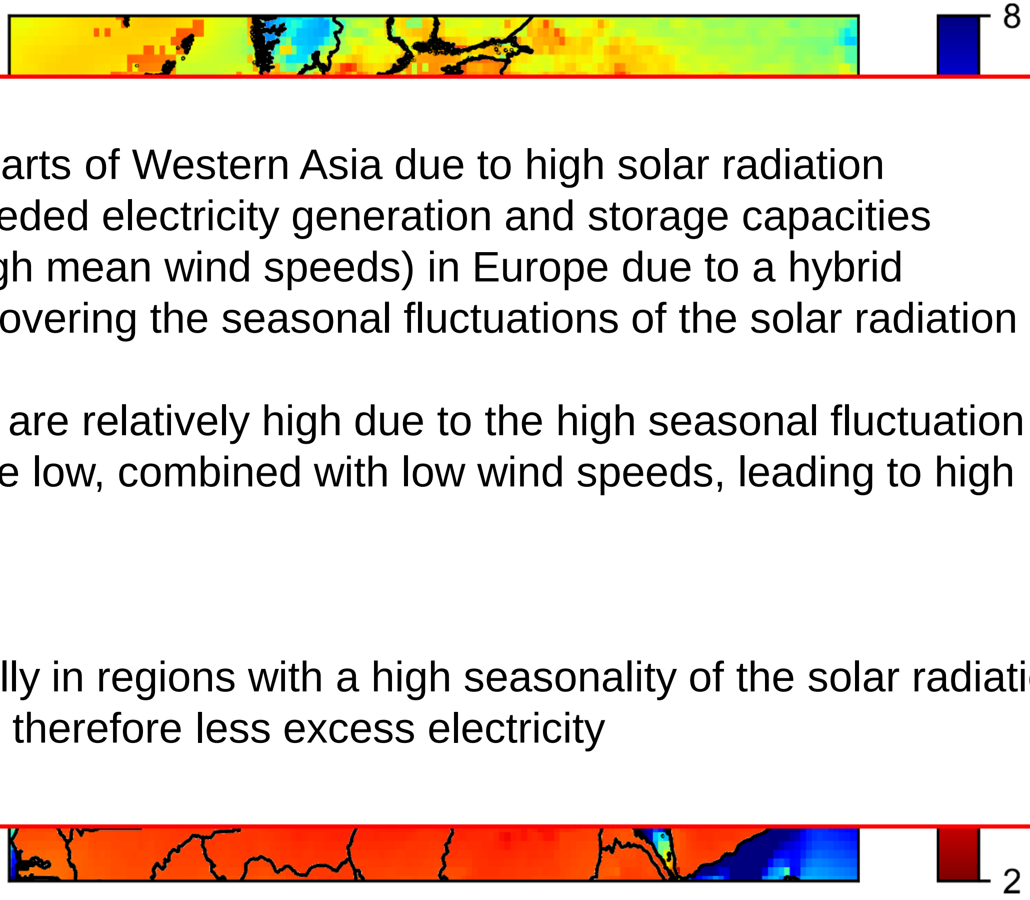
Based on: Sens et al. 2022; *includes the costs for the electricity generation, electrolyzer, compressor and storage systems for a hourly constant onsite hydrogen supply

Hydrogen Production Cost*

Pressure Tank Scenario



Salt Cavern Scenario



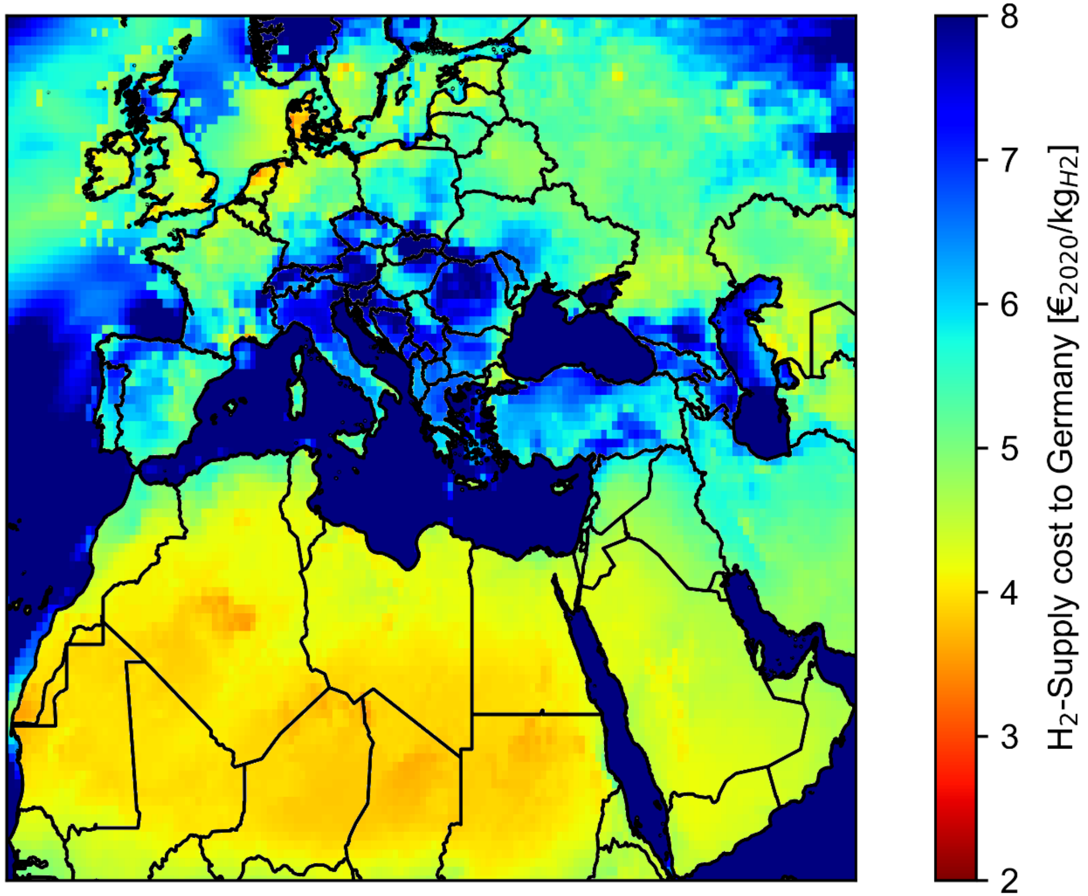
1. In the case of a **pressure tank** use:
   - ➢ Lowest hydrogen production cost reached in Africa and parts of Western Asia due to high solar radiation combined with low seasonal fluctuation leading to low needed electricity generation and storage capacities
   - ➢ Similar costs can be reached for 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 capacites

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

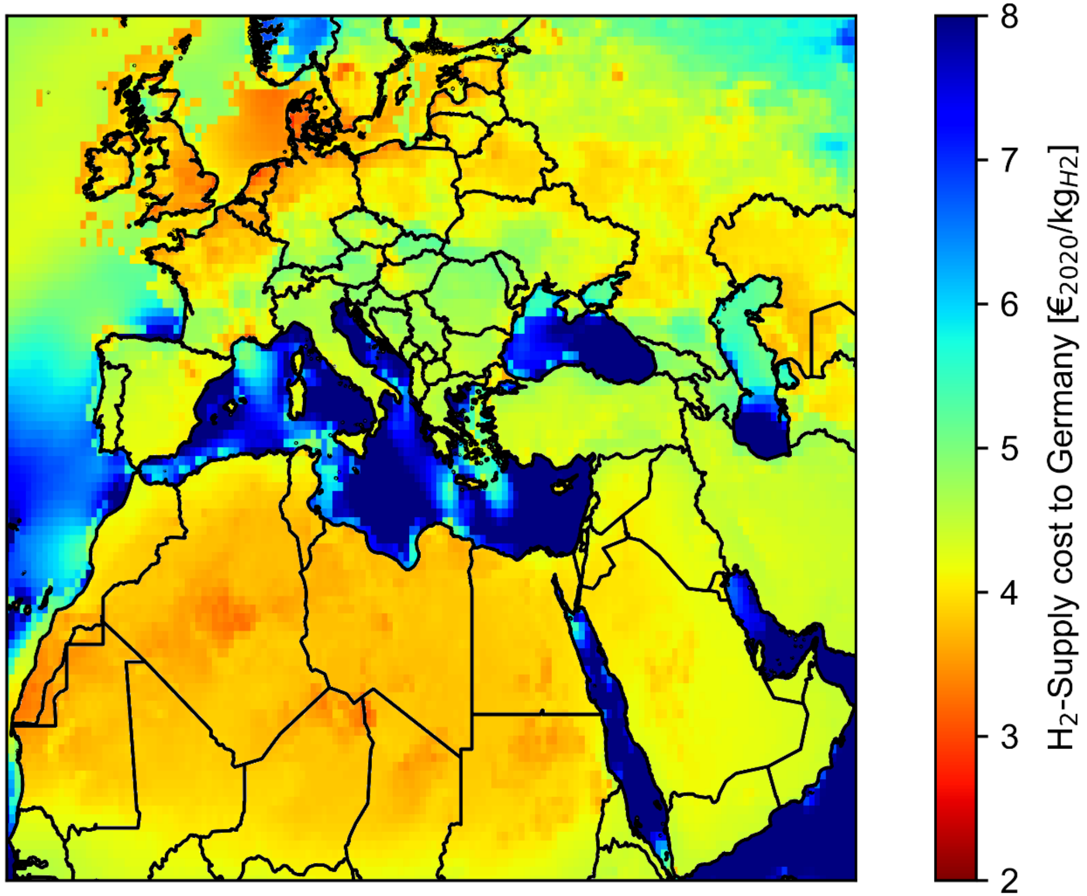
Based on: Sens et al. 2022; *includes the costs for the electricity generation, electrolyzer, compressor and storage systems for a hourly constant onsite hydrogen supply

Hydrogen Supply Cost to Germany*

Pressure Tank Scenario



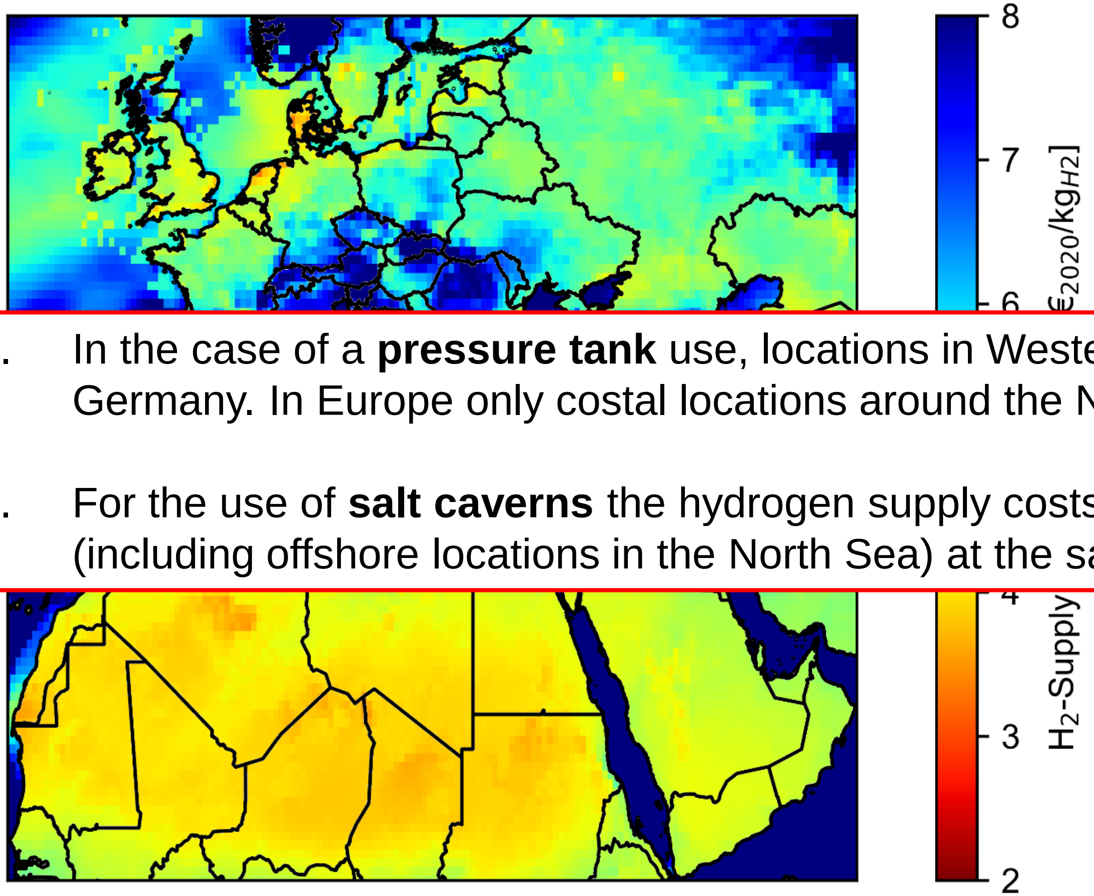
Salt Cavern Scenario



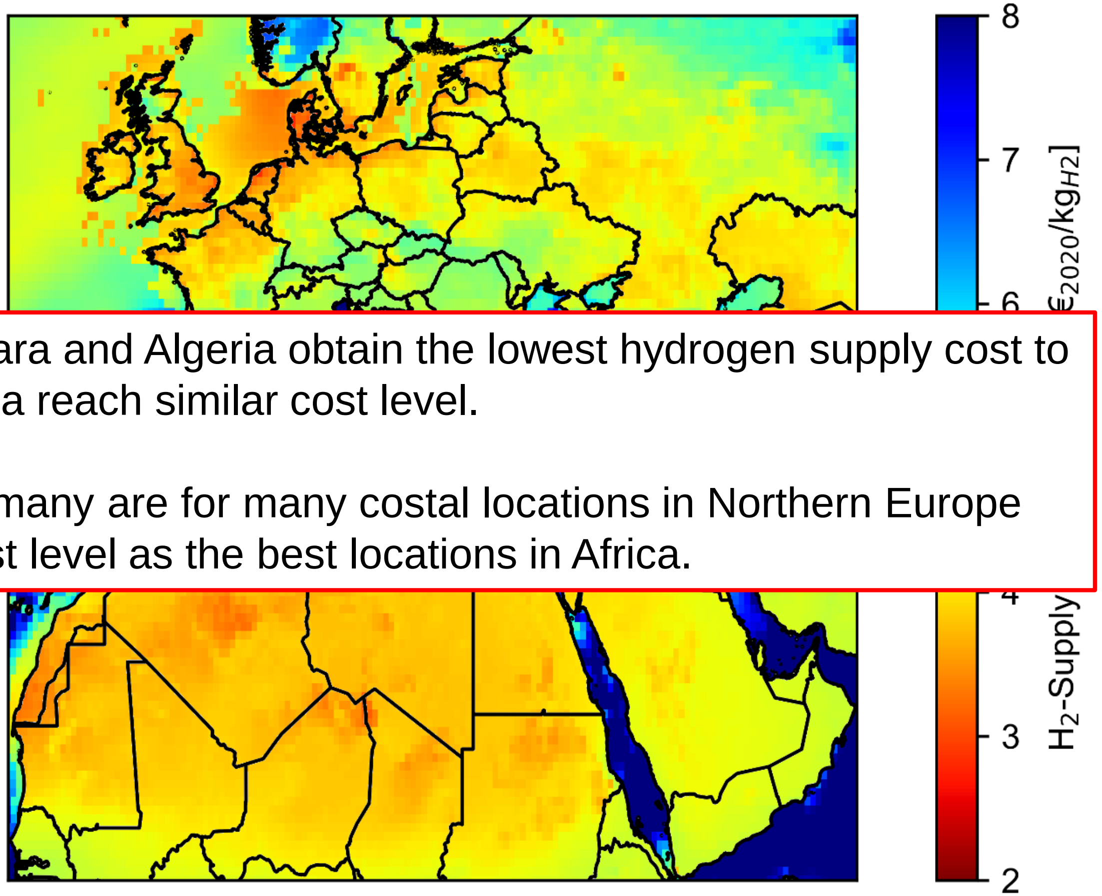
Based on: Sens et al. 2022; *includes the hydrogen production and transportation costs per pipeline

Hydrogen Supply Cost to Germany*

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.

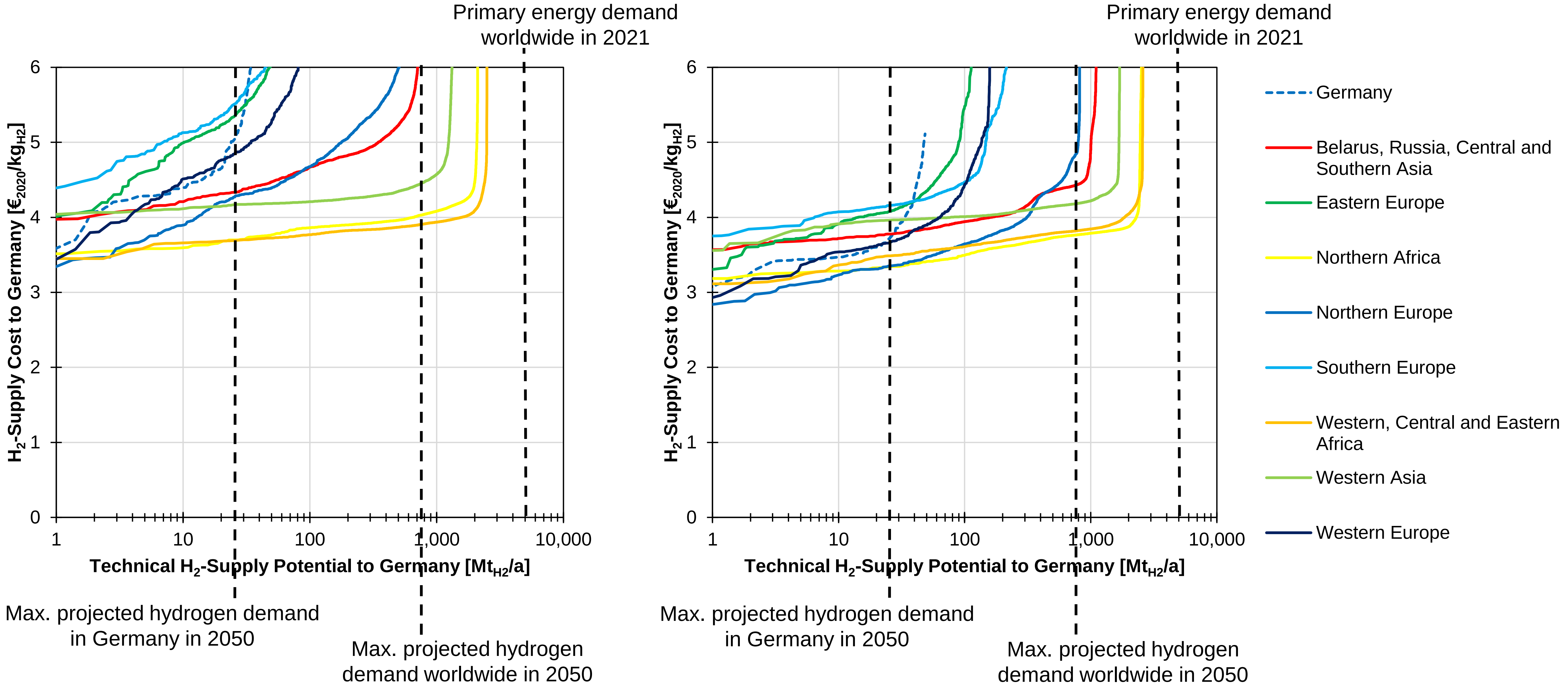
2. For the use of **salt caverns** the hydrogen supply costs to Germany are for many costal locations in Northern Europe (including offshore locations in the North Sea) at the same cost level as the best locations in Africa.

Based on: Sens et al. 2022; *includes the hydrogen production and transportation costs per pipeline

Hydrogen Supply Potential

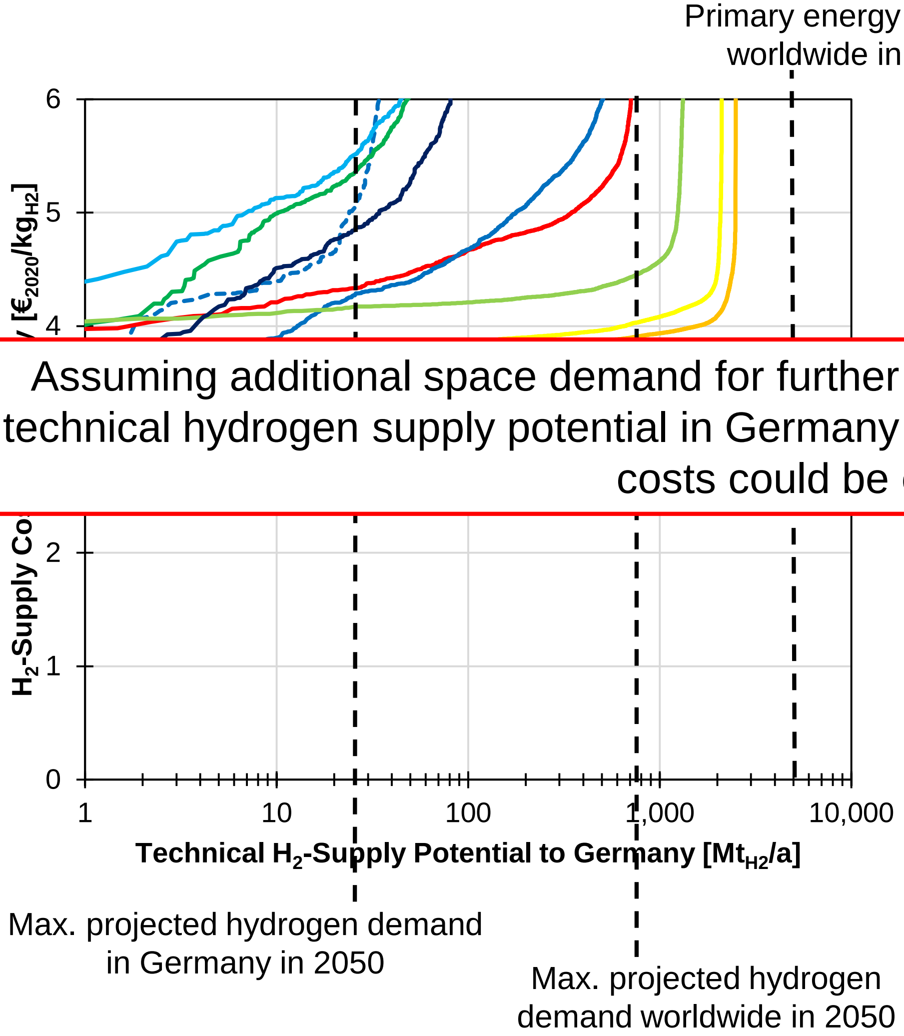
Pressure Tank Scenario

Salt Cavern Scenario

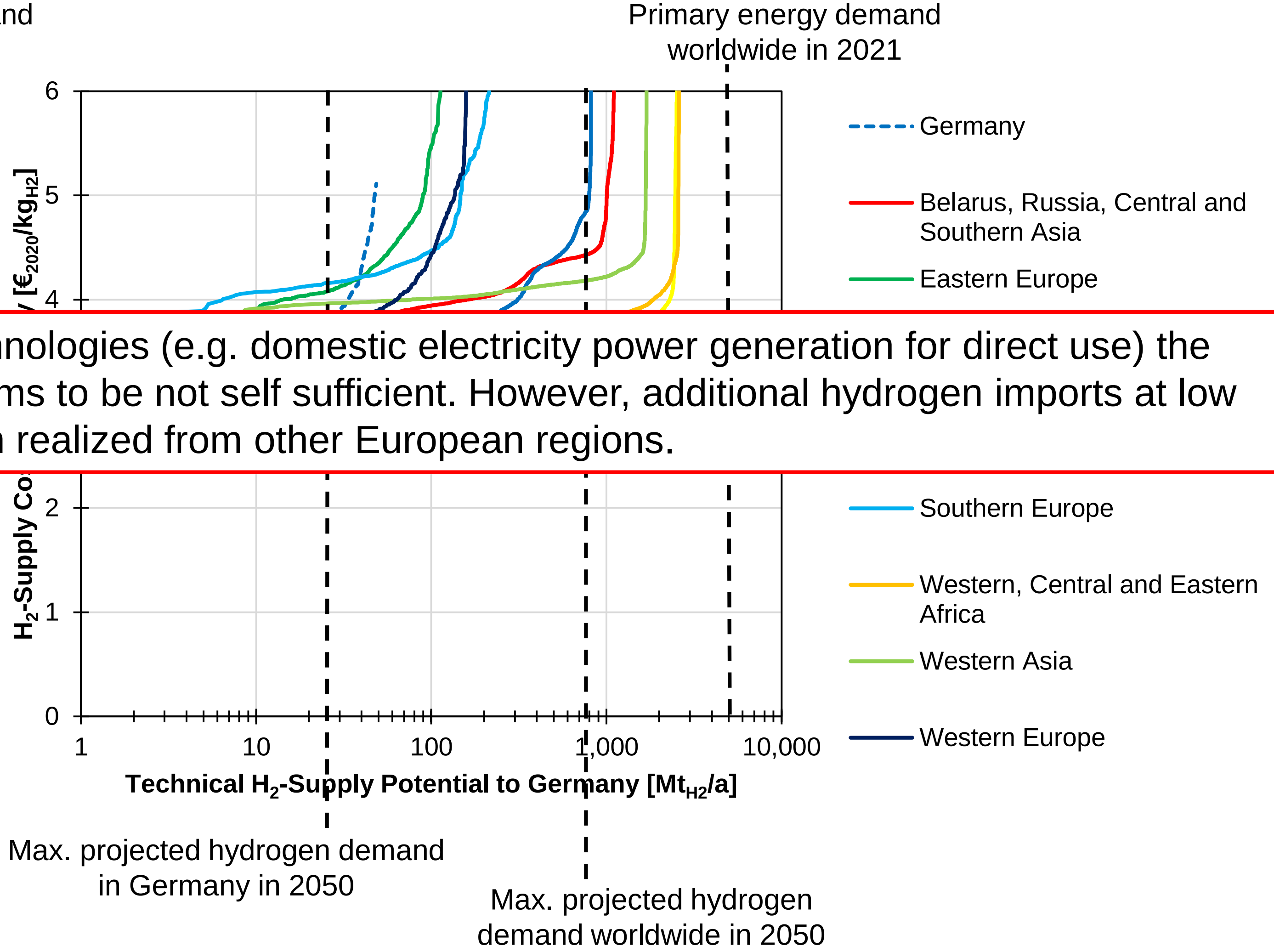


Hydrogen Supply Potential

Pressure Tank Scenario



Salt Cavern Scenario



Assuming additional space demand for further technologies (e.g. domestic electricity power generation for direct use) the technical 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.

Based on: Sens et al. 2022

4. Key Conclusions

Conclusion

1. Are hydrogen costs below 2 $€_{2020}/kg_{H2}$ realistic in the future?

   ➢ Hydrogen production cost of 2 $€_{2020}/kg_{H2}$ 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 $€_{2020}/kg_{H2}$**

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**

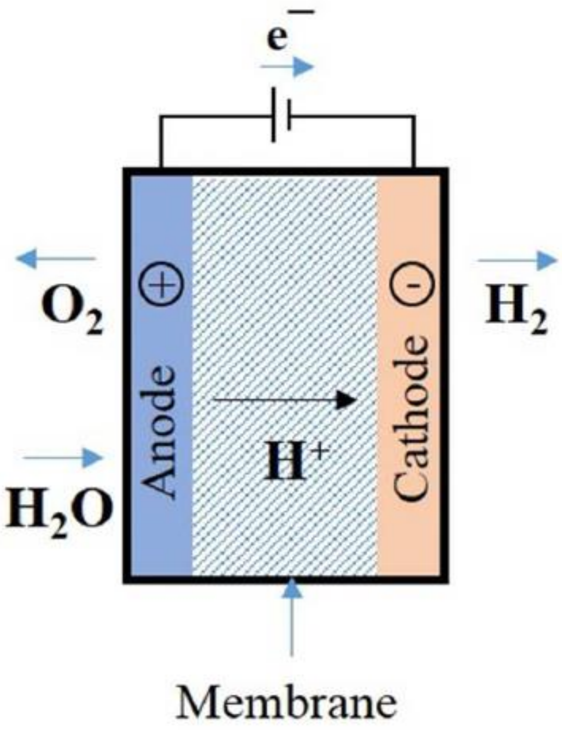
Thank you for your Attention!

Questions and Discussion

Hamburg University of Technology (TUHH)
Institute of Environmental Technology and Energy Economics (IUE)
Eißendorfer Str. 40, D-21073 Hamburg

Lucas Sens | lucas.sens@tuhh.de

Water Electrolysis



$$Cathode: 2H^{+} + 2e^{-} \rightarrow H_2$$

$$Anode: \; H_2O \rightarrow 0.5\; O_2 + 2H^{+} + 2e^{-}$$

$$Total\ reaction: \; H_2O + Energy \rightarrow H_2 + 0.5\; O_2$$

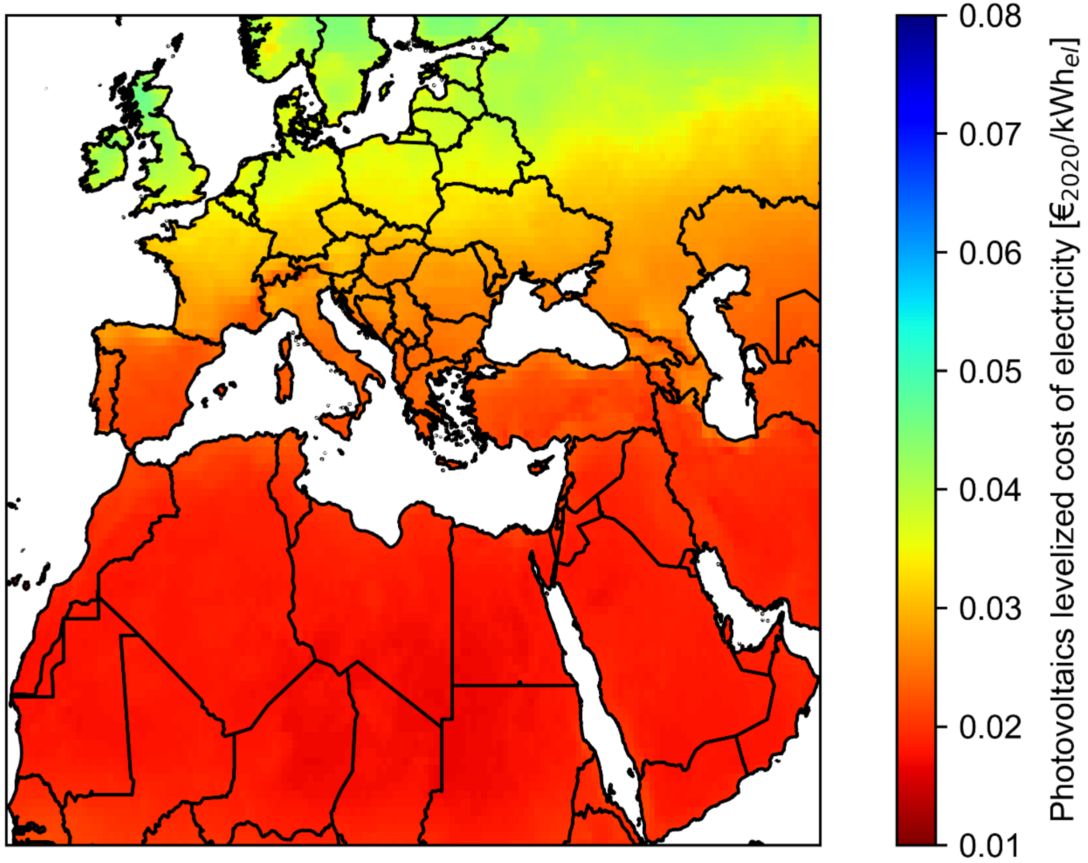
Data and Calculation

	Photovoltaics	Onshore Wind	Offshore Wind	PEM-Electrolyzer	Compressor	Battery	Pressure Tank	Salt Cavern
CAPEX	370 $€_{2020}$/kW	1,090 $€_{2020}$/kW	1,820 $€_{2020}$/kW 2,690 $€_{2020}$/kW	740 $€_{2020}$/kW	1,780 $€_{2020}/(kg_{H2}/h)$	150 $€_{2020}$/kWh	460 $€_{2020}$/kW	46 $€_{2020}$/kW
Efficiency	-	-	-	0.68 $kWh_{H2,LHV}/kWh_{el}$	0.8 kWh_{ideal}/kWh_{real}	0.9 kWh_{in}/kWh_{out}	-	-

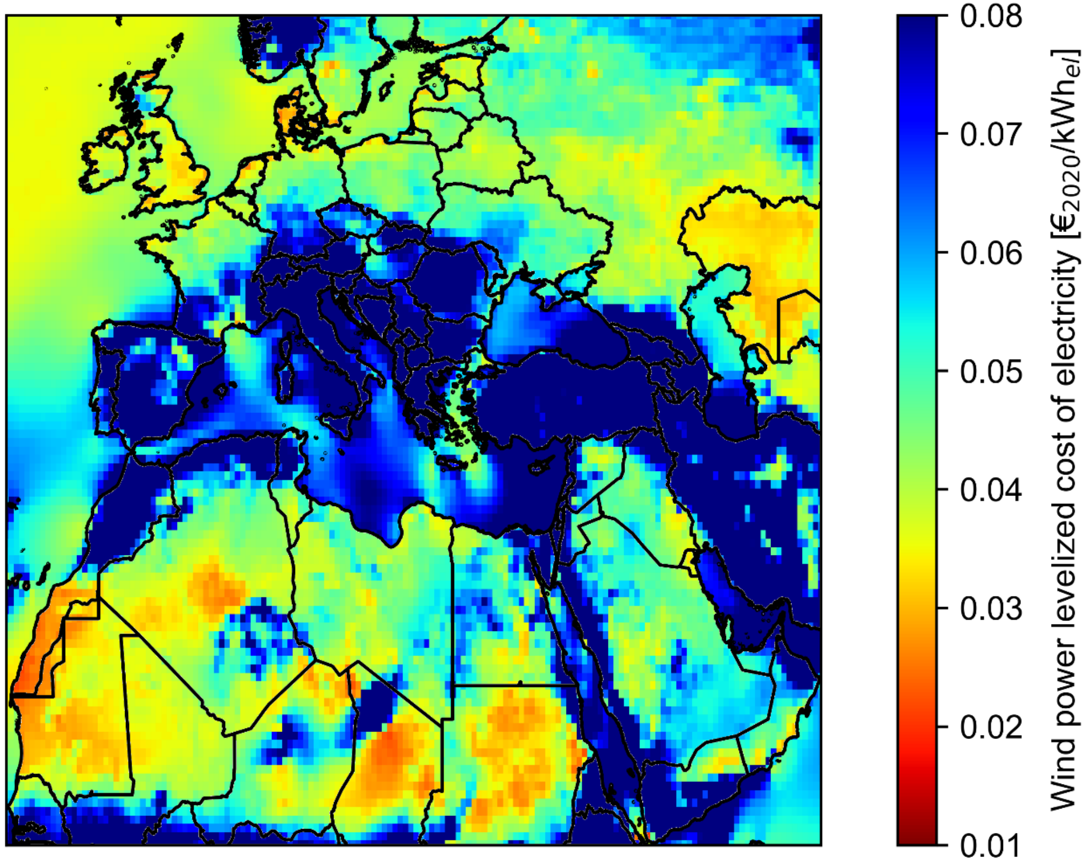
- ERA5 data set (weather year 2012) for hourly solar radiation and wind speed
- Land cover classification system (LCCS) for the land availability
- Annuity methodology for cost quantification
- Depreciation period equals technical lifetime
- All costs based on nominal 2020 Euro values
- Year 2035 assumed for techno-economic parameters

Levelized Cost of Electricity

Photovoltaics

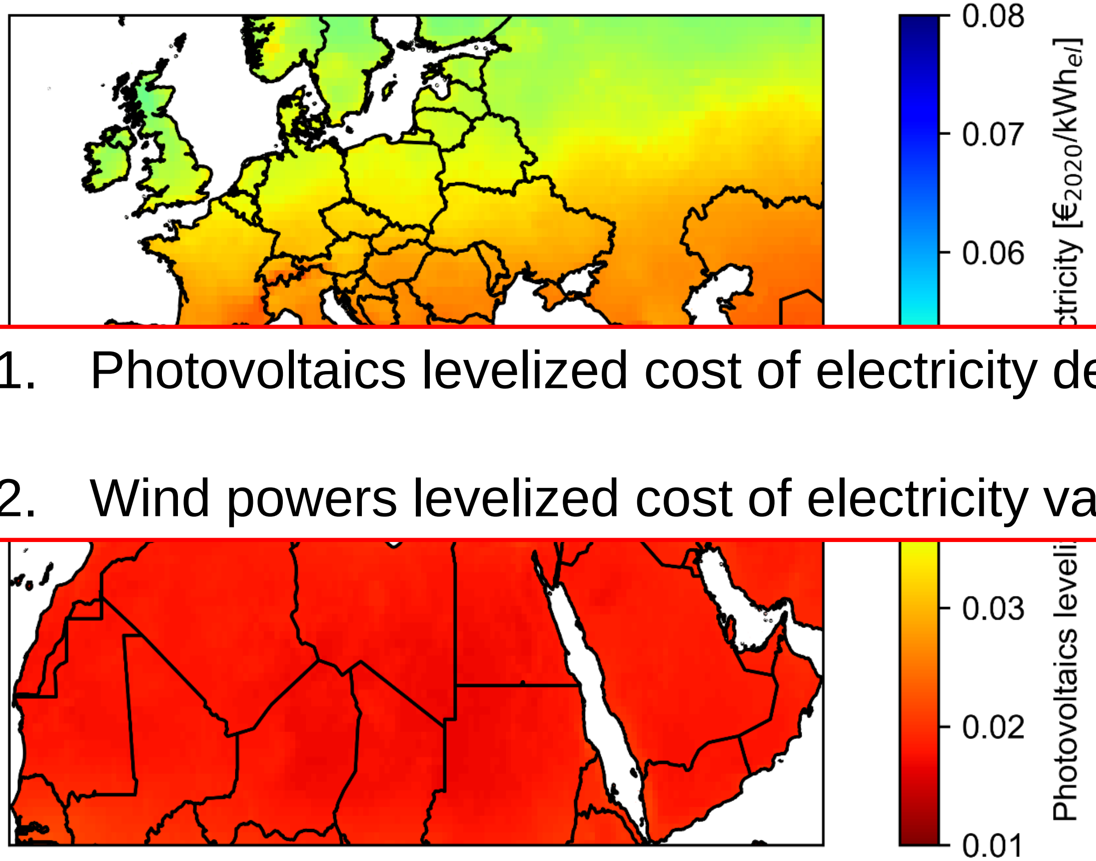


Wind Power

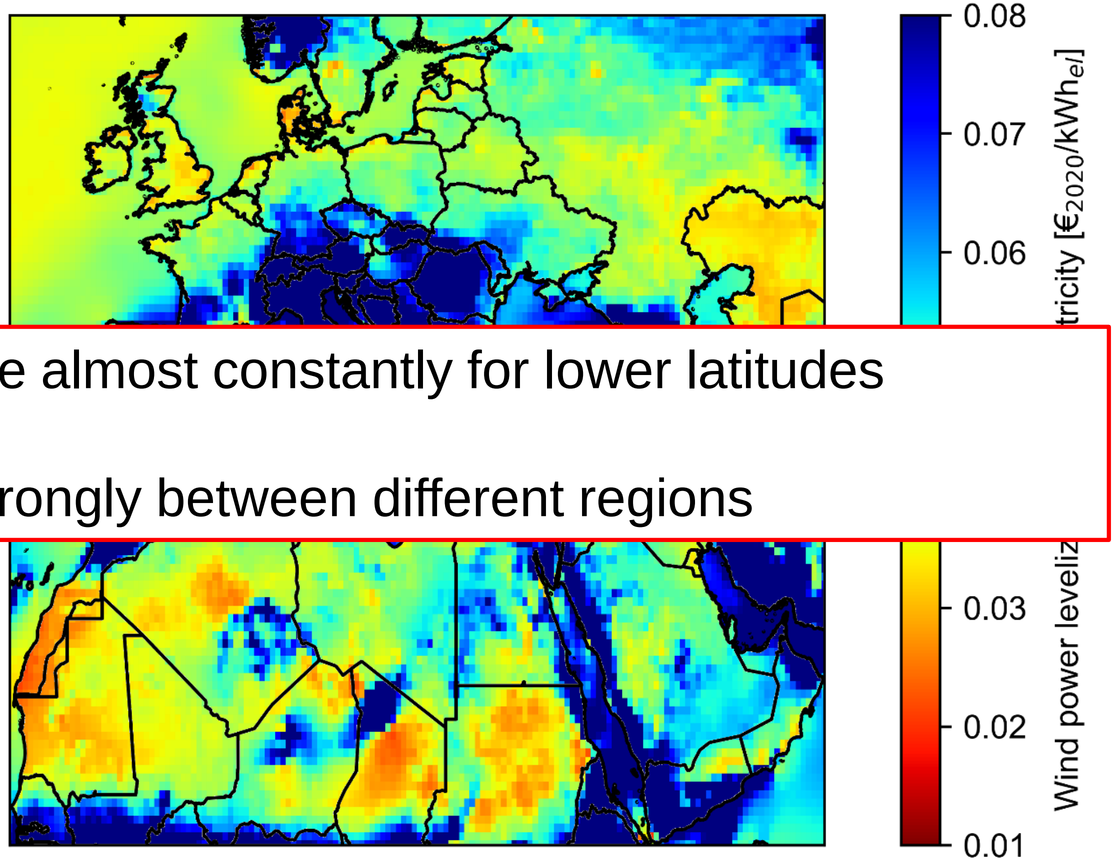


Levelized Cost of Electricity

Photovoltaics



Wind Power

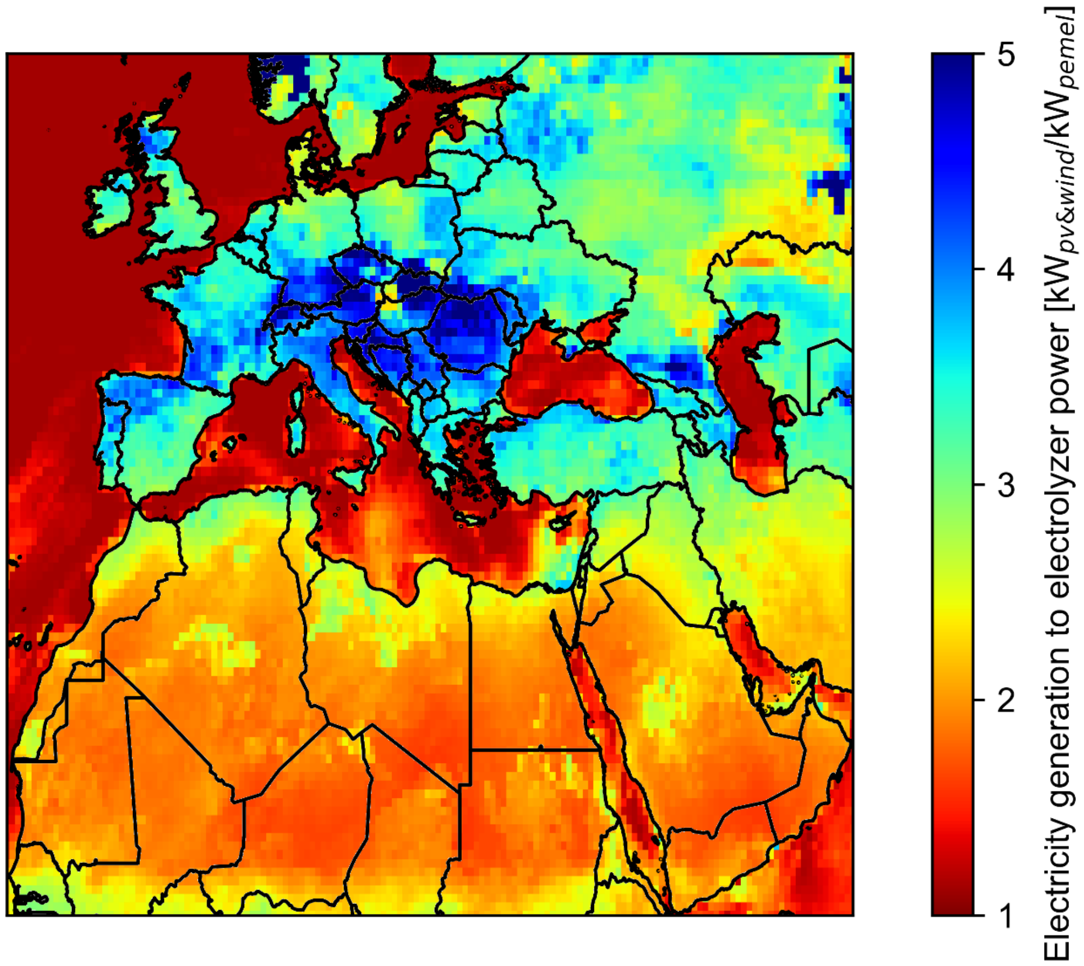


1. Photovoltaics levelized cost of electricity decrease almost constantly for lower latitudes

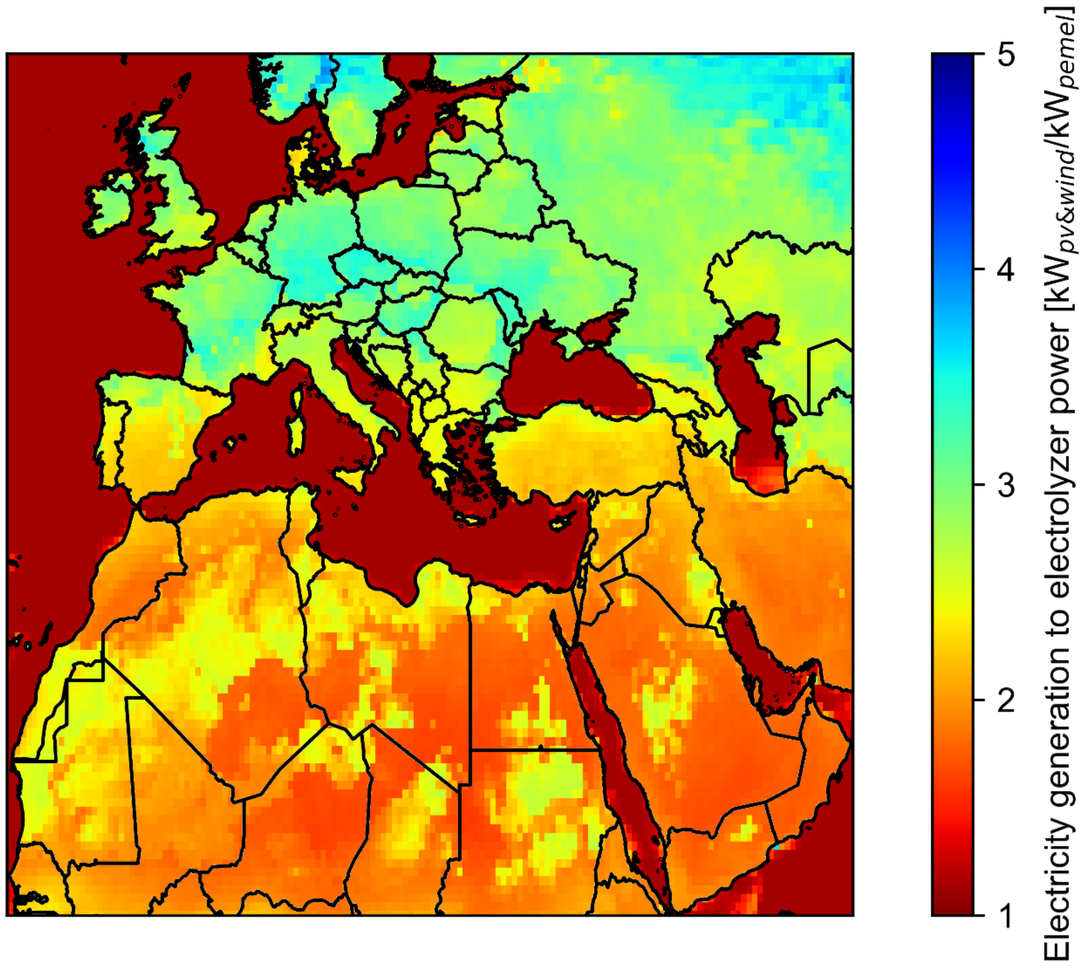
2. Wind powers levelized cost of electricity varies strongly between different regions

Electricity Generation to Electrolyzer Power

Pressure Tank Scenario



Salt Cavern Scenario



Electricity Generation to Electrolyzer Power

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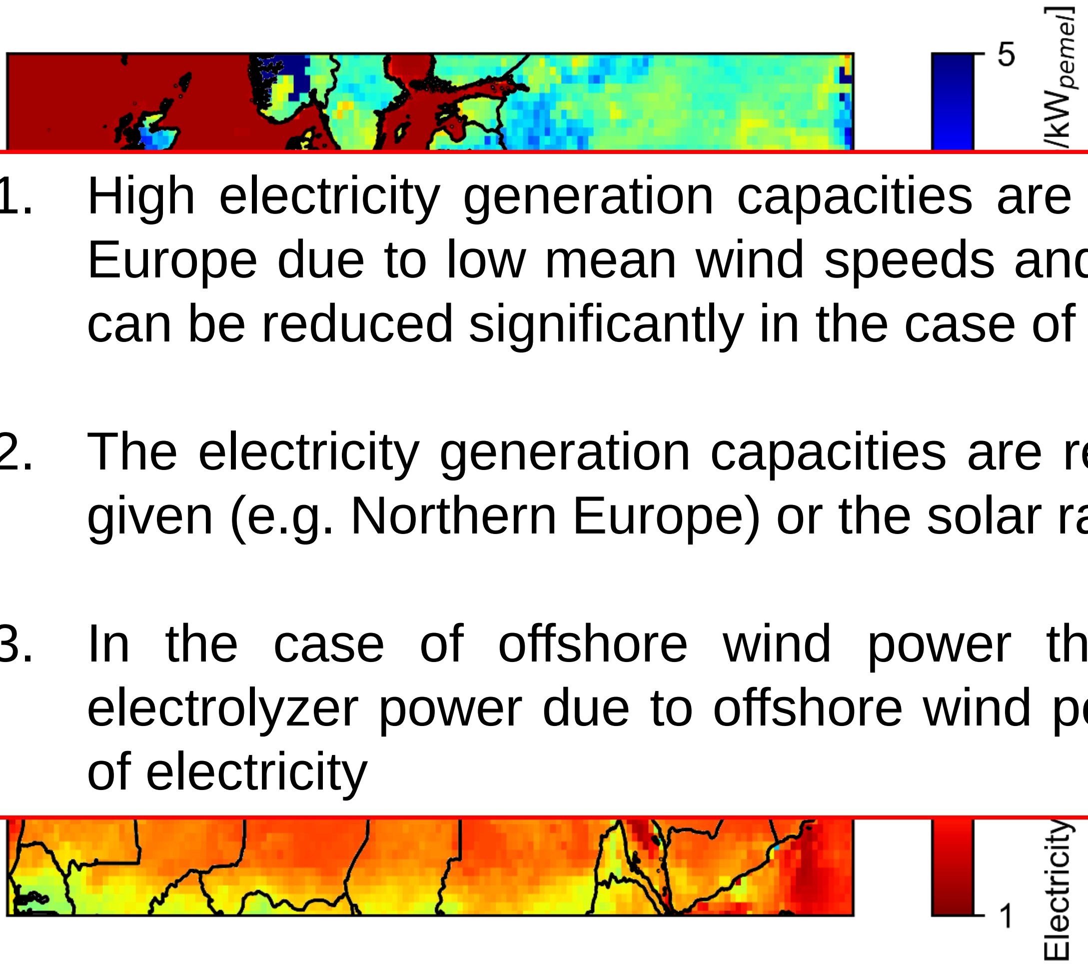
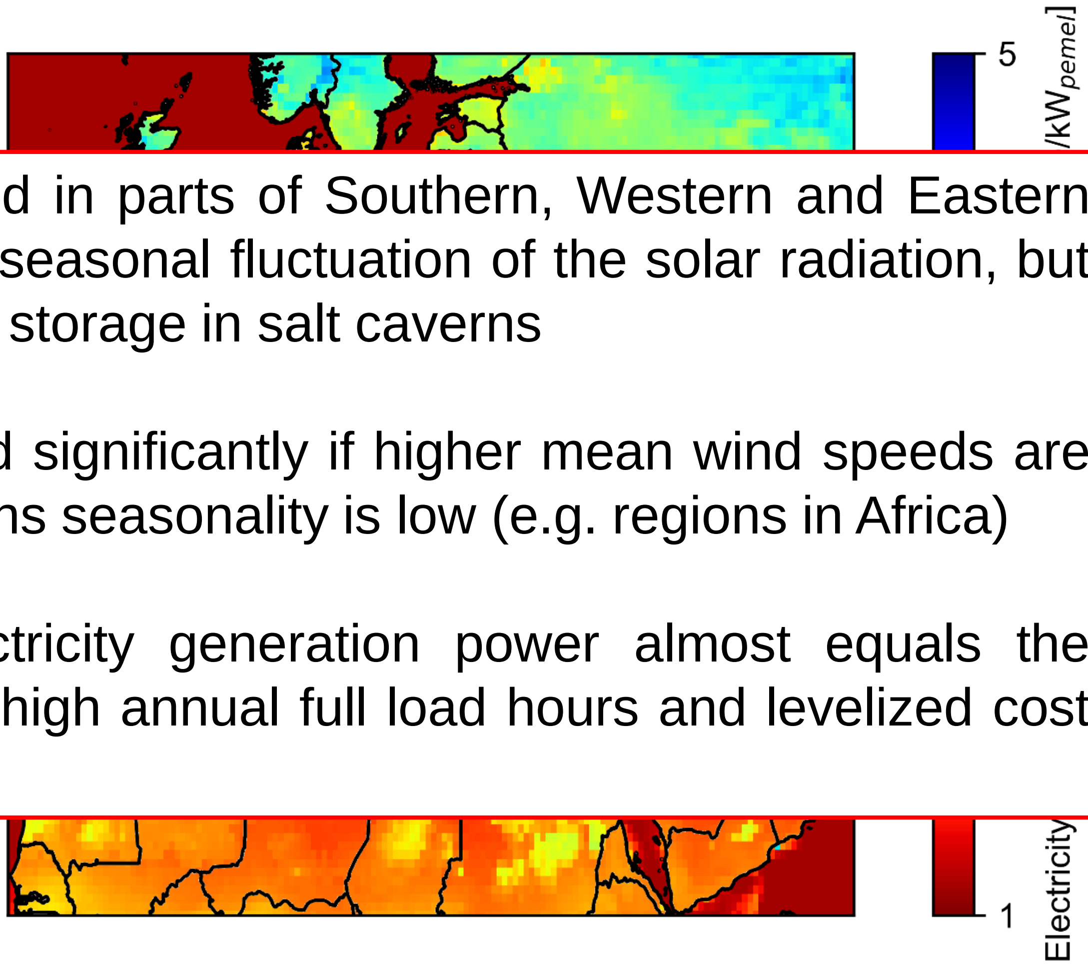


Salt Cavern Scenario



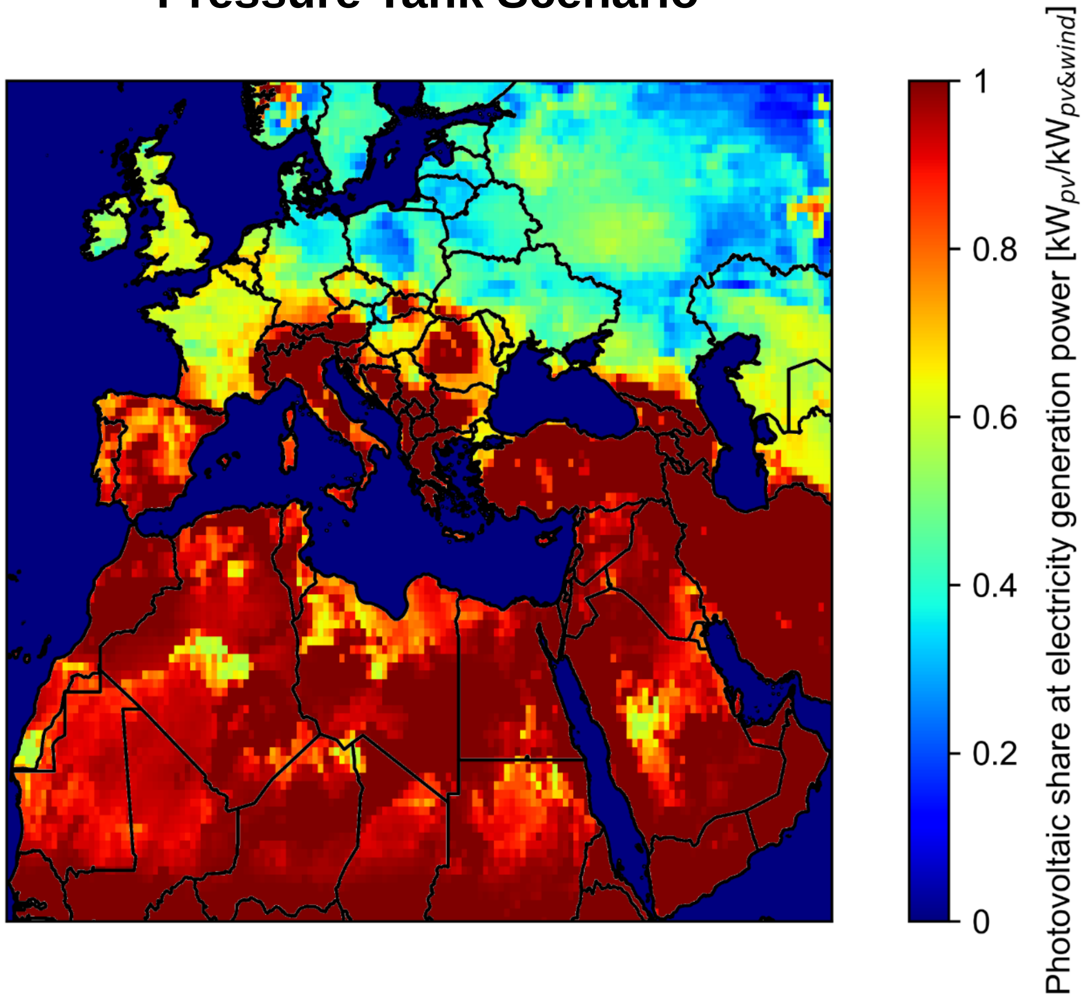
1. High electricity generation capacities are needed in parts of Southern, Western and Eastern Europe due to low mean wind speeds and high seasonal fluctuation of the solar radiation, but can be reduced significantly in the case of cheap storage in salt caverns

2. The electricity generation capacities are reduced significantly if higher mean wind speeds are given (e.g. Northern Europe) or the solar radiations seasonality is low (e.g. regions in Africa)

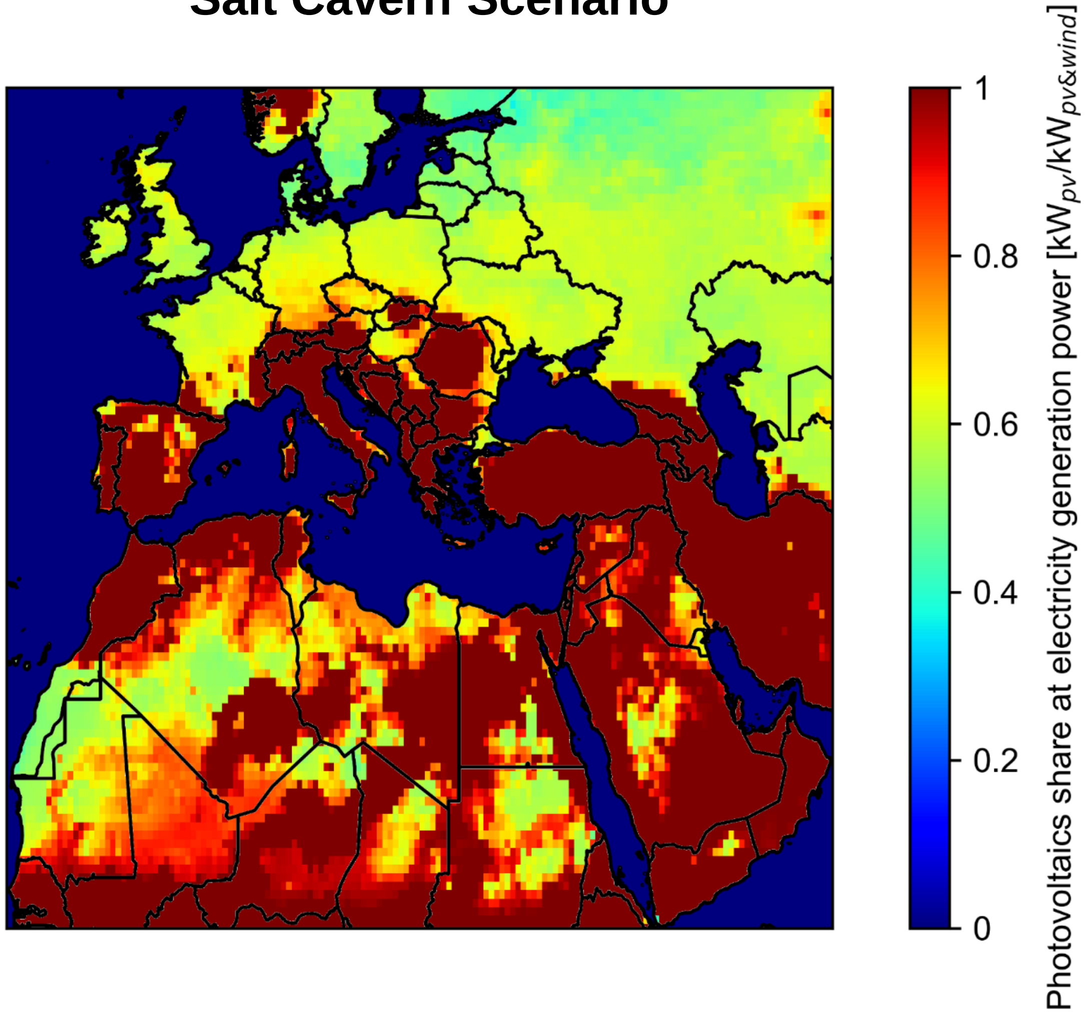
3. In the case of offshore wind power the electricity generation power almost equals the electrolyzer power due to offshore wind powers high annual full load hours and levelized cost of electricity

Share of Photovoltaics

Pressure Tank Scenario



Salt Cavern Scenario



Share of Photovoltaics

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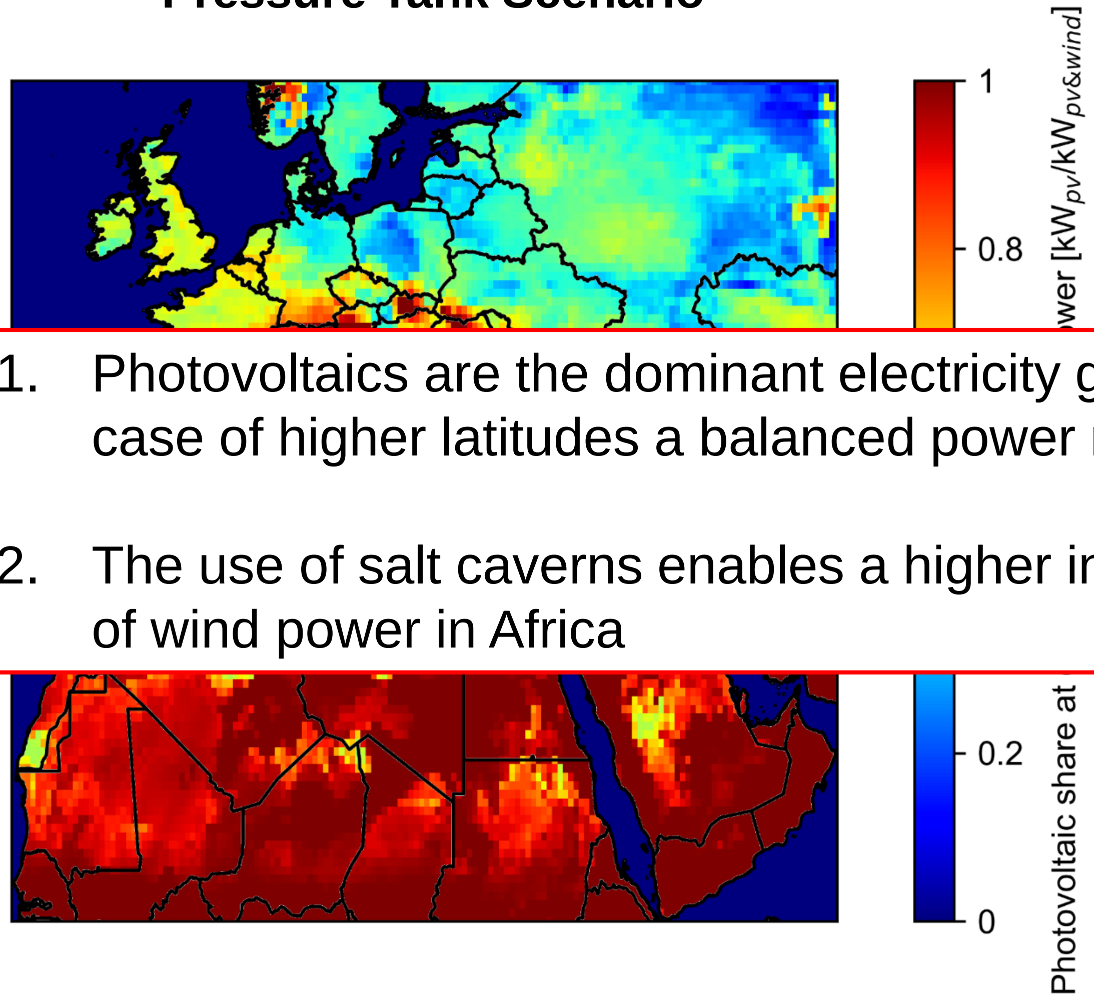
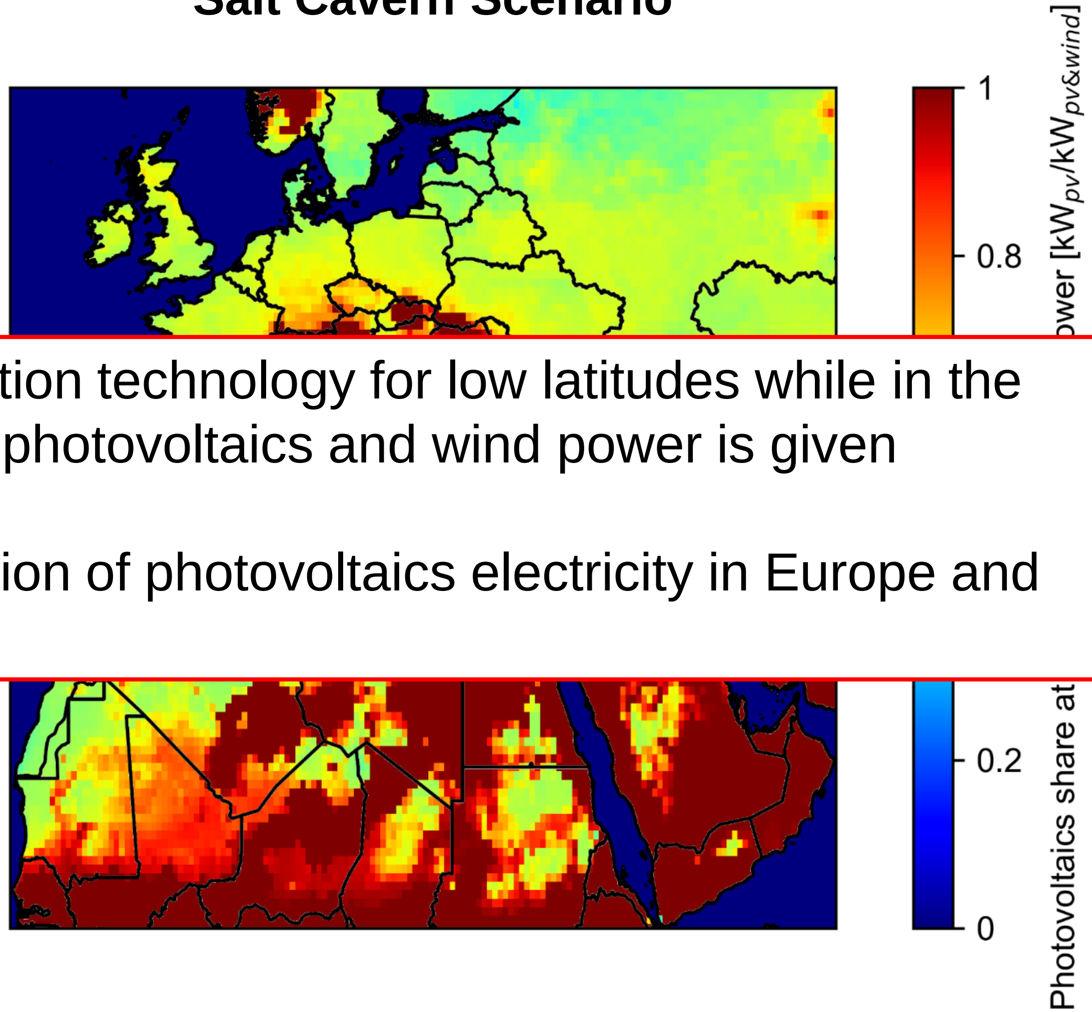


Salt Cavern Scenario

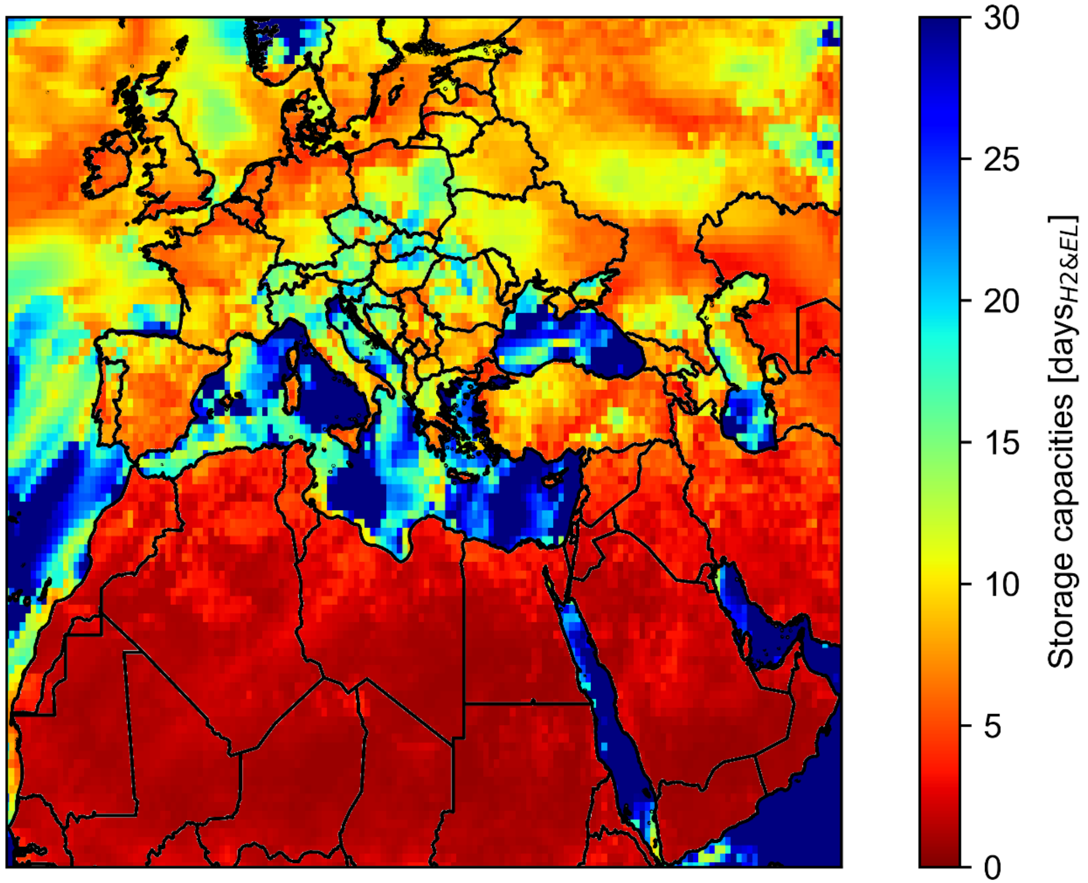


1. Photovoltaics are the dominant electricity generation technology for low latitudes while in the case of higher latitudes a balanced power mix of photovoltaics and wind power is given

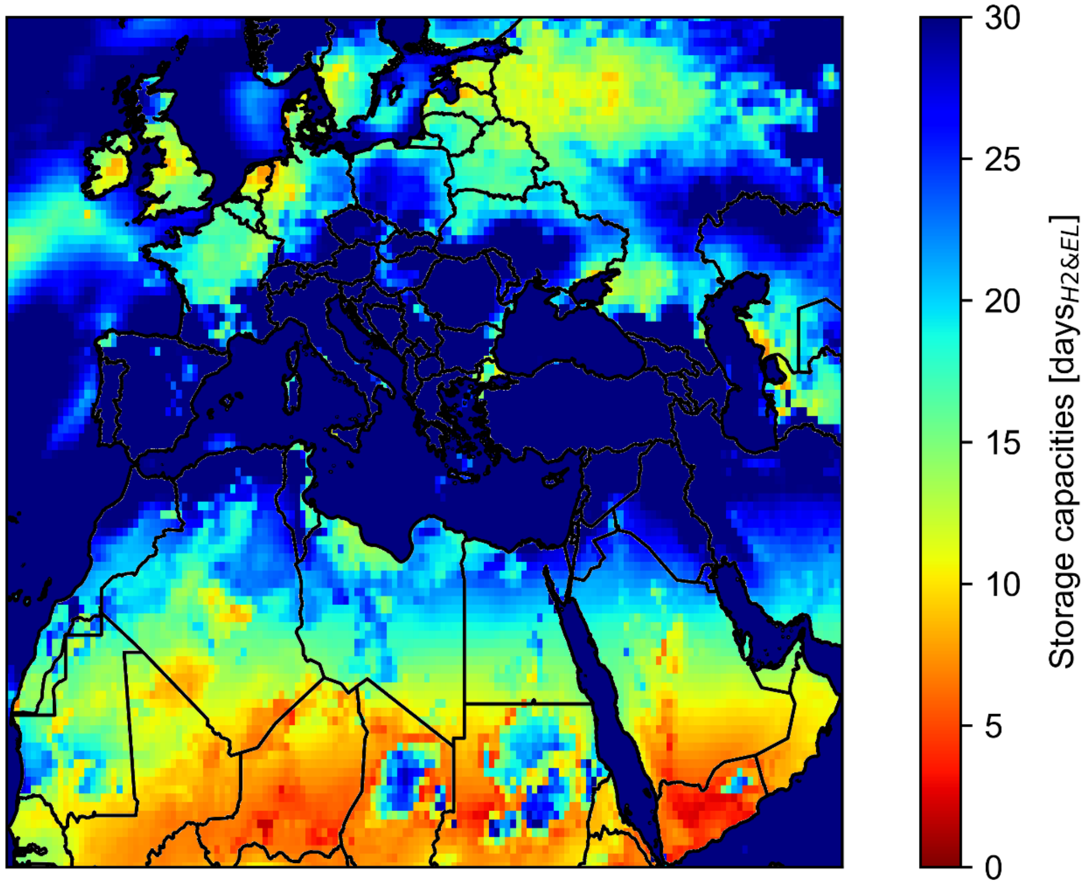
2. The use of salt caverns enables a higher integration of photovoltaics electricity in Europe and of wind power in Africa

Storage Capacities

Pressure Tank Scenario

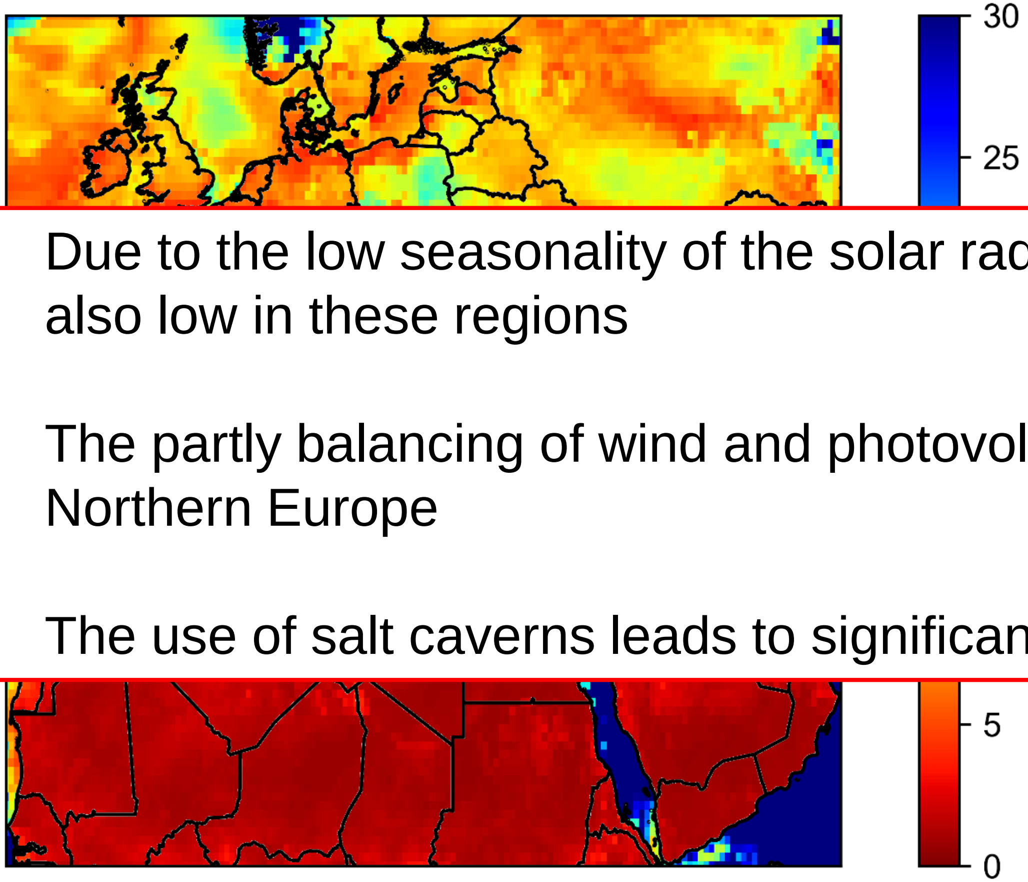


Salt Cavern Scenario

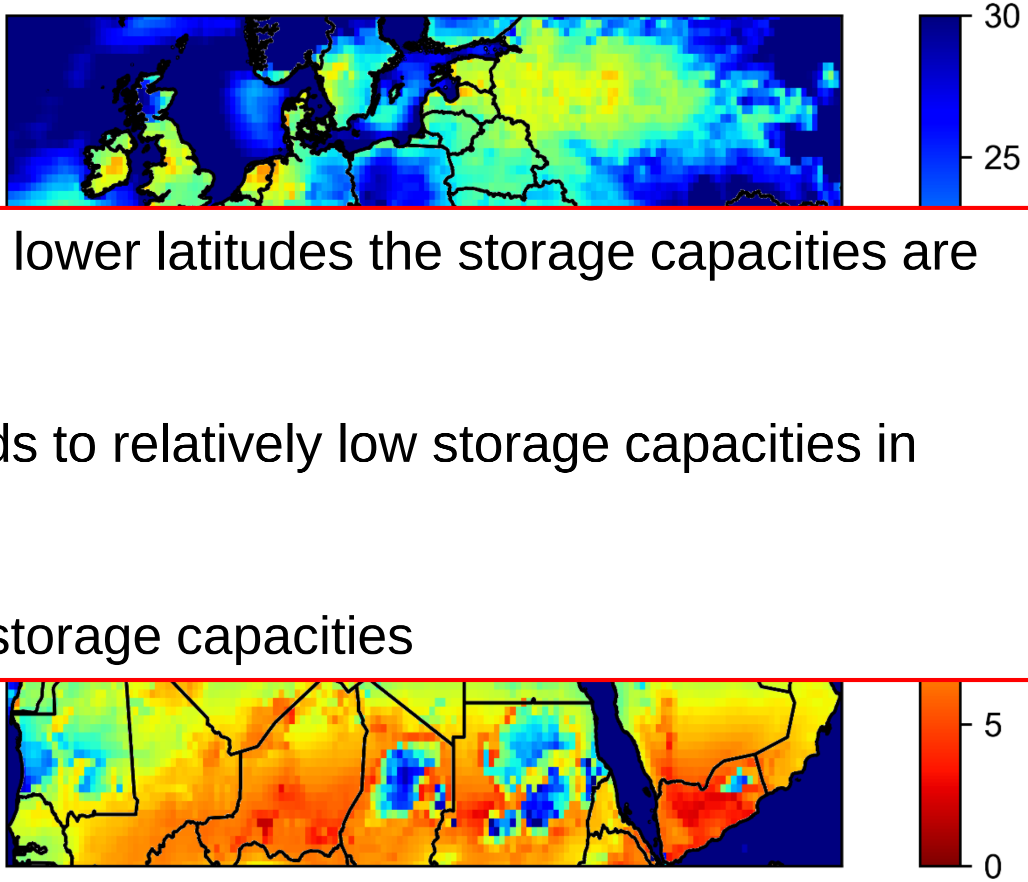


Storage Capacities

Pressure Tank Scenario



Salt Cavern Scenario



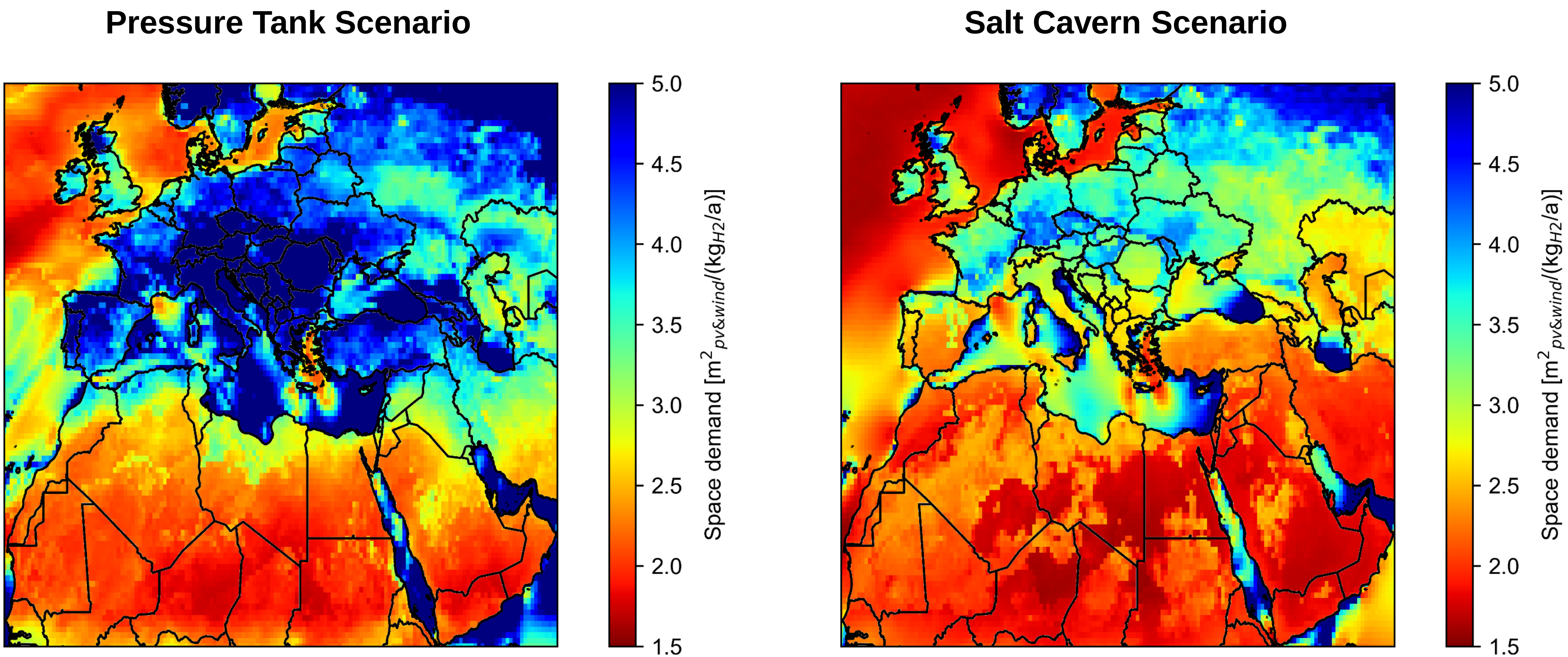
1. Due to the low seasonality of the solar radiation for lower latitudes the storage capacities are also low in these regions

2. The partly balancing of wind and photovoltaics leads to relatively low storage capacities in Northern Europe

3. The use of salt caverns leads to significant higher storage capacities

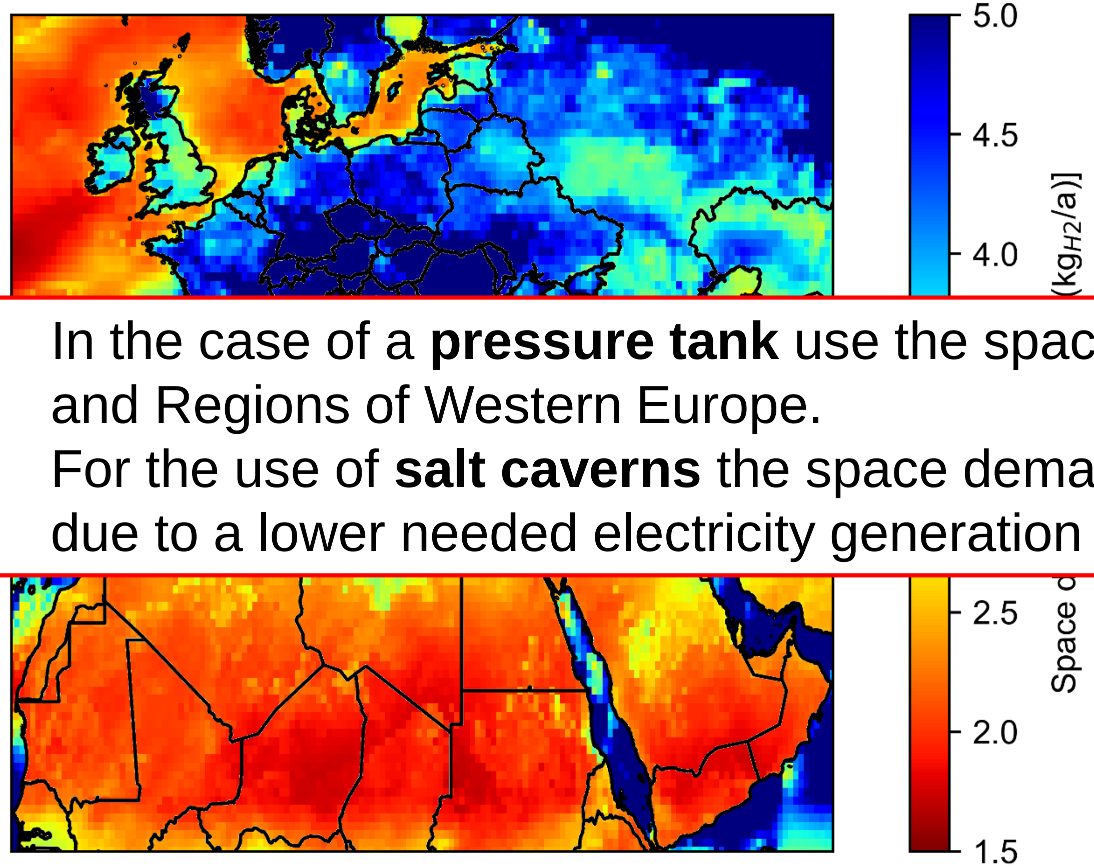
Based on: Sens et al. 2022

Space Demand for Hydrogen Production

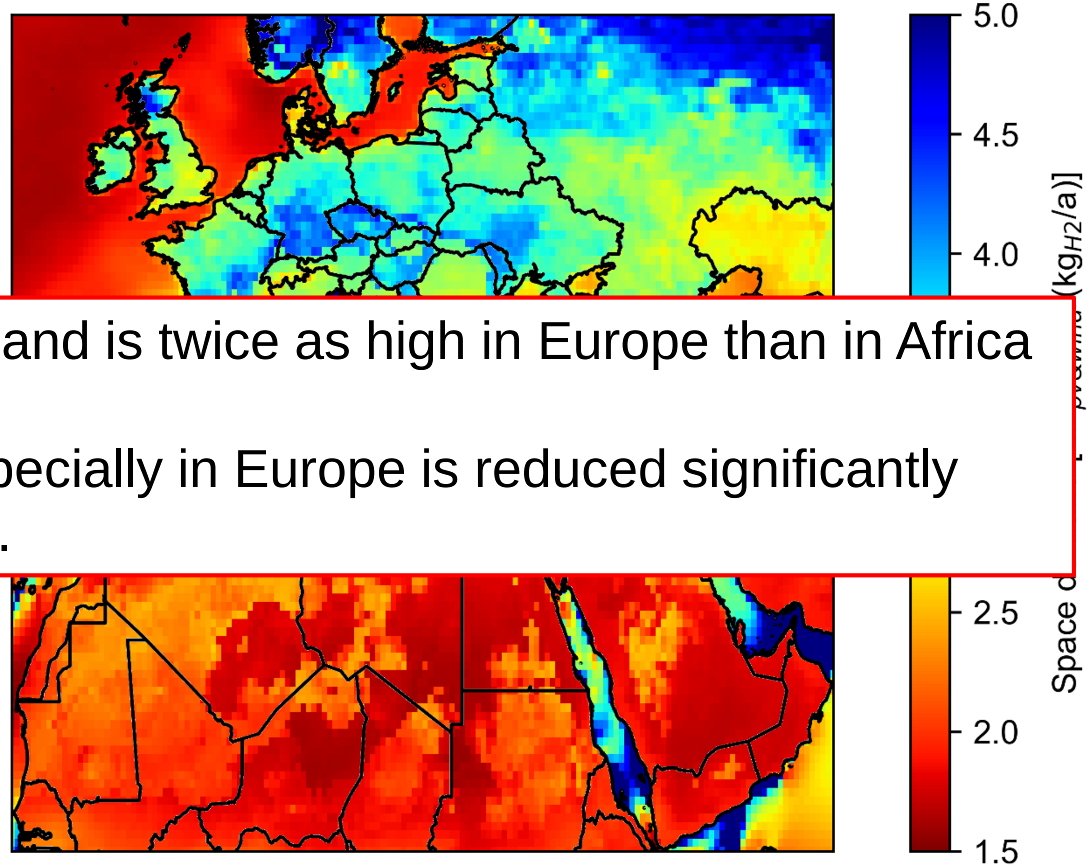


Based on: Sens et al. 2022

Pressure Tank Scenario



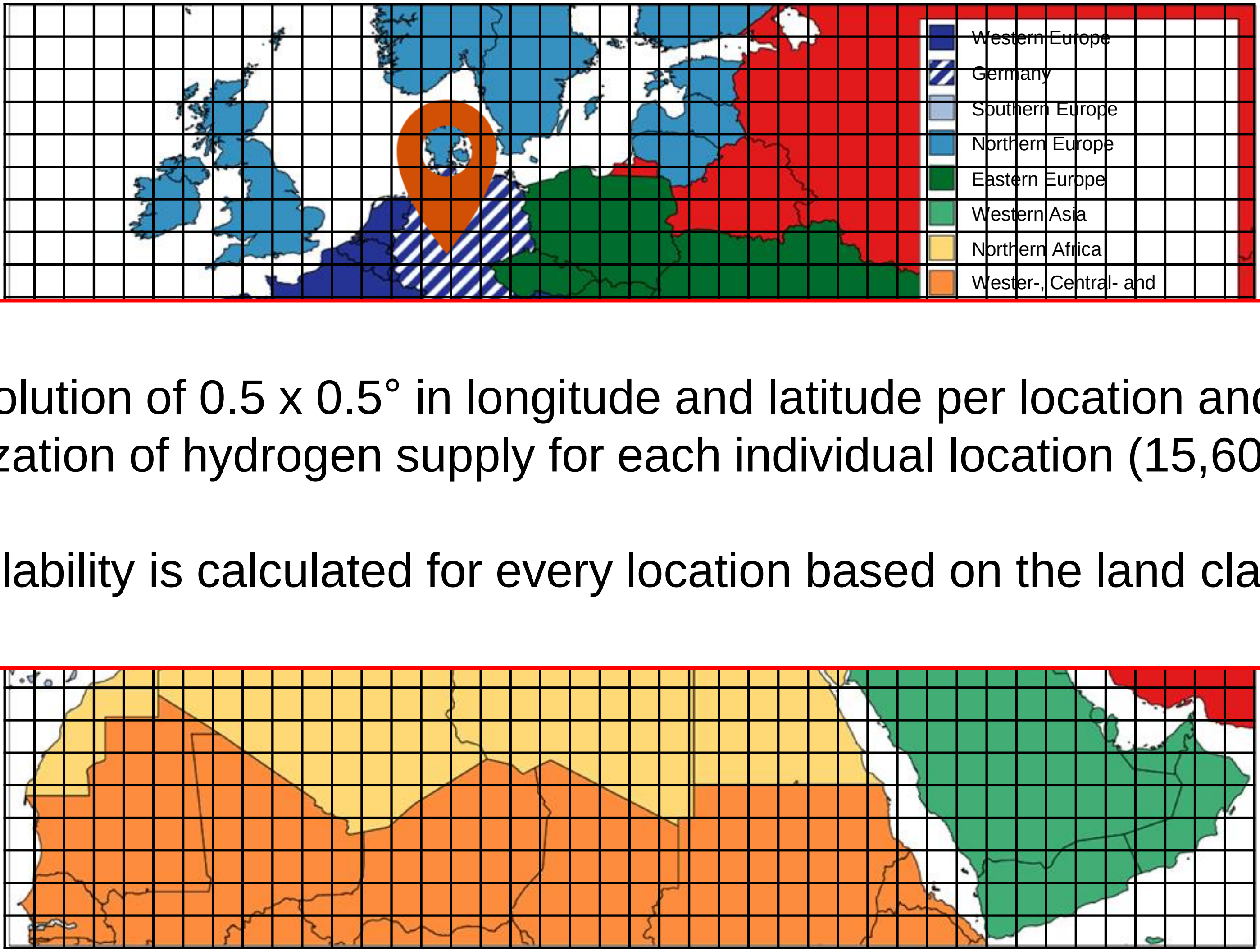
Salt Cavern Scenario



1. In the case of a **pressure tank** use the space demand is twice as high in Europe than in Africa and Regions of Western Europe.
2. For the use of **salt caverns** the space demand especially in Europe is reduced significantly due to a lower needed electricity generation power.

Based on: Sens et al. 2022

Hydrogen Production System



Grid with a resolution of 0.5 x 0.5° in longitude and latitude per location and subsequent cost minimization of hydrogen supply for each individual location (15,600 in total).

The space availability is calculated for every location based on the land classification (LCCS)