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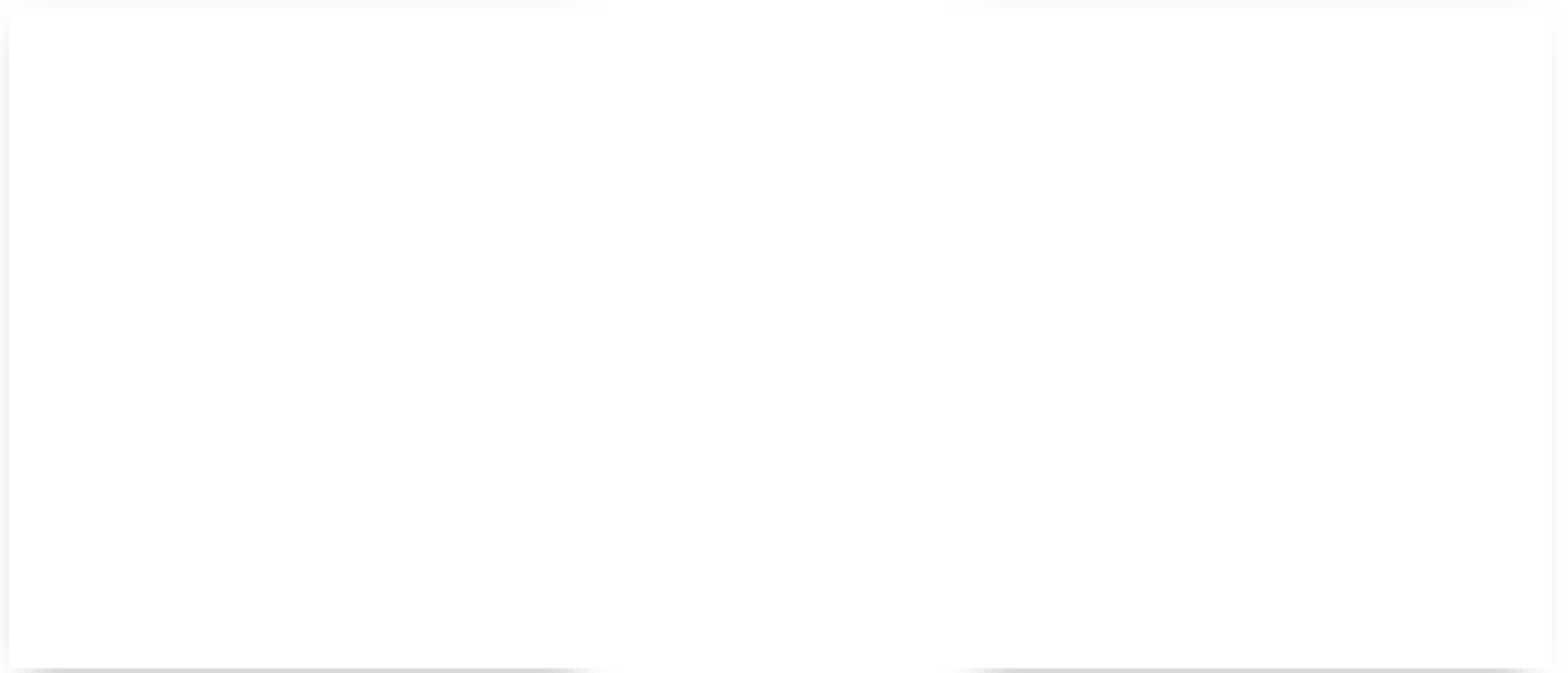
Fachgruppe Wasserstoffforschung – Hamburger Energieforschungskolloquium

16.06.2022

Cost Minimized Hydrogen from Solar and Wind – Production and Supply in the European Catchment Area

Lucas Sens, Ulf Neuling, Martin Kaltschmitt

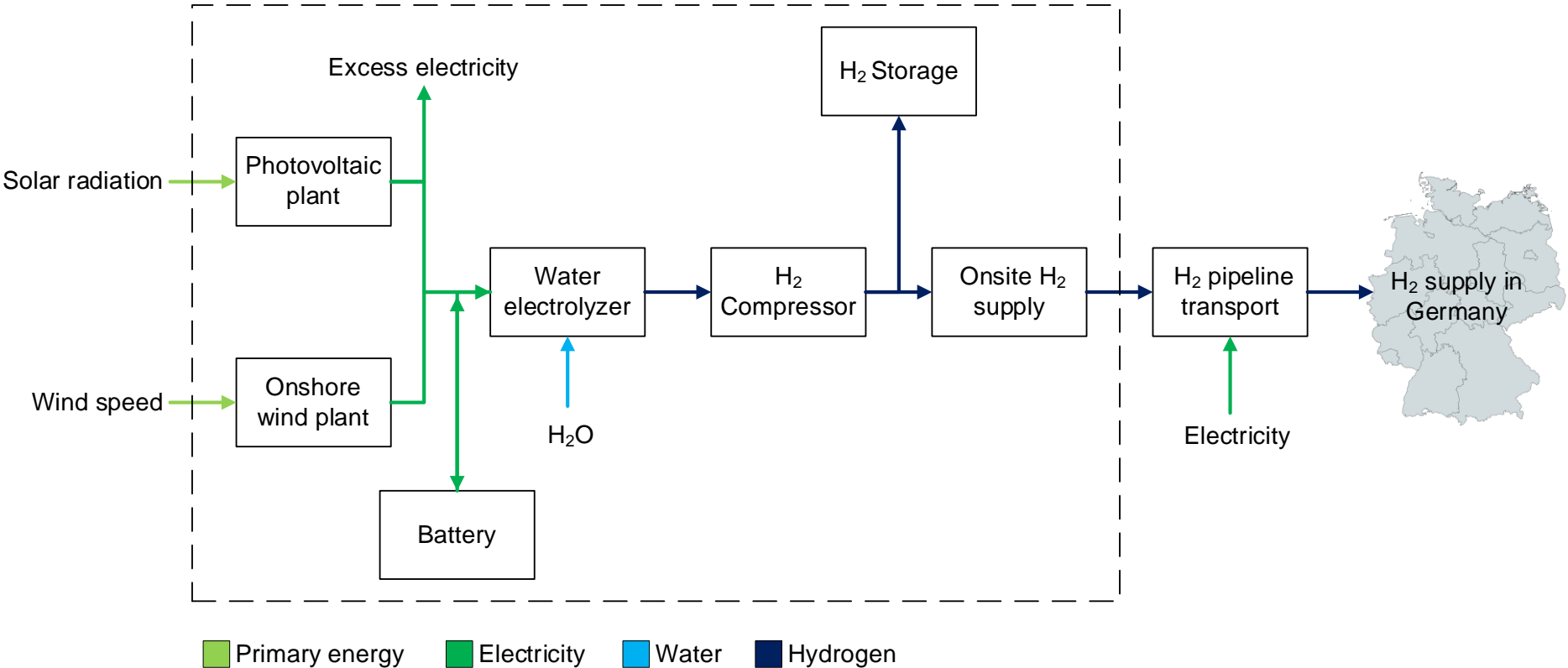
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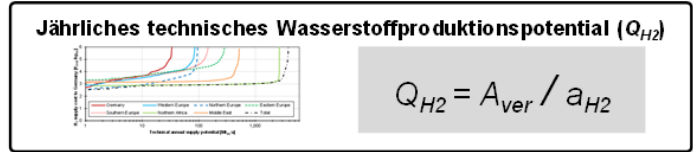
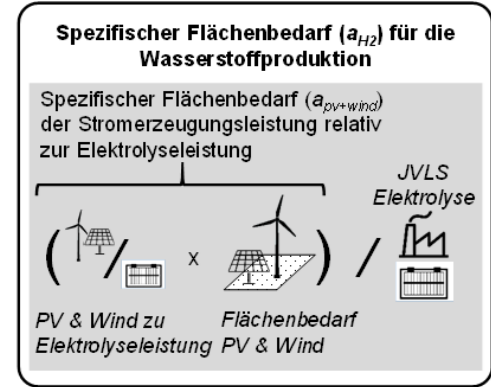
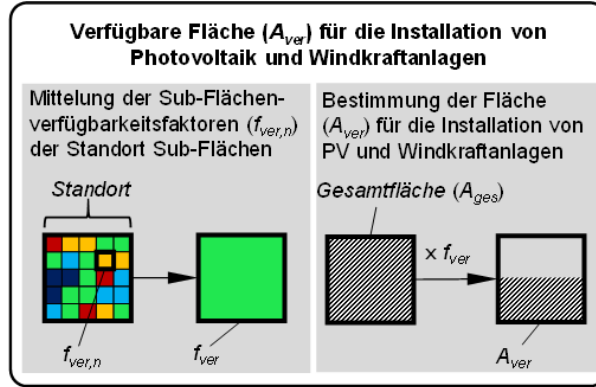
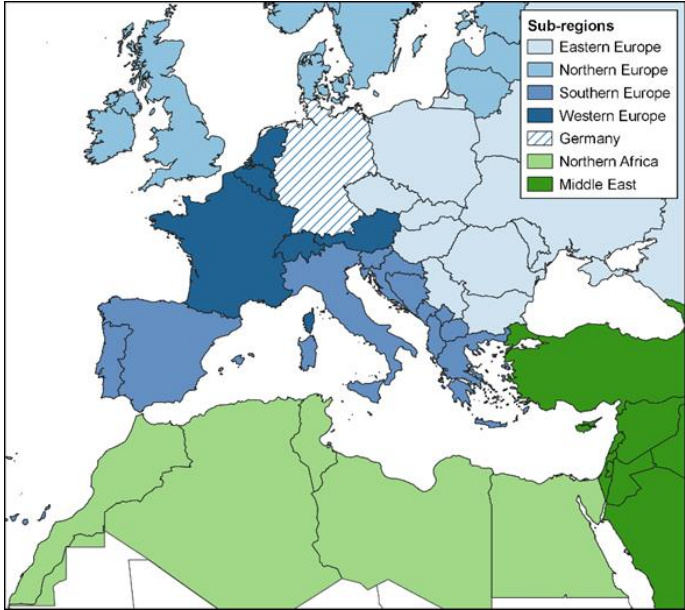
- Which regions obtain the lowest onsite hydrogen supply cost?
- What is the magnitude of the hydrogen supply potential to Germany?
- What is the optimal renewable electricity generation power ratio?
- Do we generate excess electricity?
- How many annual full load hours are achieved by the electrolyzer?
- What size of storage capacities are necessary to overcome dark doldrums?
- Does the implementation of salt cavern storage changes the overall picture?
- What is the space demand for the production of green hydrogen?

Hydrogen Supply Cost Estimation

System boundary of optimization



Hydrogen Production Potential

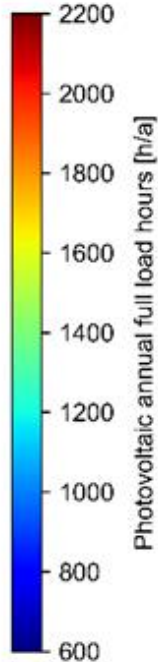
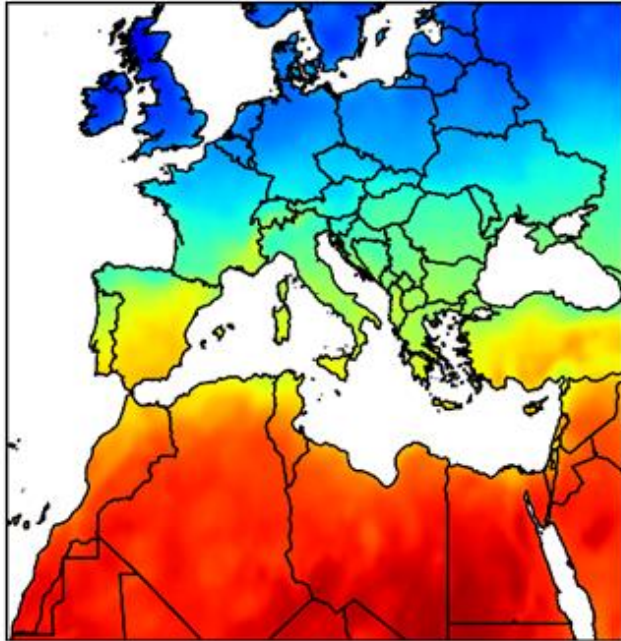


	Year	PV ^a	Onshore Wind ^a	Battery ^b	PEMEL ^a	Pressure Tank ^c	Salt Cavern ^c
CAPEX ^a [€ ₂₀₂₀ /kW] ^b [€ ₂₀₂₀ /kWh] ^c [€ ₂₀₂₀ /kg _{H2}]	2030	400	1,110	180	860	460	50
	2050	280	1,010	90	510		
	Efficiency	2030	-	-	87%	67%	-
	2050	-	-	71%		-	-

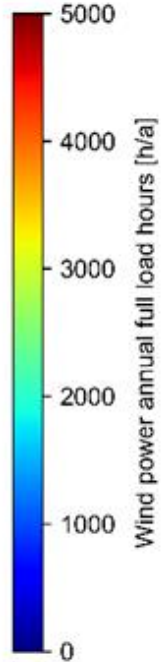
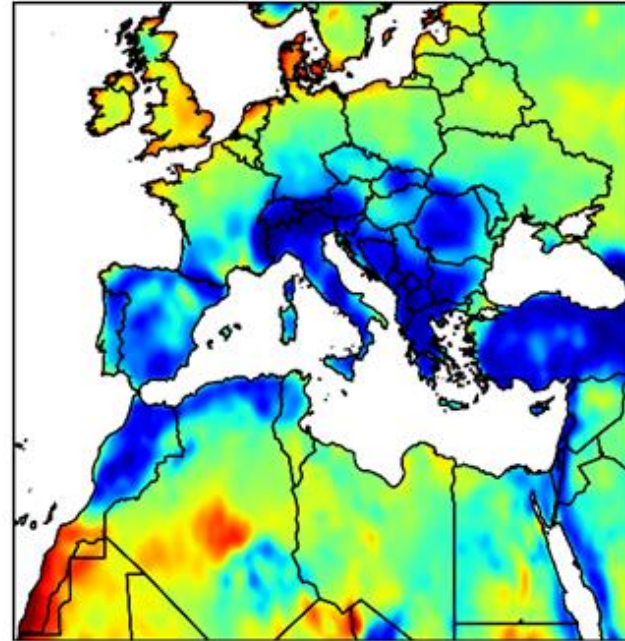
- Climate dataset: ERA5 (hourly resolution)
- Weather year: 2012
- Supply profile: Constant hourly hydrogen supply
- Value of excess electricity: 0 €₂₀₂₀/kWh
- Real weighted average cost of capital: 6%

Annual Full Load Hours of PV and Wind

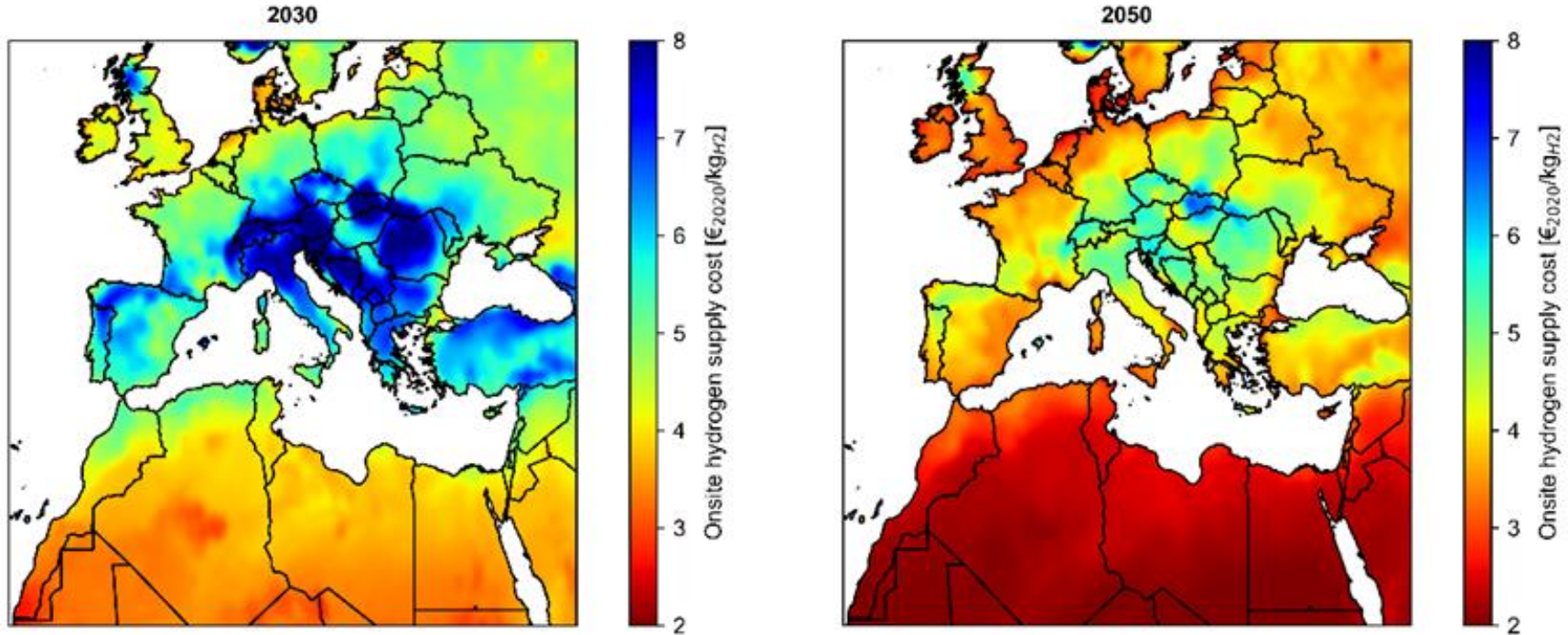
PV



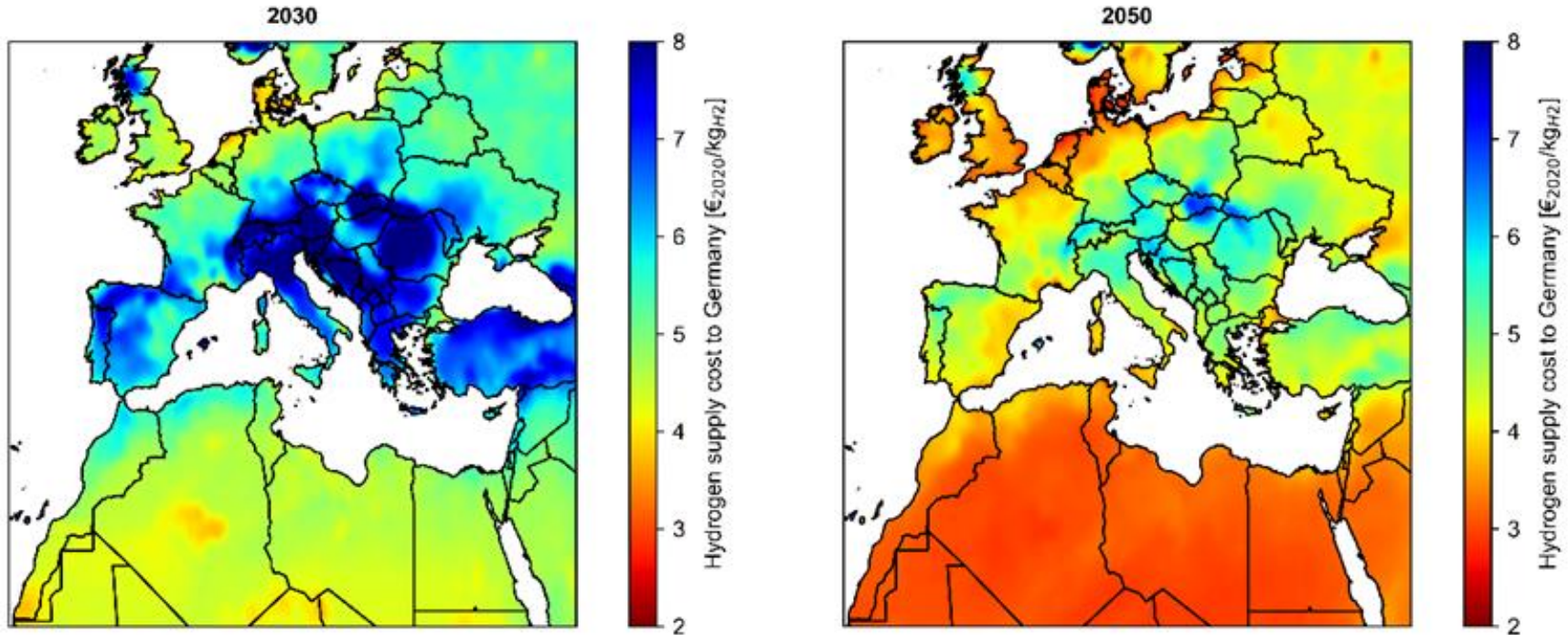
Wind



Onsite Hydrogen Supply Cost

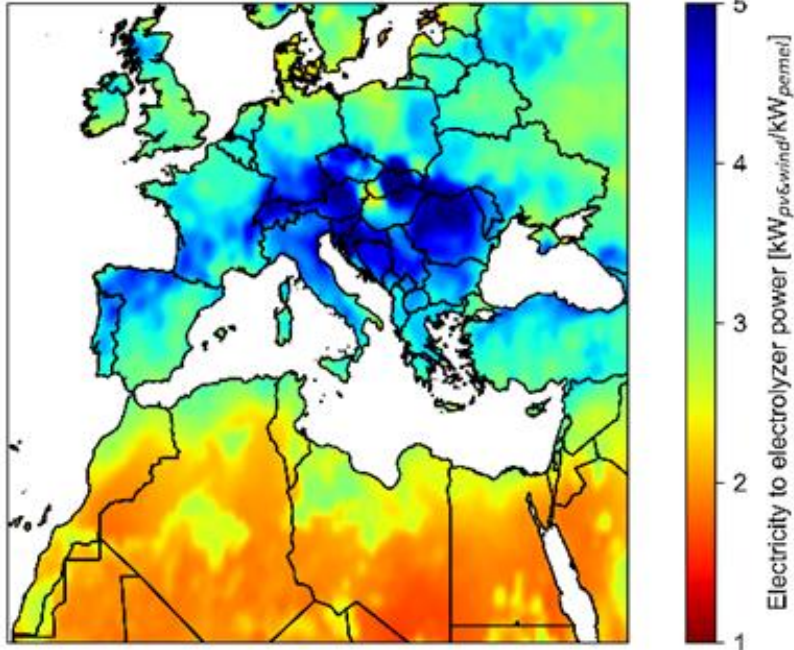


Hydrogen Supply Cost to Germany



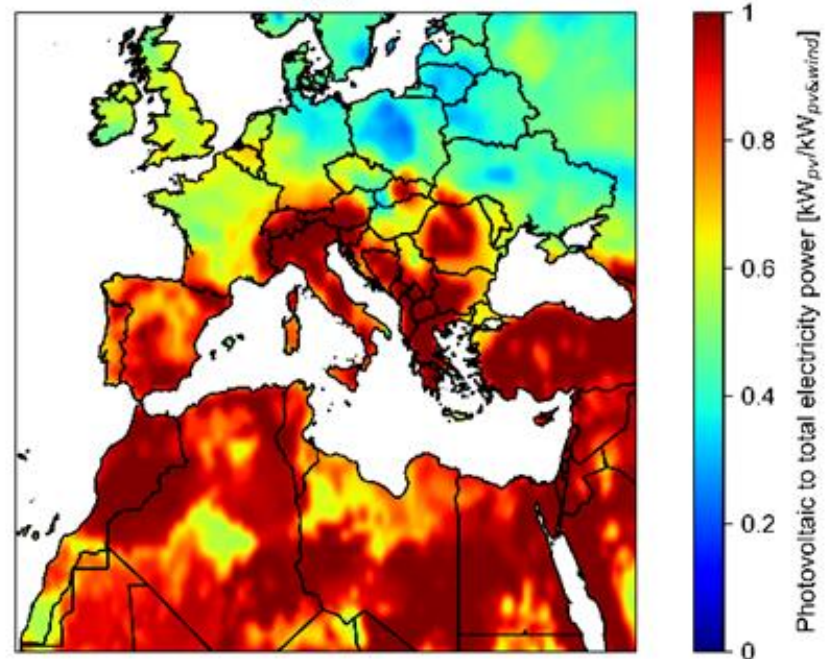
PV/Wind to Electrolyzer Power

2030

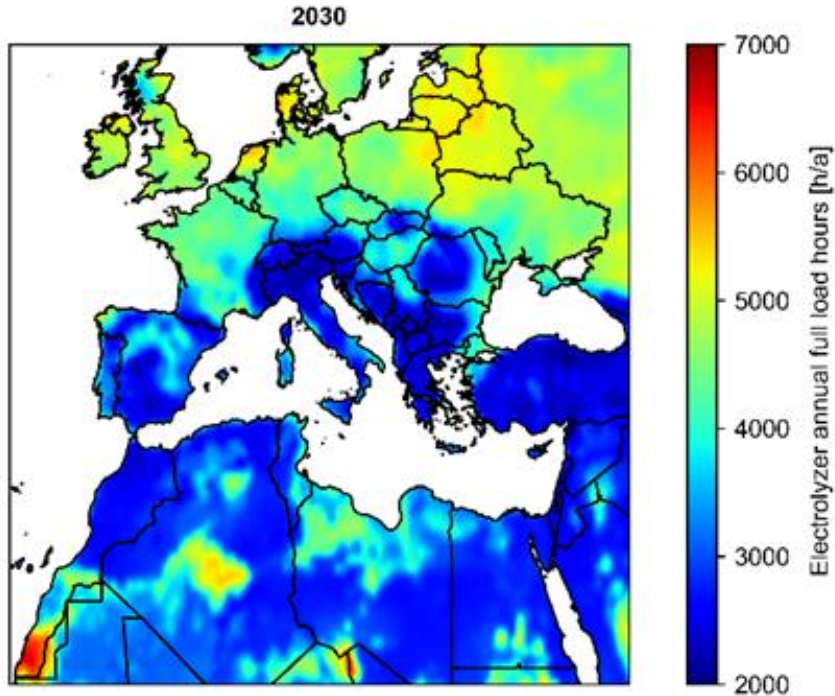


PV Share

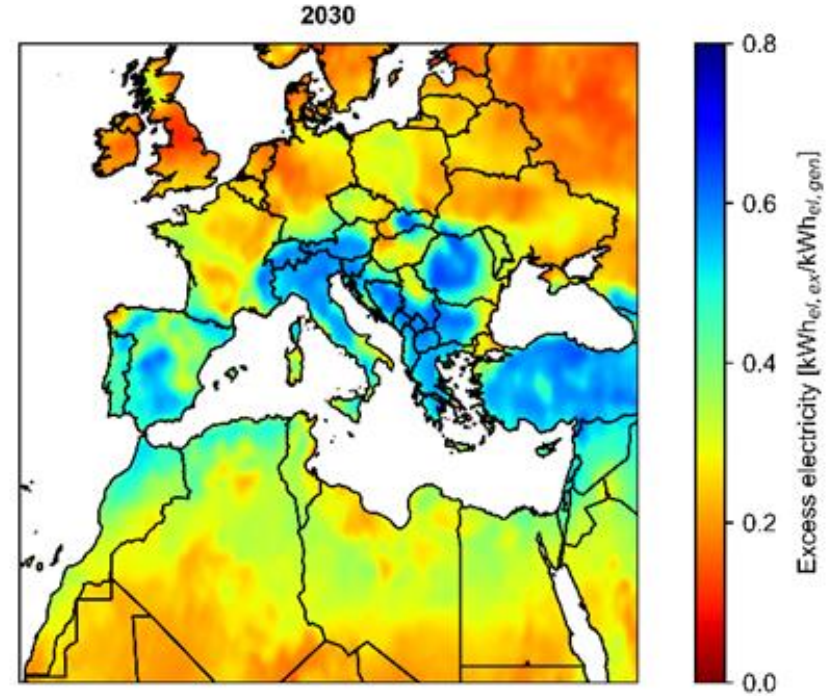
2030



Electrolyzer Annual Full Load Hours

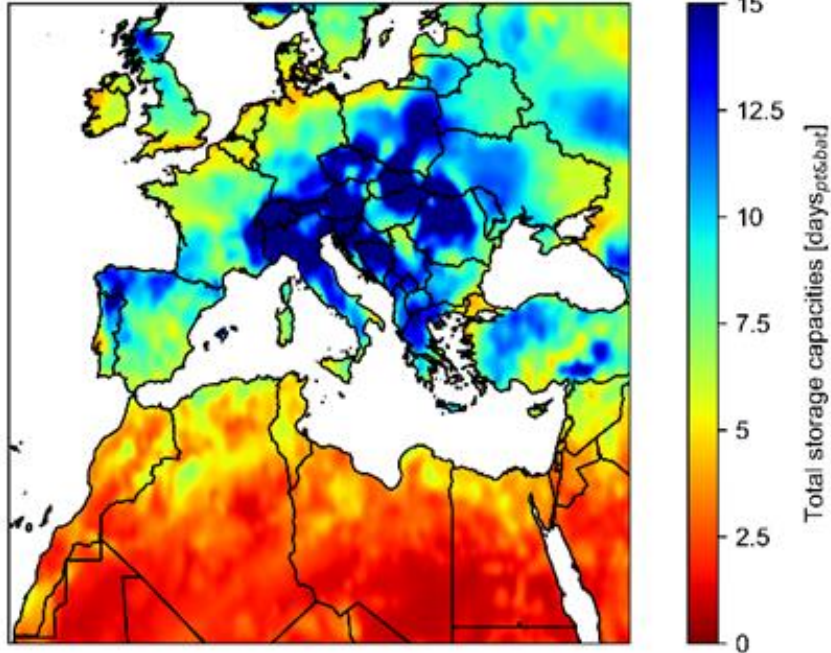


Excess Electricity



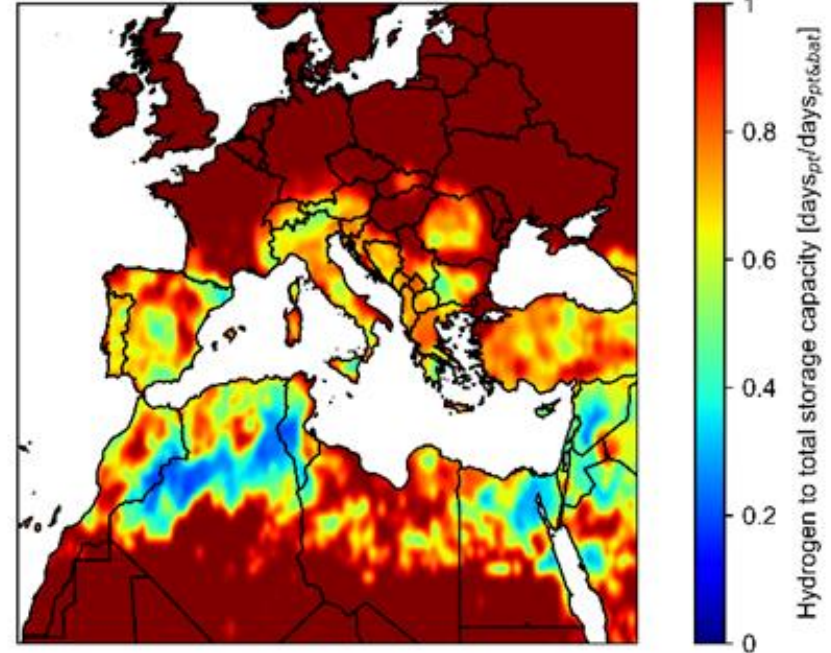
Total Storage Capacities

2030



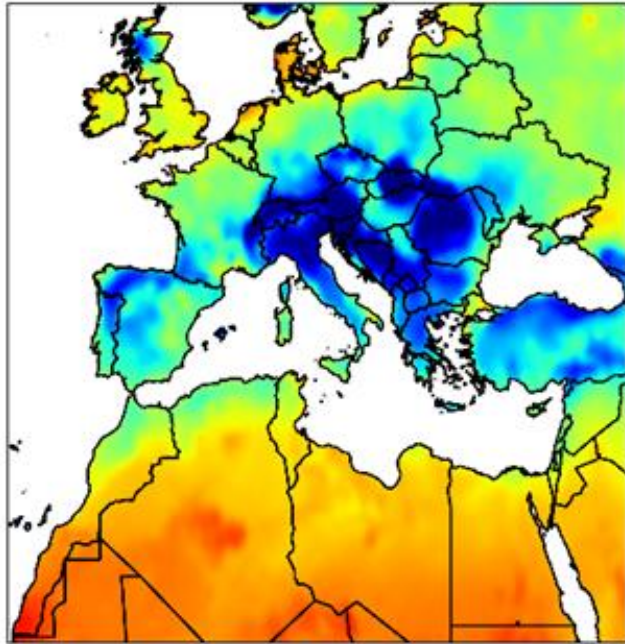
Hydrogen to Battery Storage Ratio

2030



Without Salt Cavern

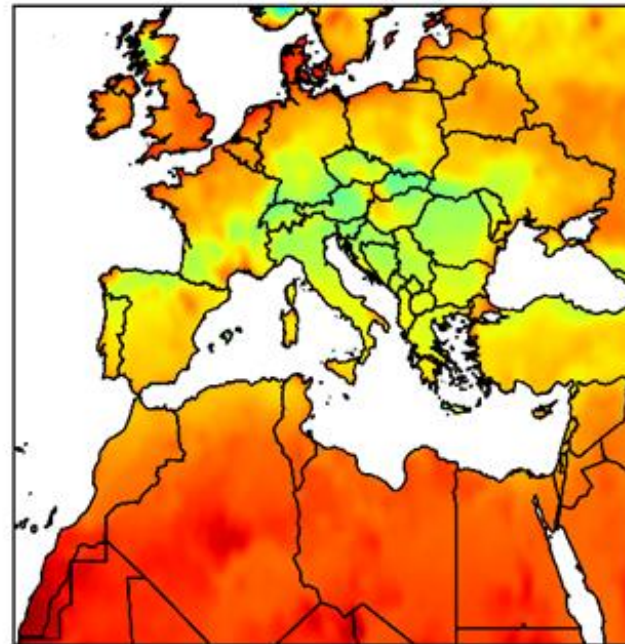
2030



8
7
6
5
4
3
2
Onsite hydrogen supply cost [€/2020/kgH₂]

With Salt Cavern

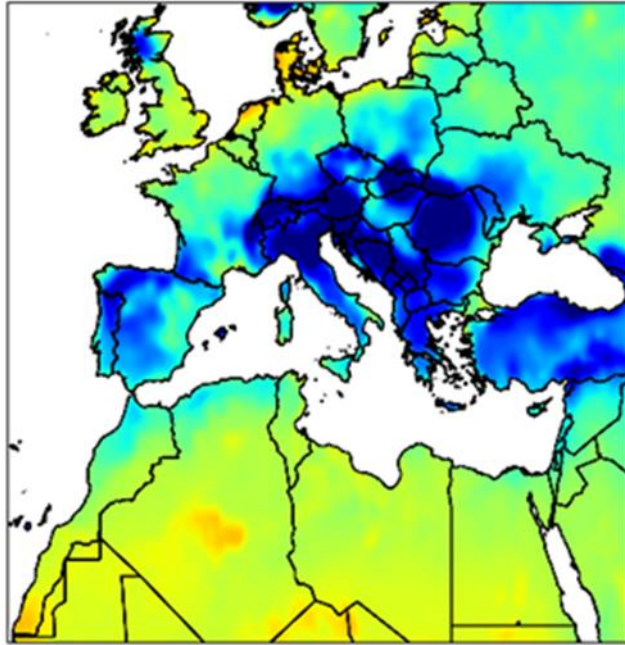
2030 - Additional hydrogen cavern storage



8
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Onsite hydrogen supply cost [€/2020/kgH₂]

Without Salt Cavern

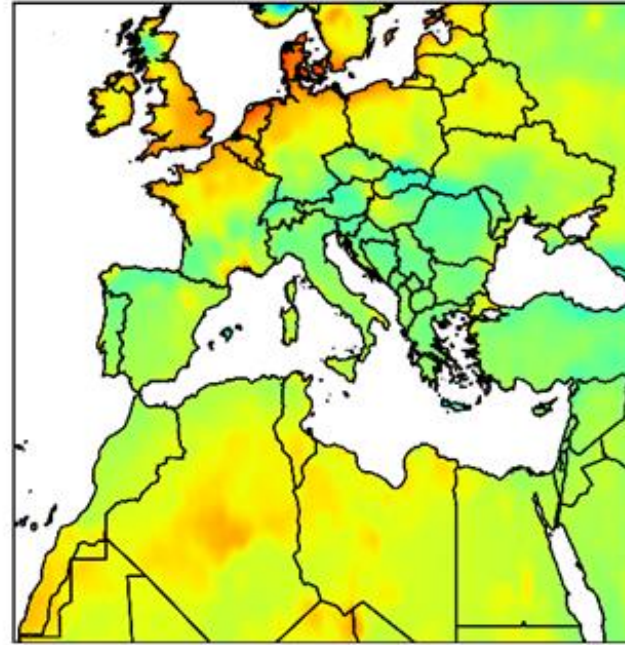
2030



Hydrogen supply cost to Germany [€/kgH₂]

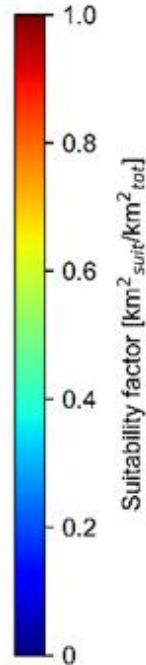
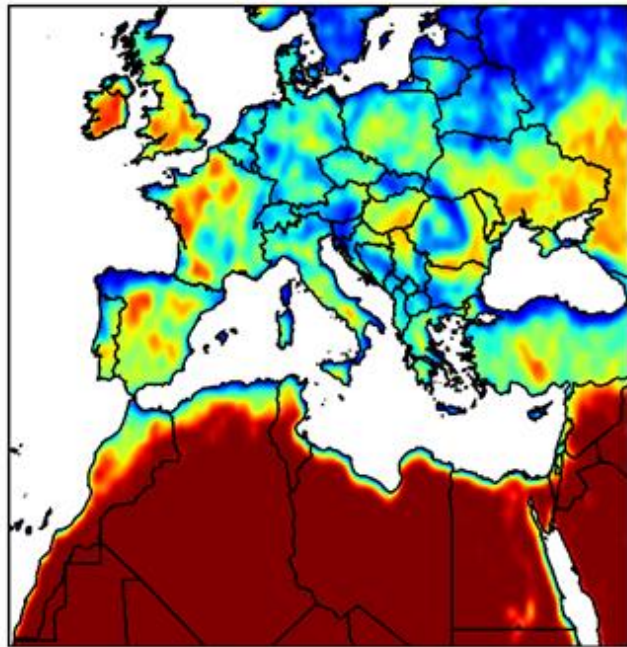
With Salt Cavern

2030 - Additional hydrogen cavern storage



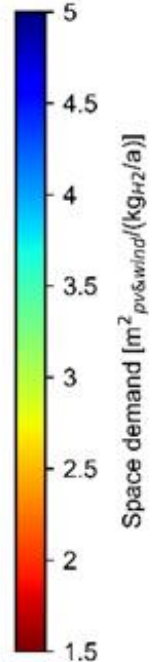
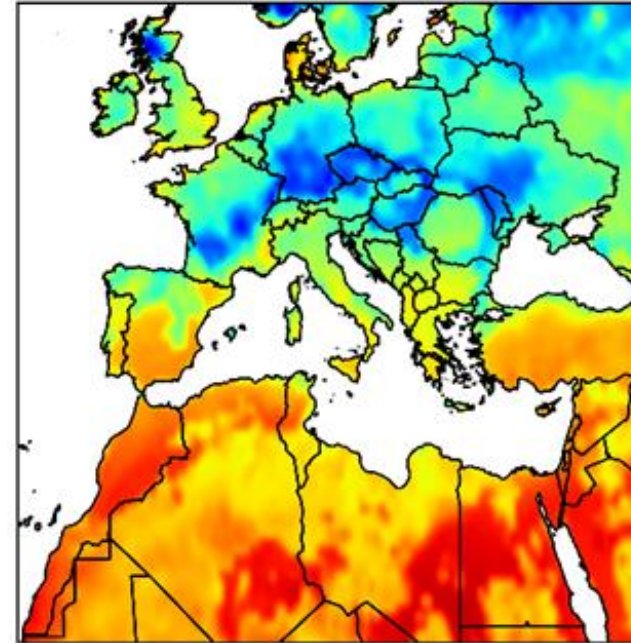
Hydrogen supply cost to Germany [€/kgH₂]

Suitability Factor

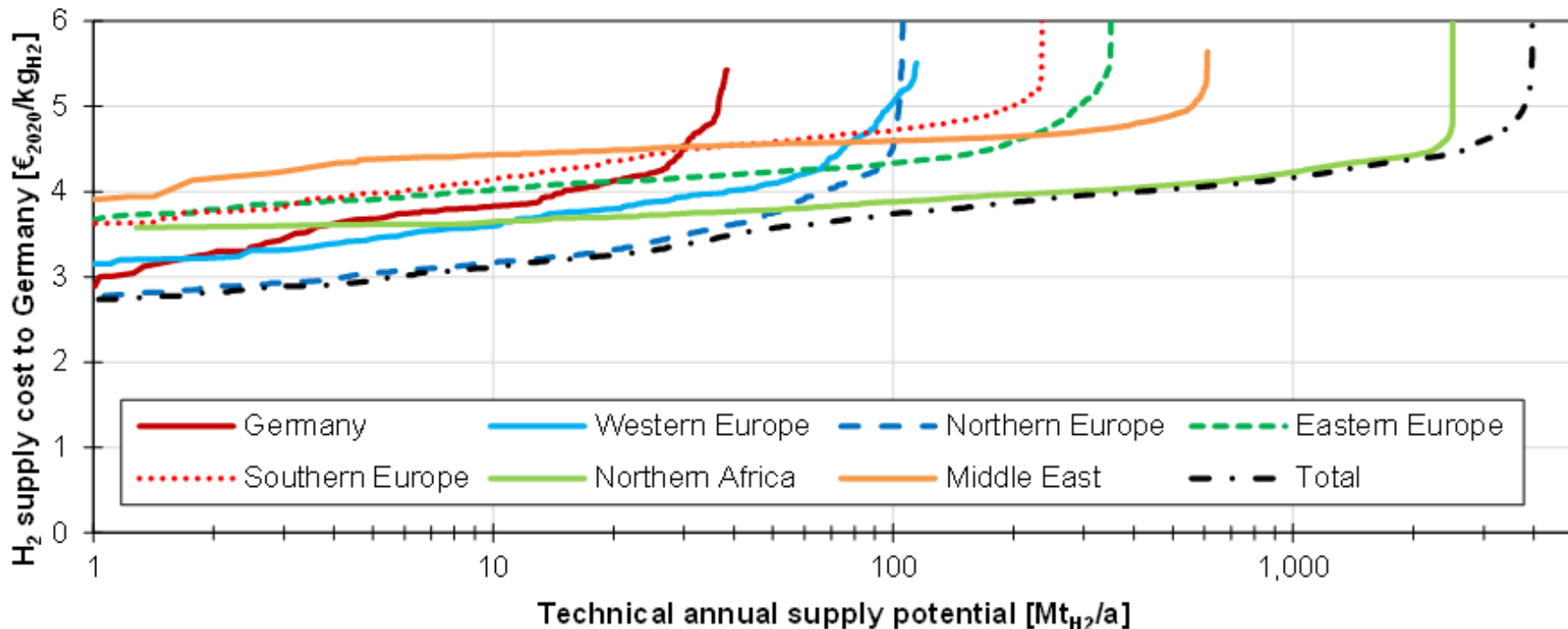


Space Demand

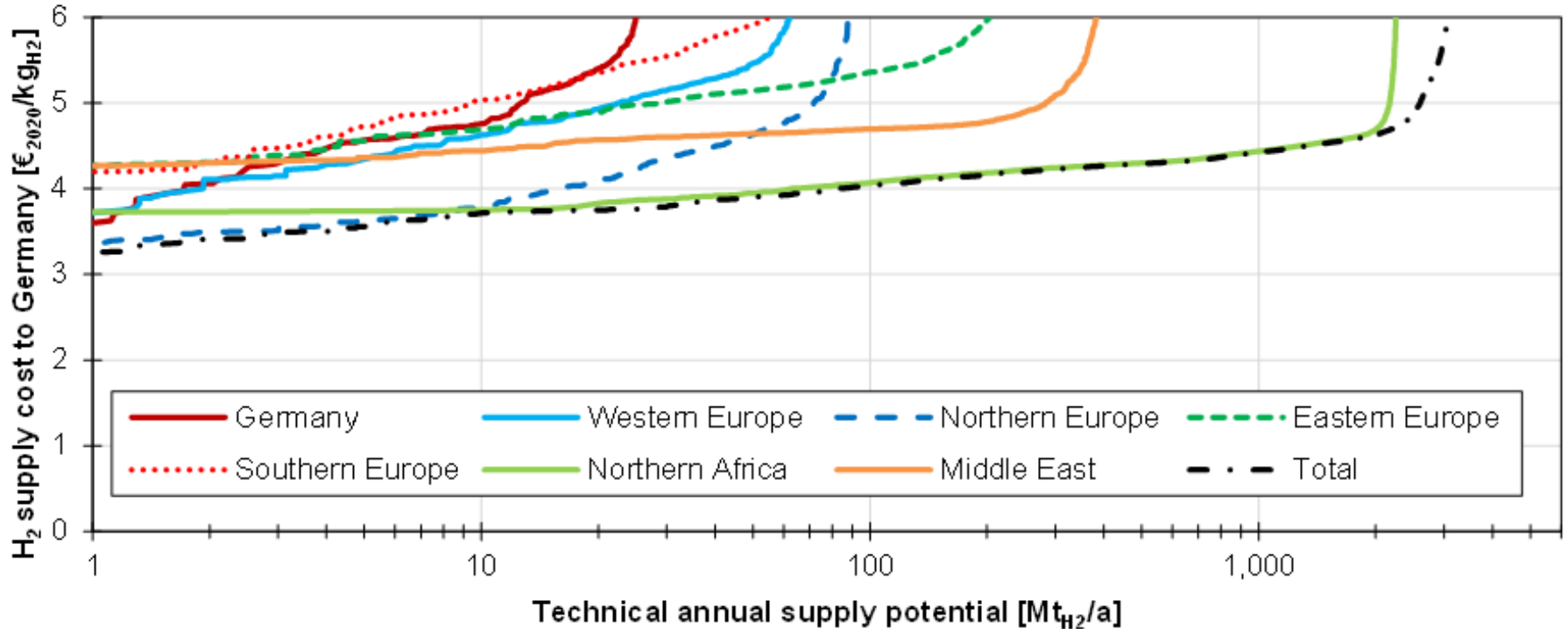
2030 - Additional hydrogen cavern storage



Supply Potential with Salt Cavern Use (2030)



Supply Potential without Salt Cavern Use (2030)



- Which regions obtain the lowest onsite hydrogen supply cost?
 - Western Sahara, Central Algeria and Coastal Location at the North Sea with $3 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ (2030) and $2 \text{ €}_{2020}/\text{kg}$ (2050)
- What is the magnitude of the hydrogen supply potential to Germany?
 - around $20 \text{ Mt}_{\text{H}_2}/\text{a}$ for $4 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ (domestic, 2030, salt cavern use) or more than $100 \text{ Mt}_{\text{H}_2}/\text{a}$ for $3.5 \text{ €}_{2020}/\text{kg}_{\text{H}_2}$ (Northern Africa, 2030, salt cavern use)
- What is the optimal renewable electricity generation power ratio?
 - Photovoltaic and wind power between 2 to 4 times higher than electrolyzer power
- Do we generate excess electricity?
 - Excess electricity lays between 10 to 30% for the best locations and can be lowered significantly if salt cavern are used

- How many annual full load hours are achieved by the electrolyzer?
 - Annual full load hours vary between 2,000 (PV dominated) to 6,000 FLH/a (Wind dominated)
- What size of storage capacities are necessary to overcome dark doldrums?
 - Around 5 to 10 days self sufficient capacity (increases in the case of salt cavern use)
- Does the implementation of salt cavern storage changes the overall picture?
 - Lowers the onsite cost significantly, especially for locations that have a high solar radiation but still a high seasonality
- What is the space demand for the production of green hydrogen?
 - Between 2 to 4 m²/(kg_{H2}/a)

Associated paper can be downloaded until 15th of July
2022 for free under:

<https://authors.elsevier.com/a/1f8SAin8VgSwA>



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- [4] <https://images.app.goo.gl/wpf5beDJPAXoCJxF6>
- [5] <https://images.app.goo.gl/bD24v1L26ANsmx4n8>
- [6] <https://images.app.goo.gl/58YNqjNLviaWJ1rZA>
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