Strategic National Advancement

Reservoir air-conditioning: a sustainable seasonal thermal energy storage technology

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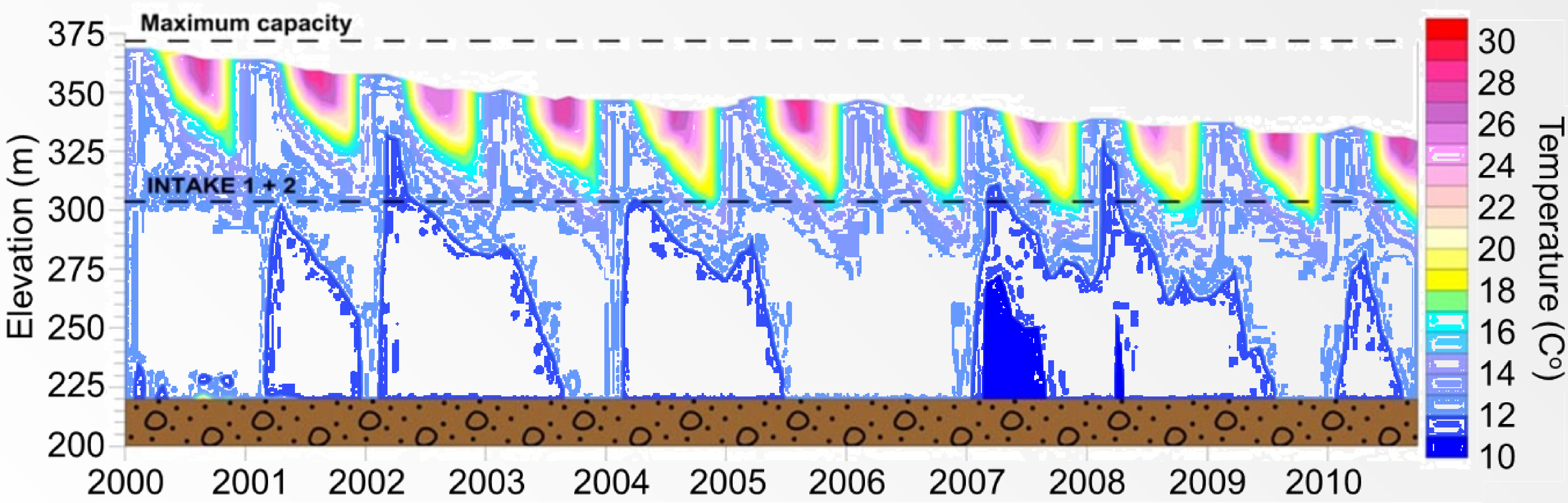
Reservoir air-conditioning: a sustainable seasonal thermal energy storage technology

- The thermocline layer works as insulation, maintaining the cold bottom of the reservoir.
- 1ºC increase in Lake Mead's temperature equials 1% global cooling demand.

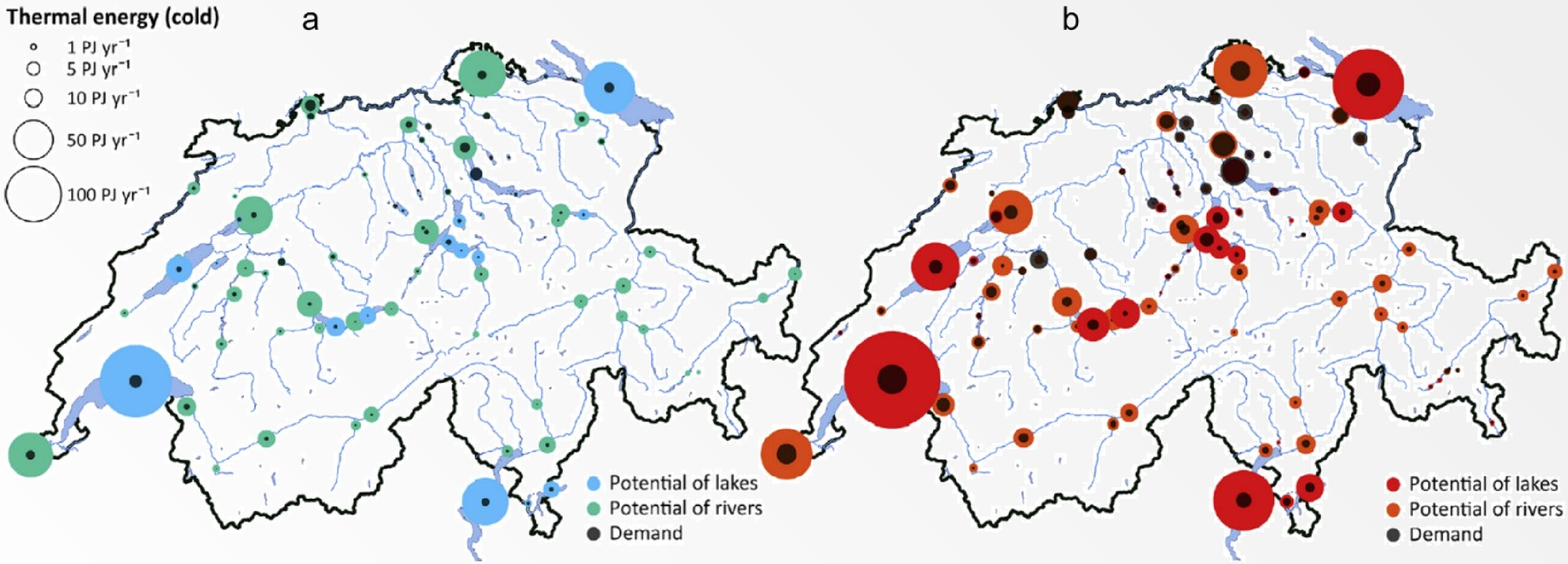


Lake Mead's temperature profile from 2000 to 2010 (https://www.nps.gov/lake/learn/hydrology.htm)

Change of subject:

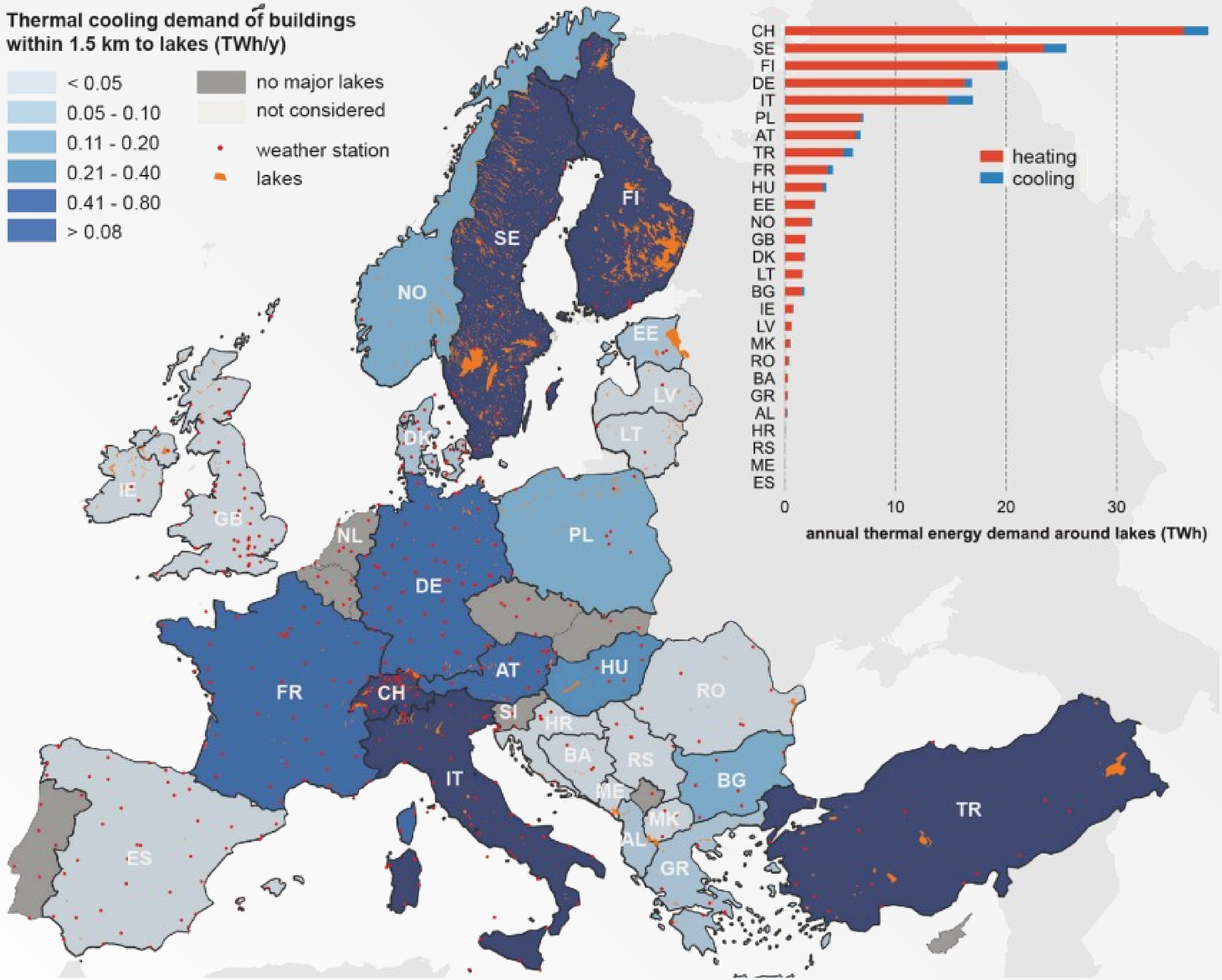
Reservoir air-conditioning: a sustainable seasonal thermal energy storage technology

- The topic has been explored both in a country and regional level.
- Decided to work in other topic.



Potentials for using lakes and rivers in Switzerland for (a) cooling and (b) heating

Gaudard A, Wüest A, Schmid M. Using lakes and rivers for extraction and disposal of heat: Estimate of regional potentials. Renew Energy 2019;134:330–42.



Potentials for using lakes and reservoirs for cooling and heating in Europe

Eggimann S, Vivian J, Chen R, Orehounig K, Patt A, Fiorentini M. The potential of lake-source district heating and cooling for European buildings. Energy Convers

New subject:

International Journal of Hydrogen Energy

Hydrogen storage in lakes, hydropower, and pumped hydro storage reservoirs

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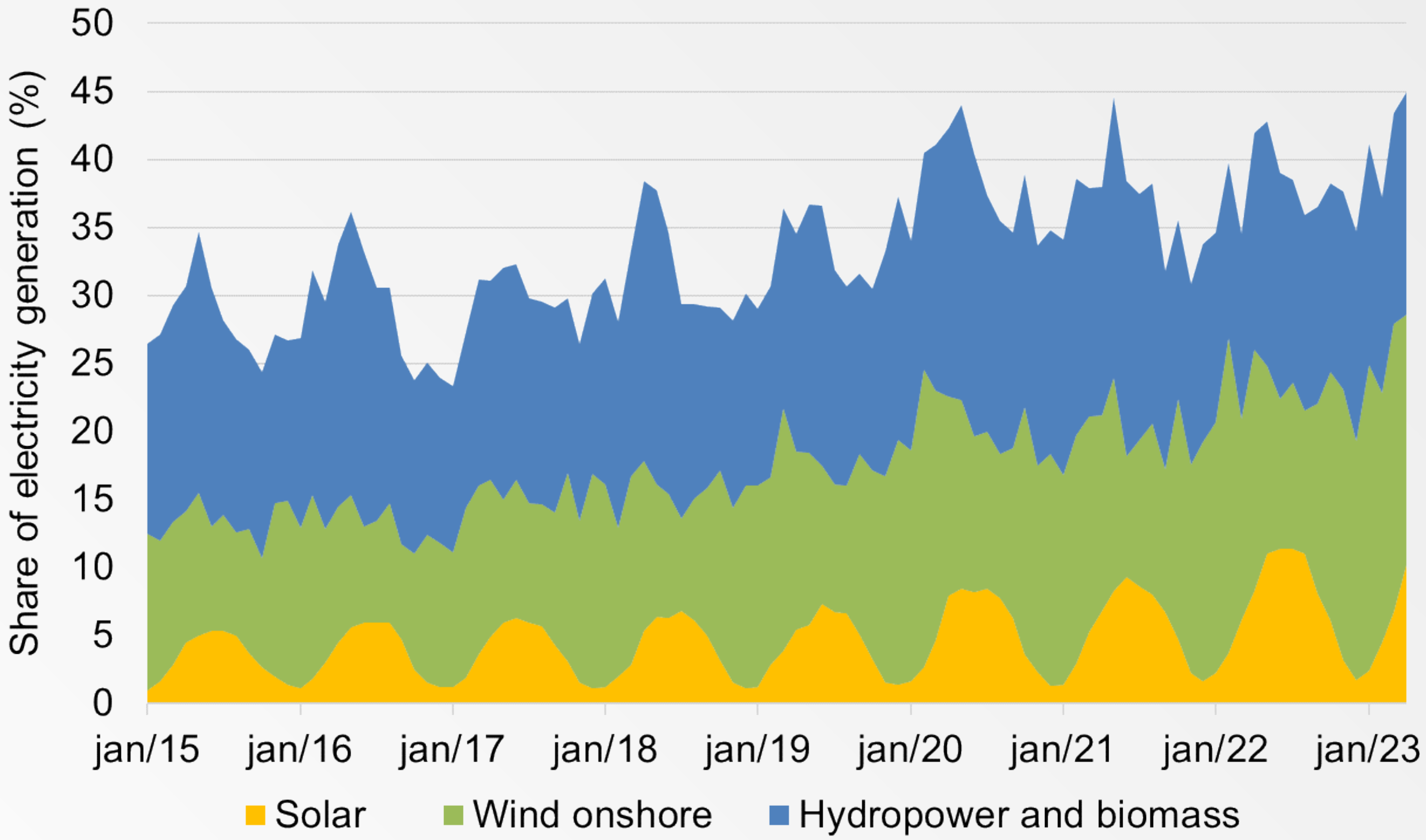
[8] Federal University of Rio de Janeiro, Brazil.

Hydrogen storage in lakes, hydropower, and pumped hydro storage reservoirs

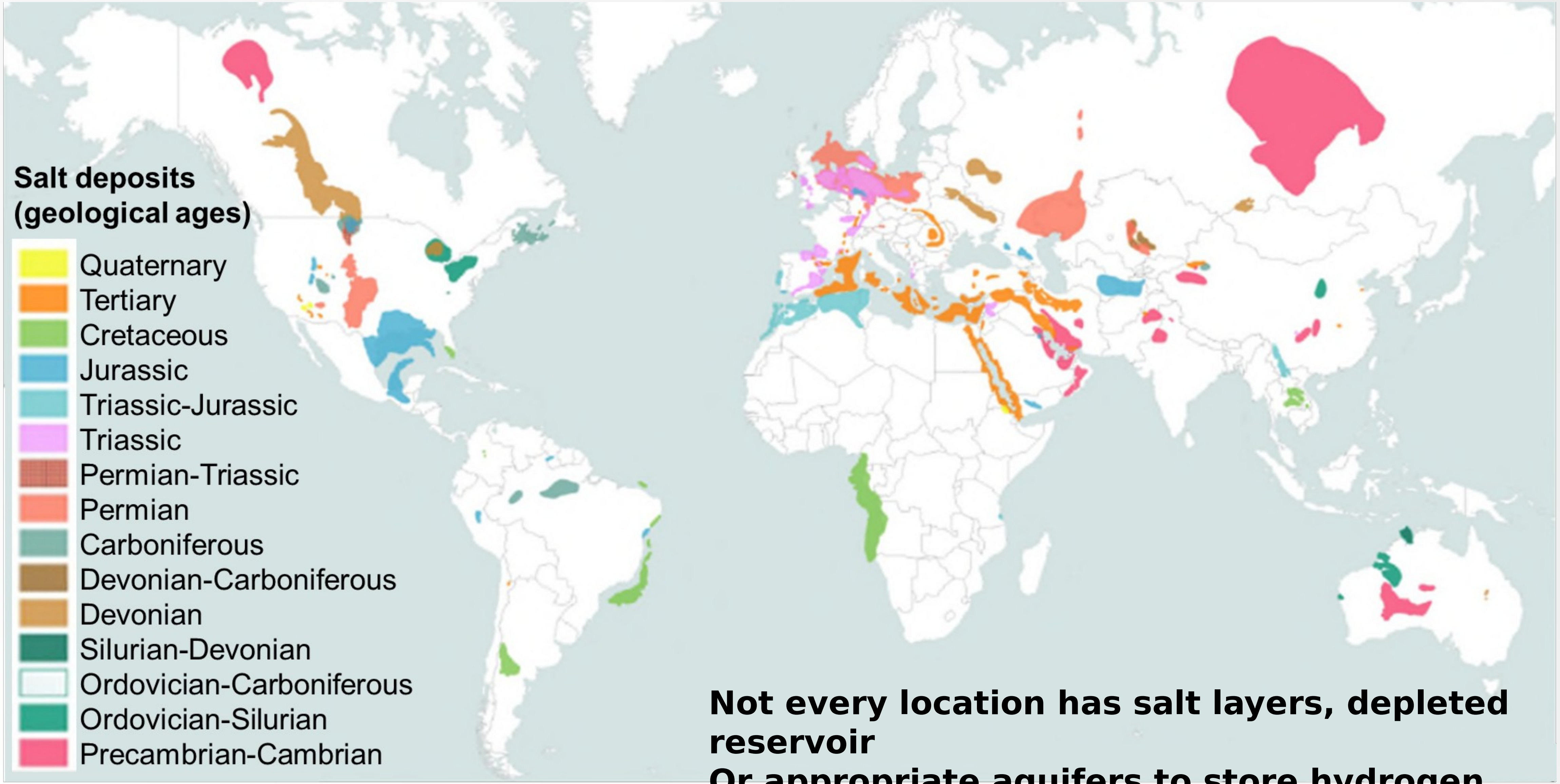
Motivation:

Share of electricity generation from renewable energy sources in the European Union from 2015 to 2023



- Increase in solar and wind increases the demand for energy storage.
- Solar energy demands seasonal energy storage.
- Hydrogen is current the most promising solution for seasonal storage.
- New hydrogen energy storage solutions should be investigated.

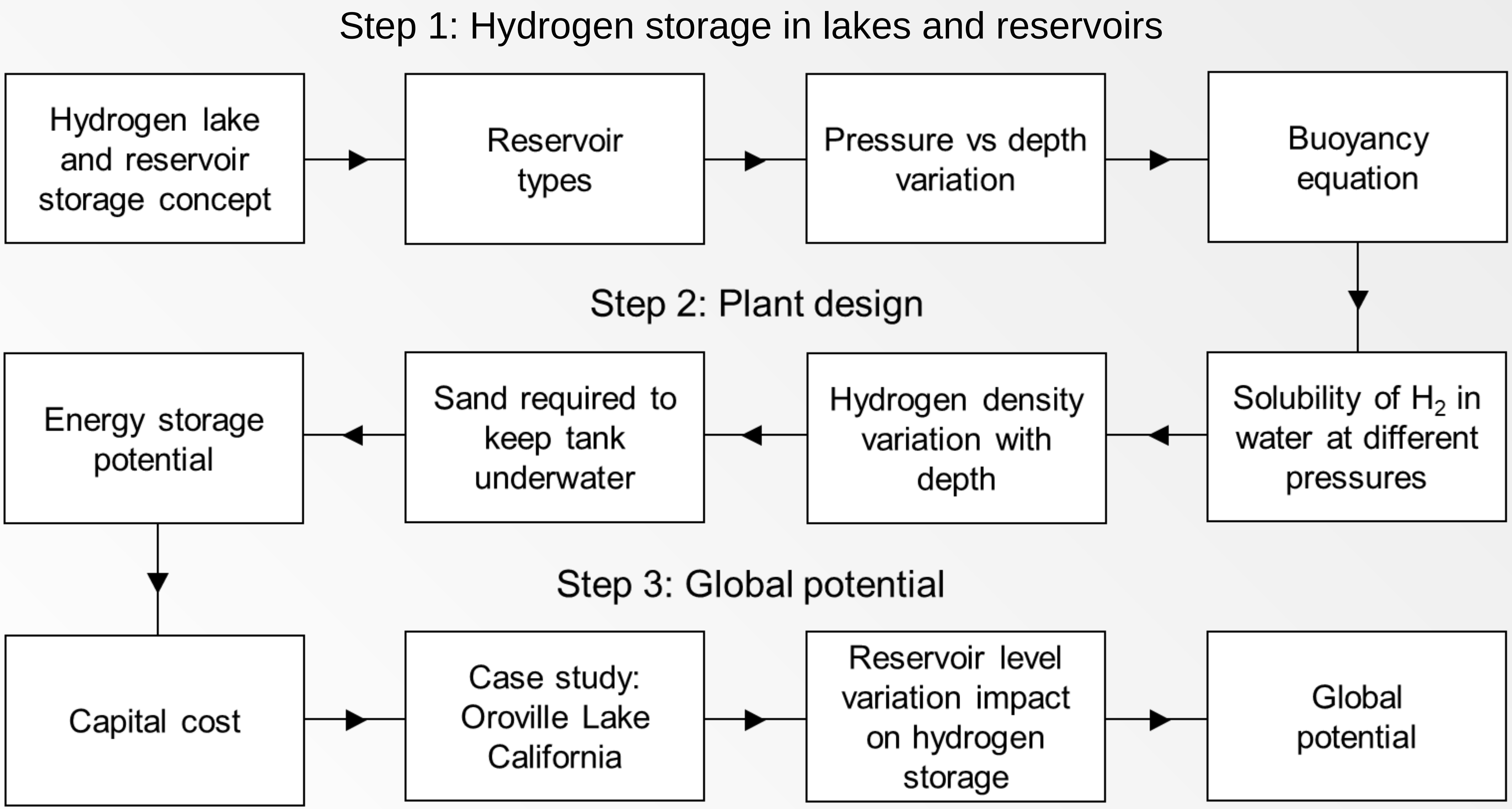
Motivation: **Existing salt layers around the world**



Not every location has salt layers, depleted reservoir
Or appropriate aquifers to store hydrogen.

Hévin, G. Underground Storage of Hydrogen in Salt Caverns. In Proceedings of the European Workshop on Underground Energy Storage, Paris, France, 7–8

Methodology: Methodological framework



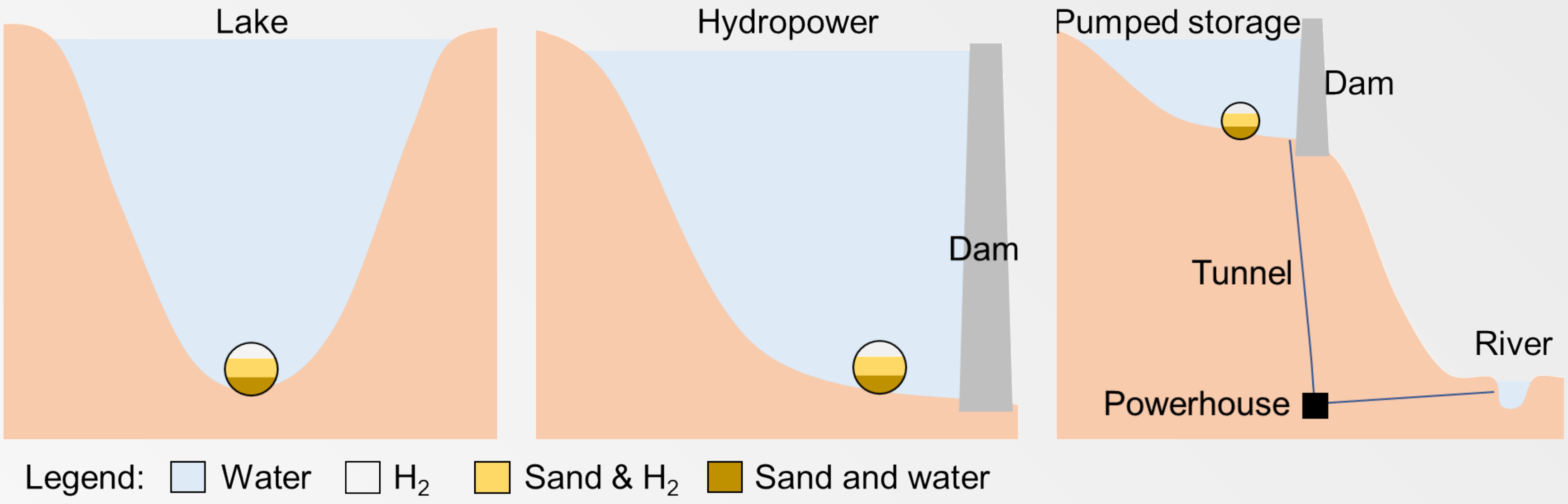
Methodology:

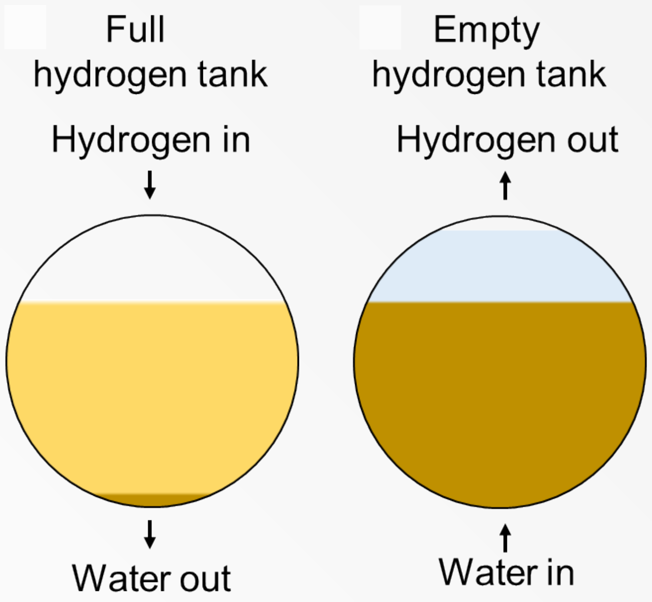
Main equation

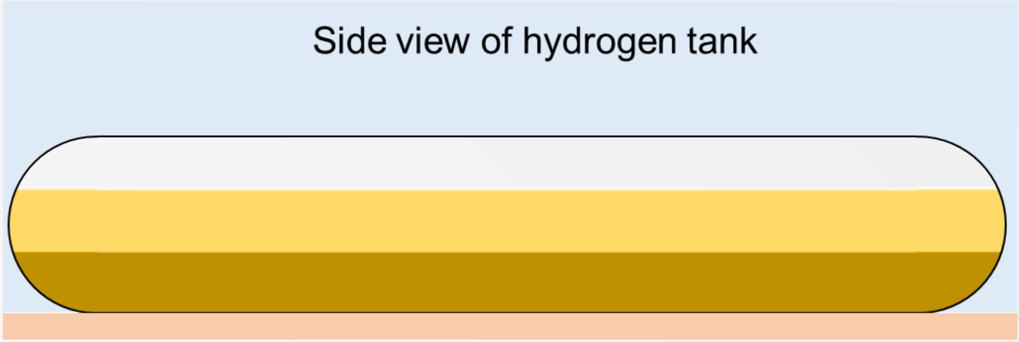
$$P_T = P_r + \frac{D}{10.2}$$

- is the pressure of the hydrogen tank.
- is the pressure of the atmosphere on the top of the reservoir/lake.
- is the depth of the storage tank.

Hydrogen storage in:

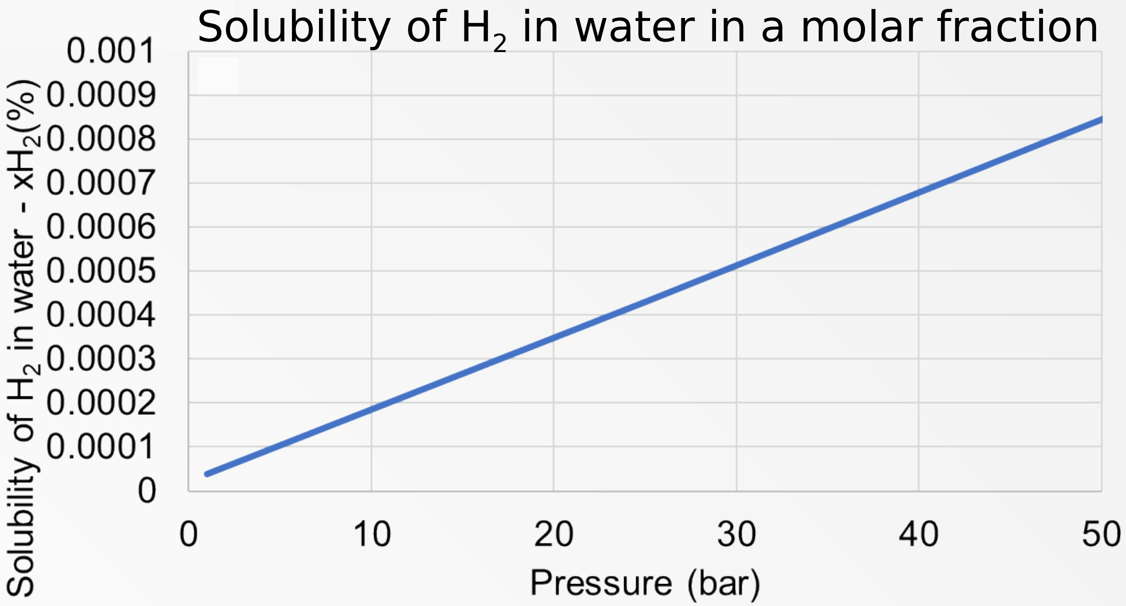




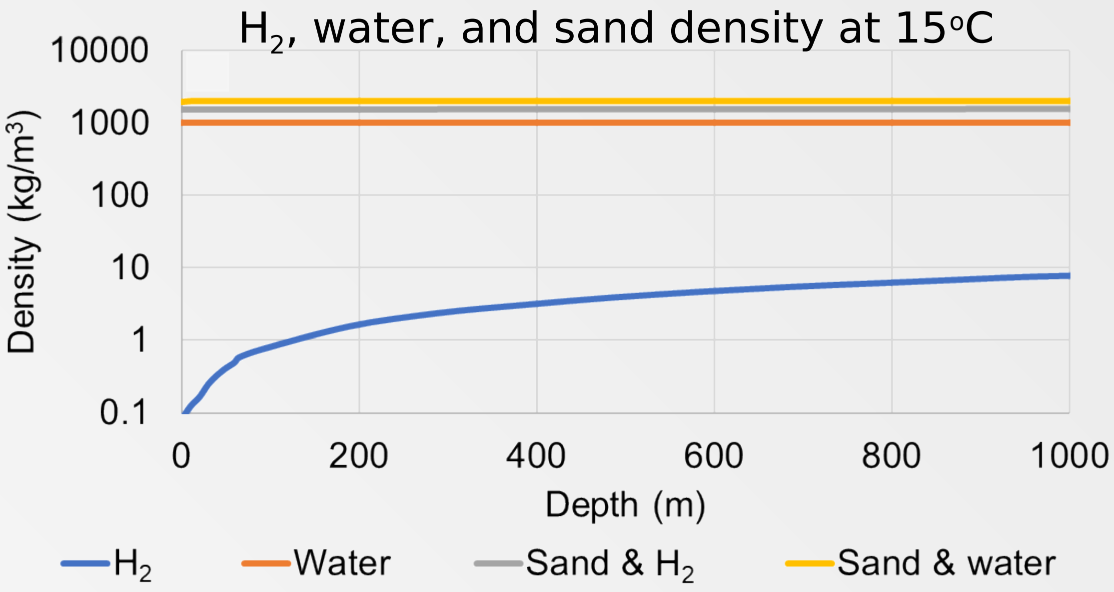


Pressure inside the tank = pressure outside the tank

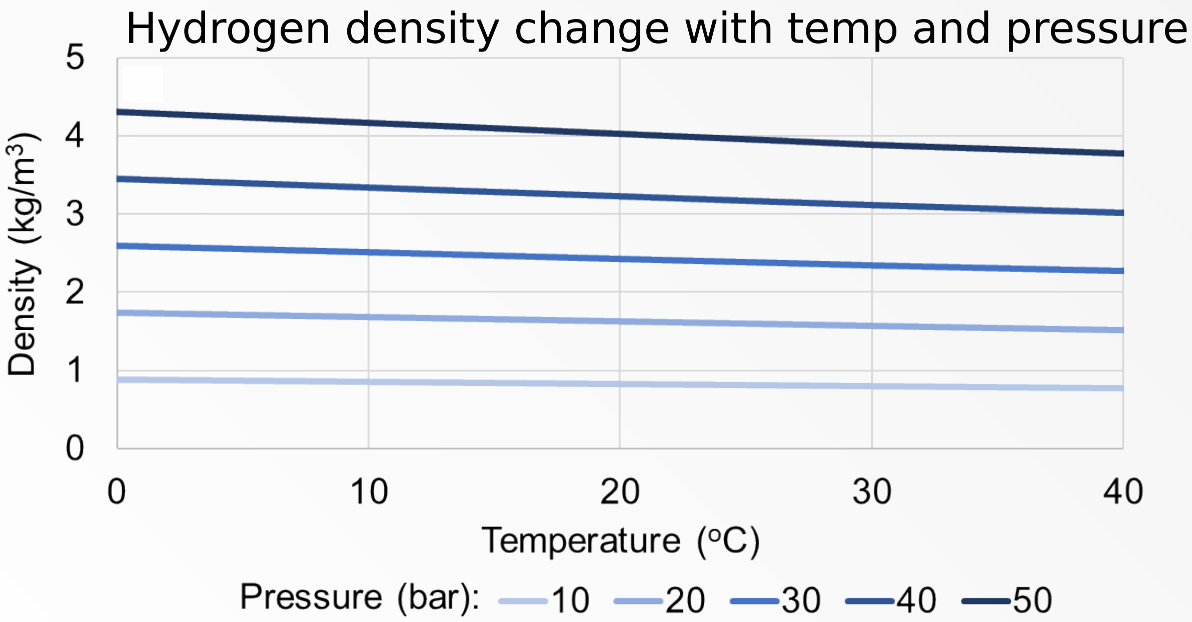
Results:



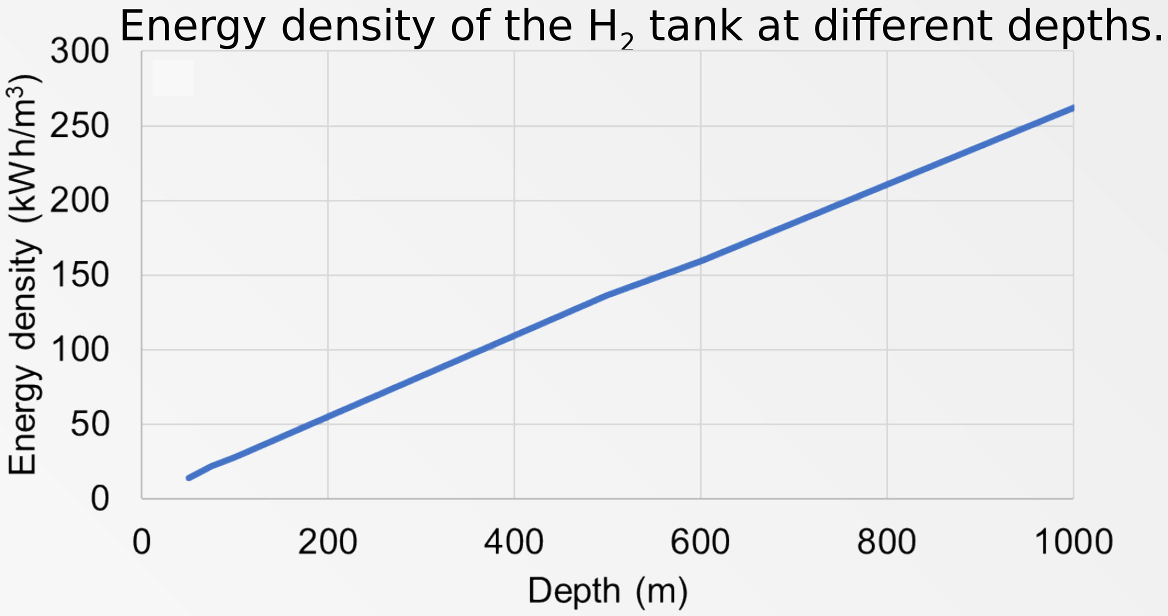
Solubility of H2 in water in a molar fraction
Solubility of H2 in water - xH2(%)
0.001
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0 10 20 30 40 50
Pressure (bar)



H2, water, and sand density at 15°C
Density (kg/m3)
10000
1000
100
10
1
0.1
0 200 400 600 800 1000
Depth (m)
H2
Water
Sand & H2
Sand & water



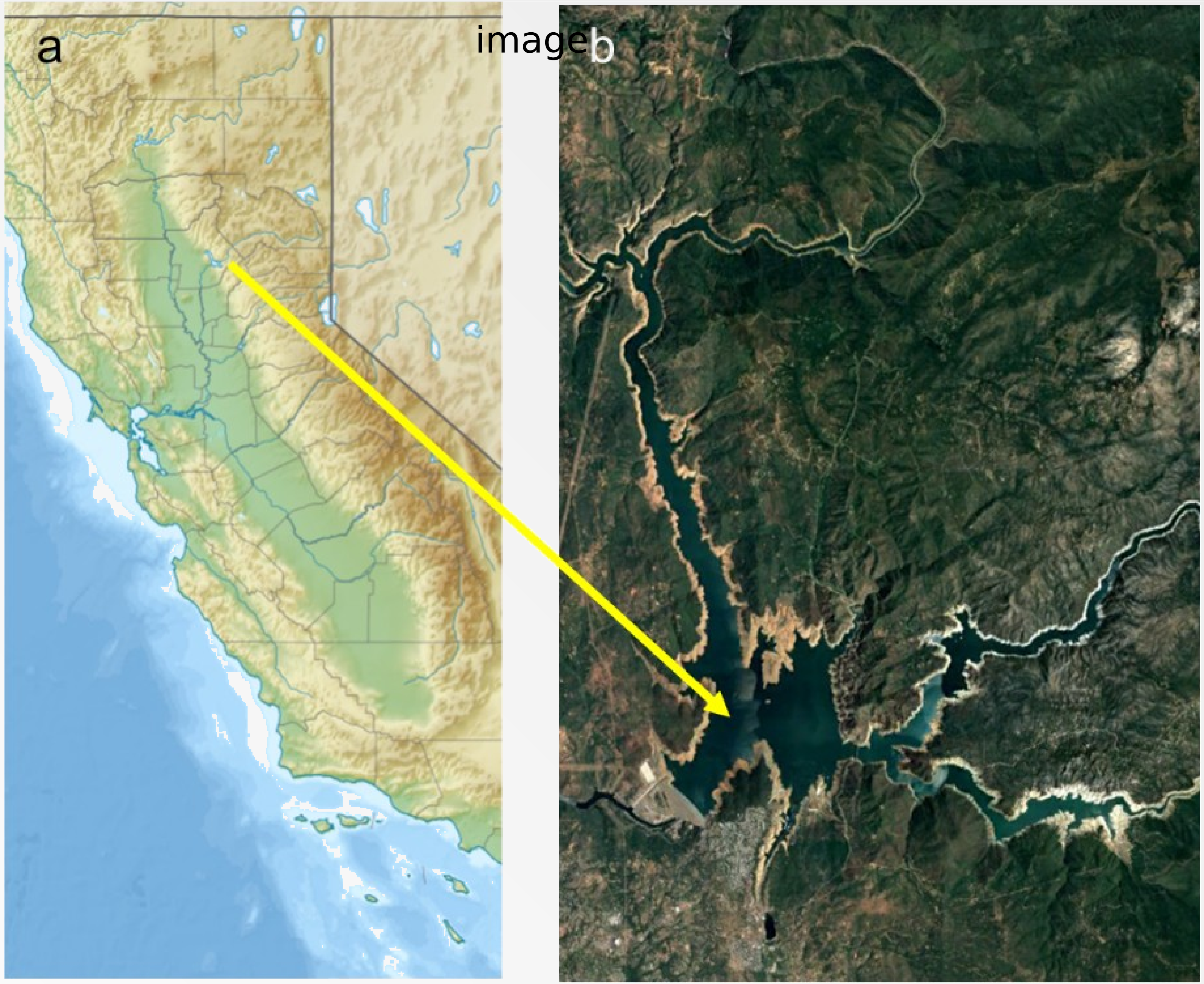
Hydrogen density change with temp and pressure
Density (kg/m3)
5
4
3
2
1
0
0 10 20 30 40
Temperature (°C)
Pressure (bar): 10 20 30 40 50



Energy density of the H2 tank at different depths.
Energy density (kWh/m3)
300
250
200
150
100
50
0
0 200 400 600 800 1000
Depth (m)

Case study:

(a) Oroville reservoir location in California, (b) Oroville reservoir satellite image



Oroville reservoir

Feather River,

Butte County,

California, USA

Reservoir area: 64.75 km^2

Reservoir volume: 4.3 km^3

Hydroelectric power capacity: 132 MW

Pump capacity: 819 MW

Case study:

Oroville reservoir maximum depth: 210 m

Reservoir bottom temperature: 8°C

Reservoir bottom area: 456.300 m^2

Pipeline diameter: 10 m

Volume storage capacity: 2.176.200 m^3

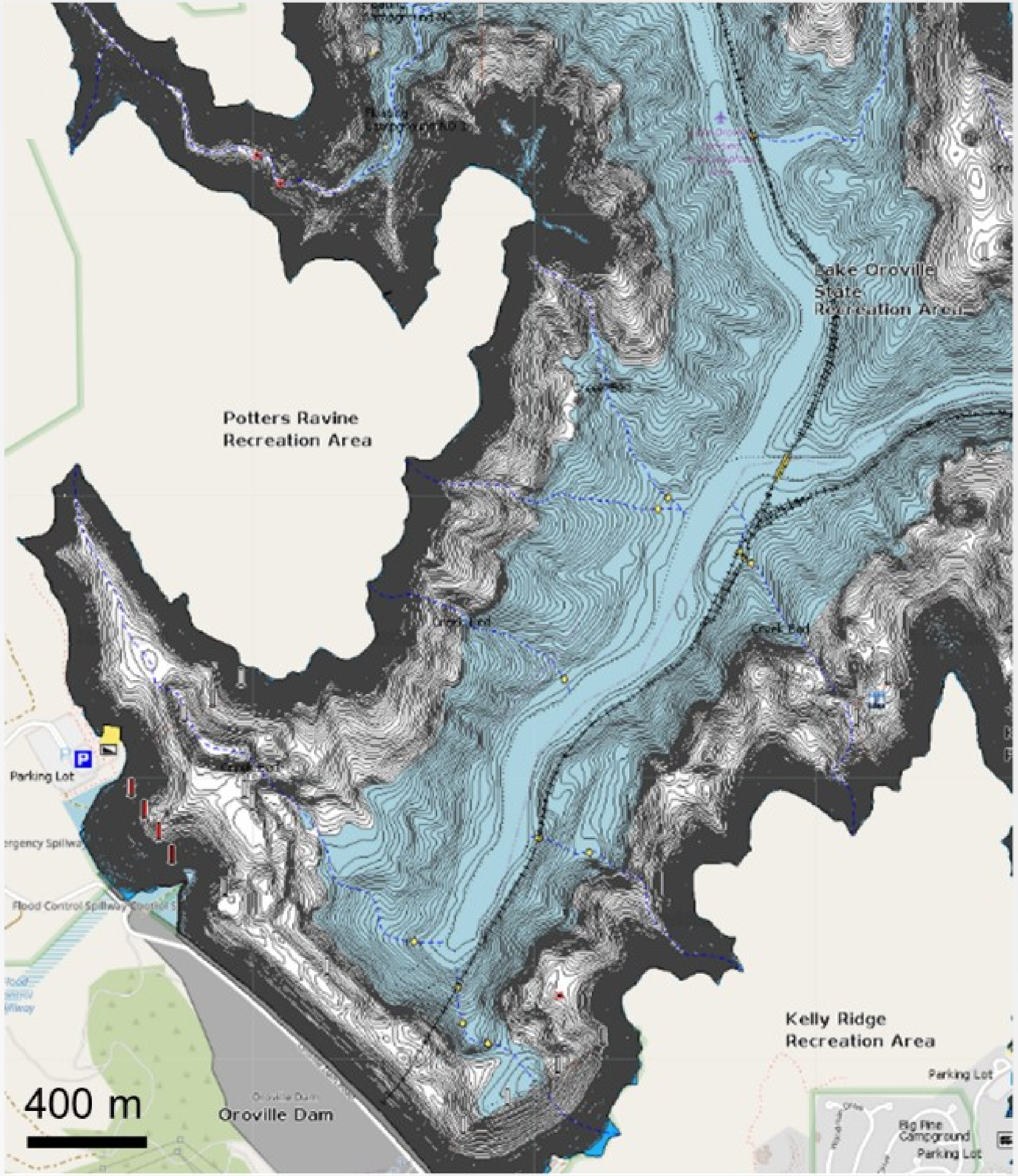
Pressure: 20.6 bar

Hydrogen density: 1.691 kg/m^3

Hydrogen storage capacity: 3.679.650 kg

Electricity storage capacity: 86 GWh

Oroville reservoir bathymetry



Case study:

Solar capacity: 400 MW

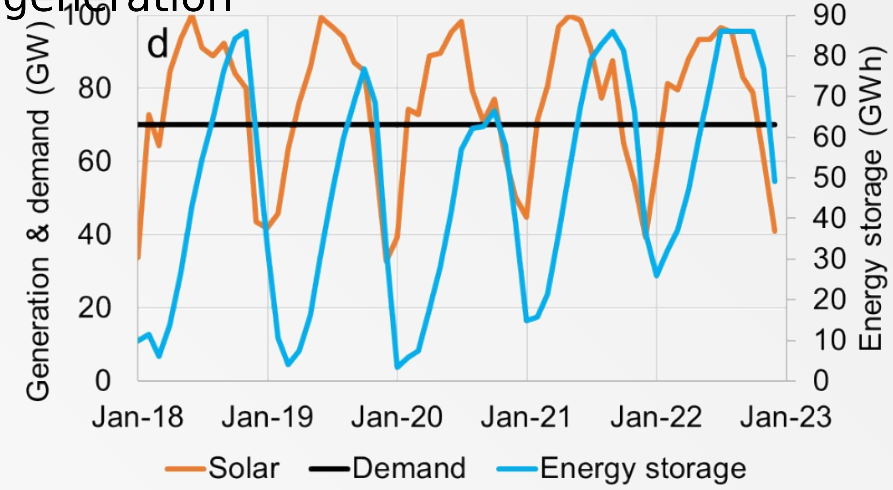
Demand: 70 MW

Electrolysis & batteries: 330 MW

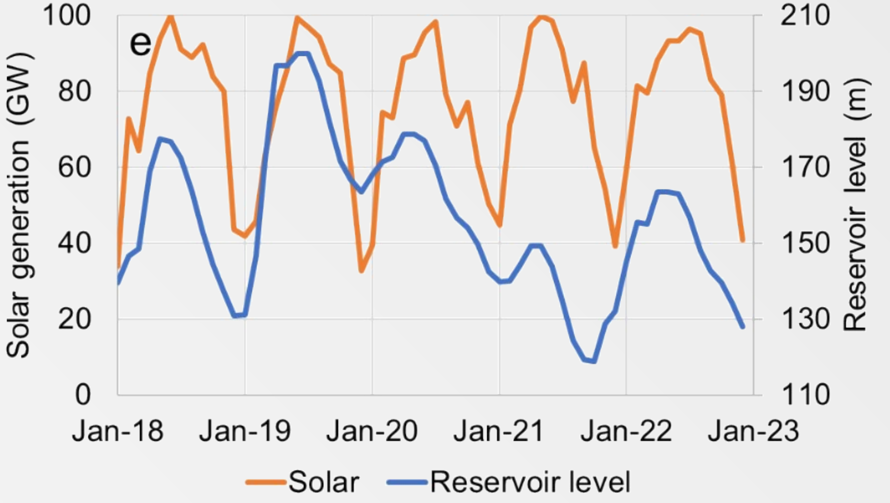
Energy curtailed: 14%

Reservoir levels have a significant impact on the hydrogen storage capacity

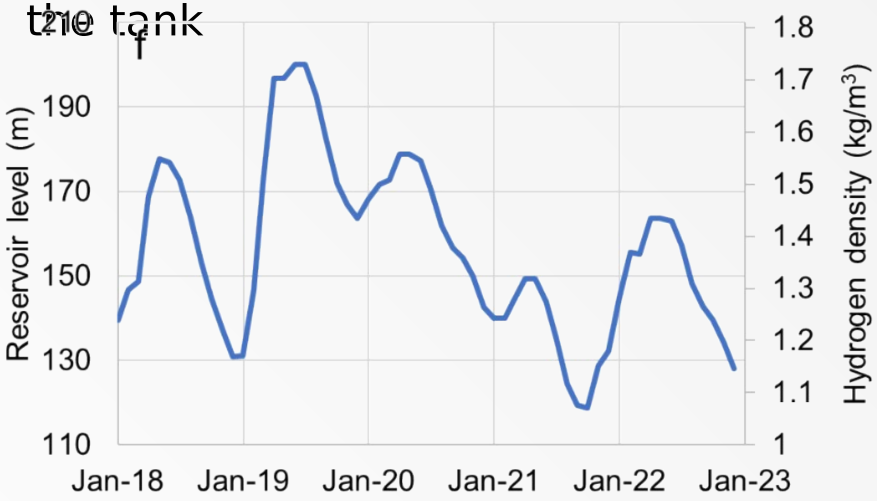
Solar generation, demand and energy storage generation



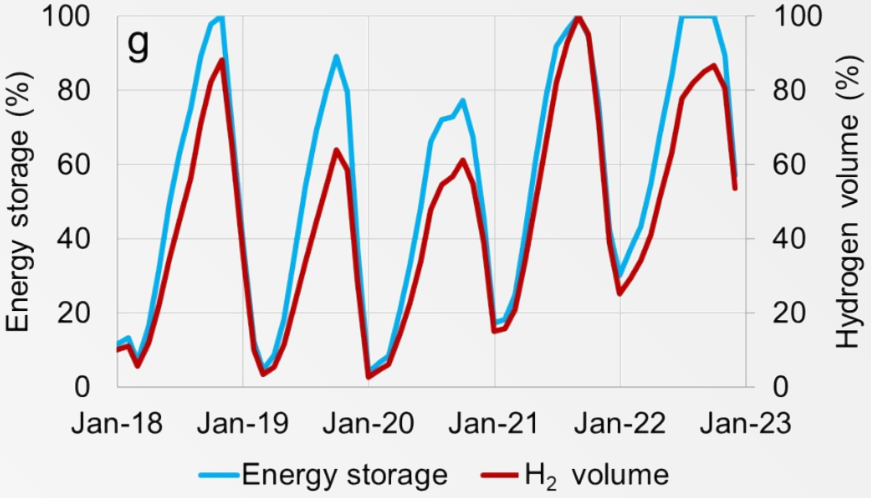
Reservoir level and solar



Reservoir level and H_2 density in the tank



Energy storage and H_2 volume in the tank



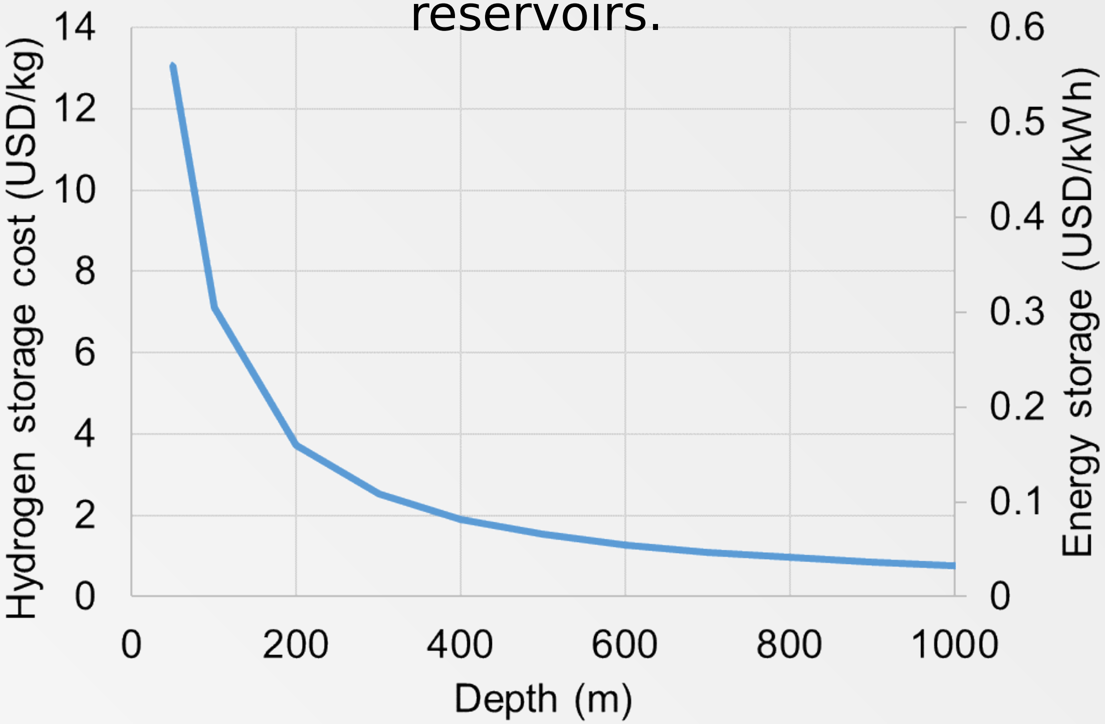
Results

Capital cost for H_2 storage 200 m deep and 15°C

Component	Cost description	Cost
Pipe	HDPE pipe with 10 meters in diameter and 100 m long (7,850 m³), extrapolating the costs in [38].	12,000 USD
Pipe sand	Desert sand for 1 USD per tonne [39] to fill a volume of 5,024 m³ with a density of 1,600 kg/m³ (8,038 tonnes).	8,000 USD
Construction	50% of the equipment costs, as equipment costs are very low.	10,000 USD
Total costs	-	30,000 USD
Hydrogen storage capacity	The hydrogen storage capacity is 4,836 m³ at 20.6 bar pressure and 1,651 kg/m³ density.	7,983 kg
Hydrogen storage capital cost	Store 7,983 kg at an installed capacity of 30,000 USD.	3.76 USD/kg
Energy storage costs	Assuming an energy density of 33.3 kWh/kg and a generation efficiency of 70%, the energy storage capacity of the tank is 186 MWh.	0.16 USD/kWh

Hydrogen storage and energy storage capital cost variation with depth in existing lakes and reservoirs.

system.



5 to 25 times cheaper than storing hydrogen in salt caverns

Global Potential

Databases:
HydroLAKES
GRanD

Lakes and reservoirs average depth > 30 m

Number of lakes: 1760

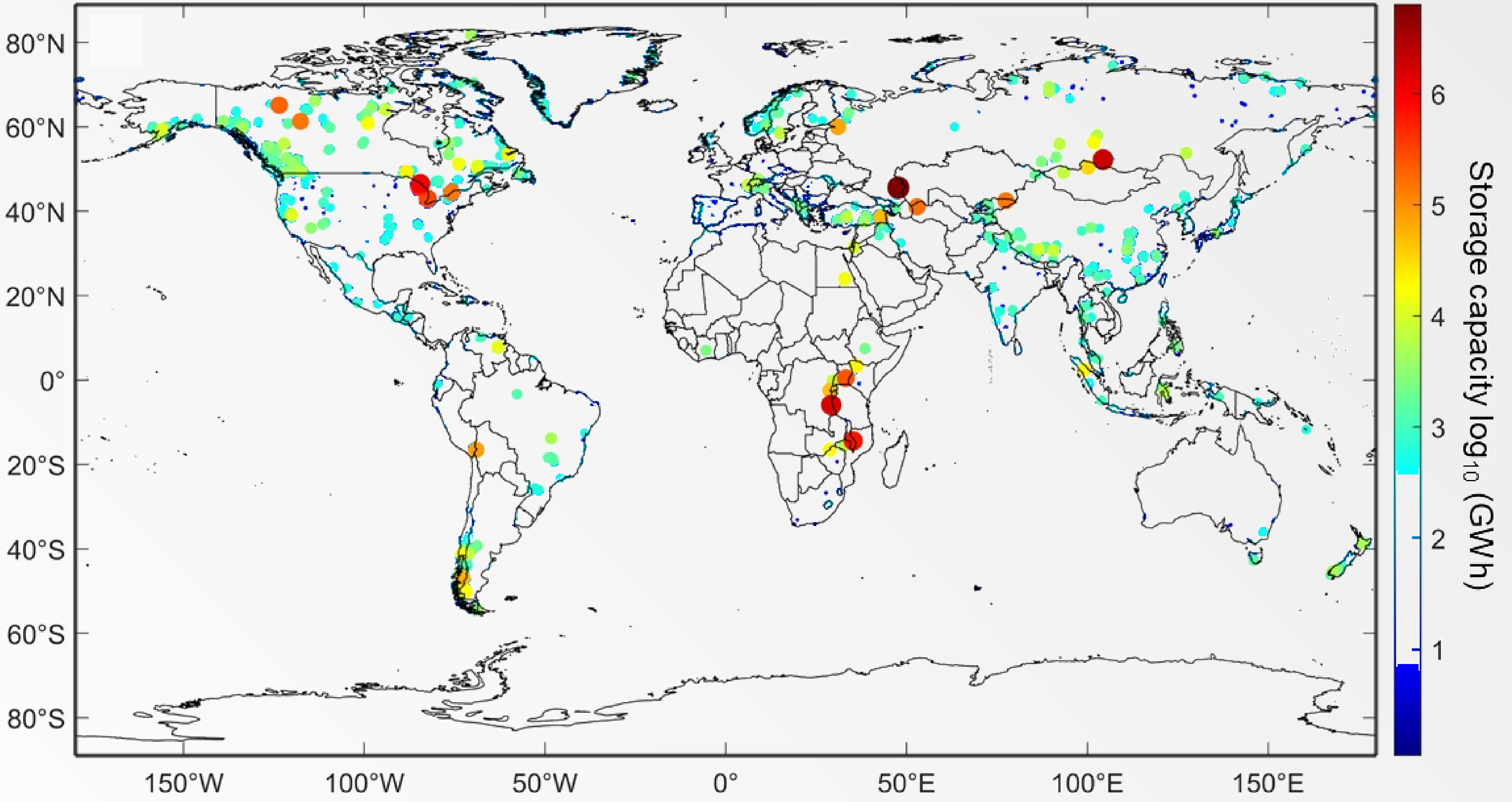
Lakes storage capacity: 12 PWh

Number of reservoirs: 3403.

Reservoirs storage capacity: 3 PWh

Total storage capacity: 15 PWh

Lakes and reservoirs hydrogen storage global potential organized by storage.



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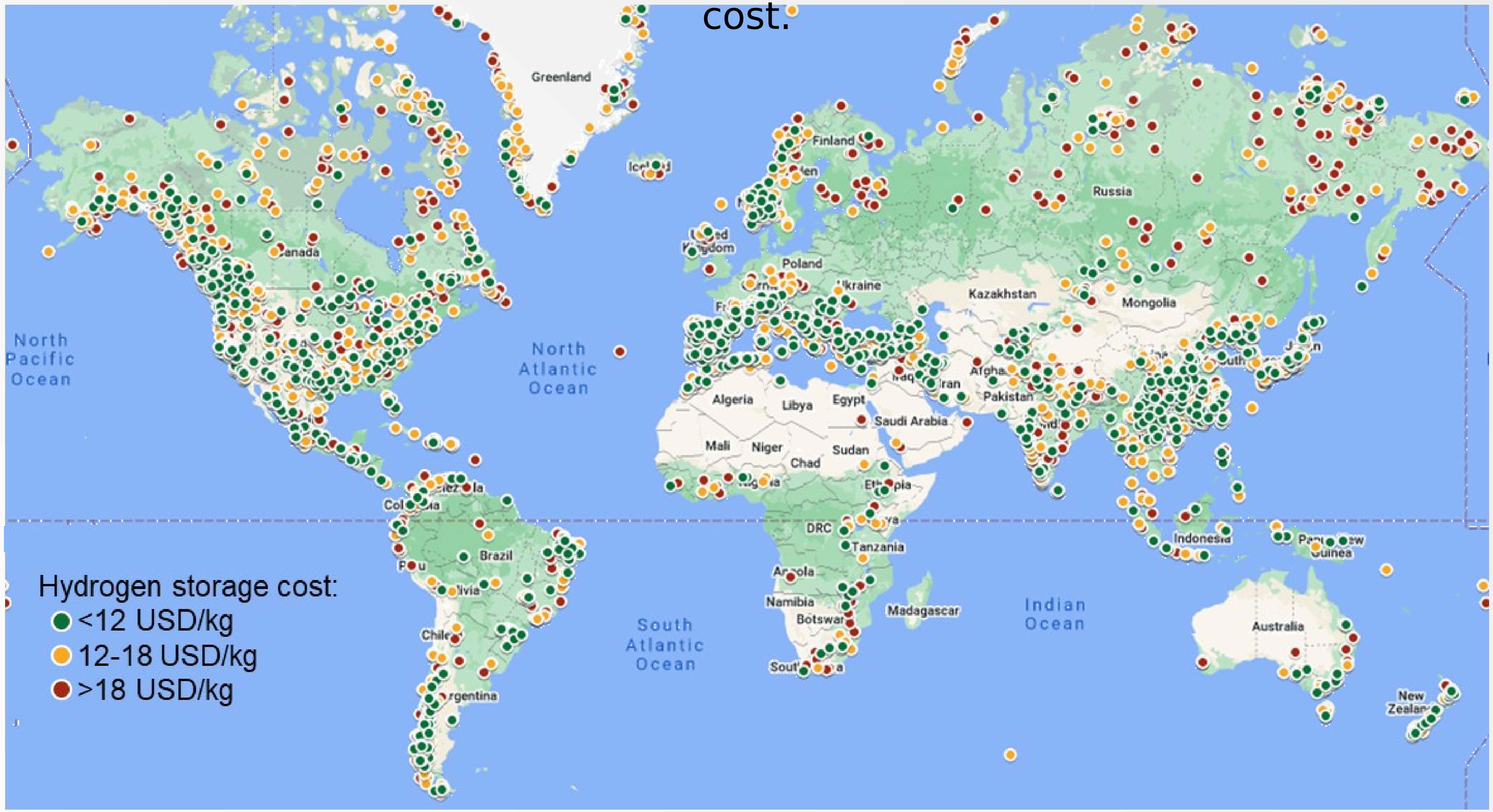
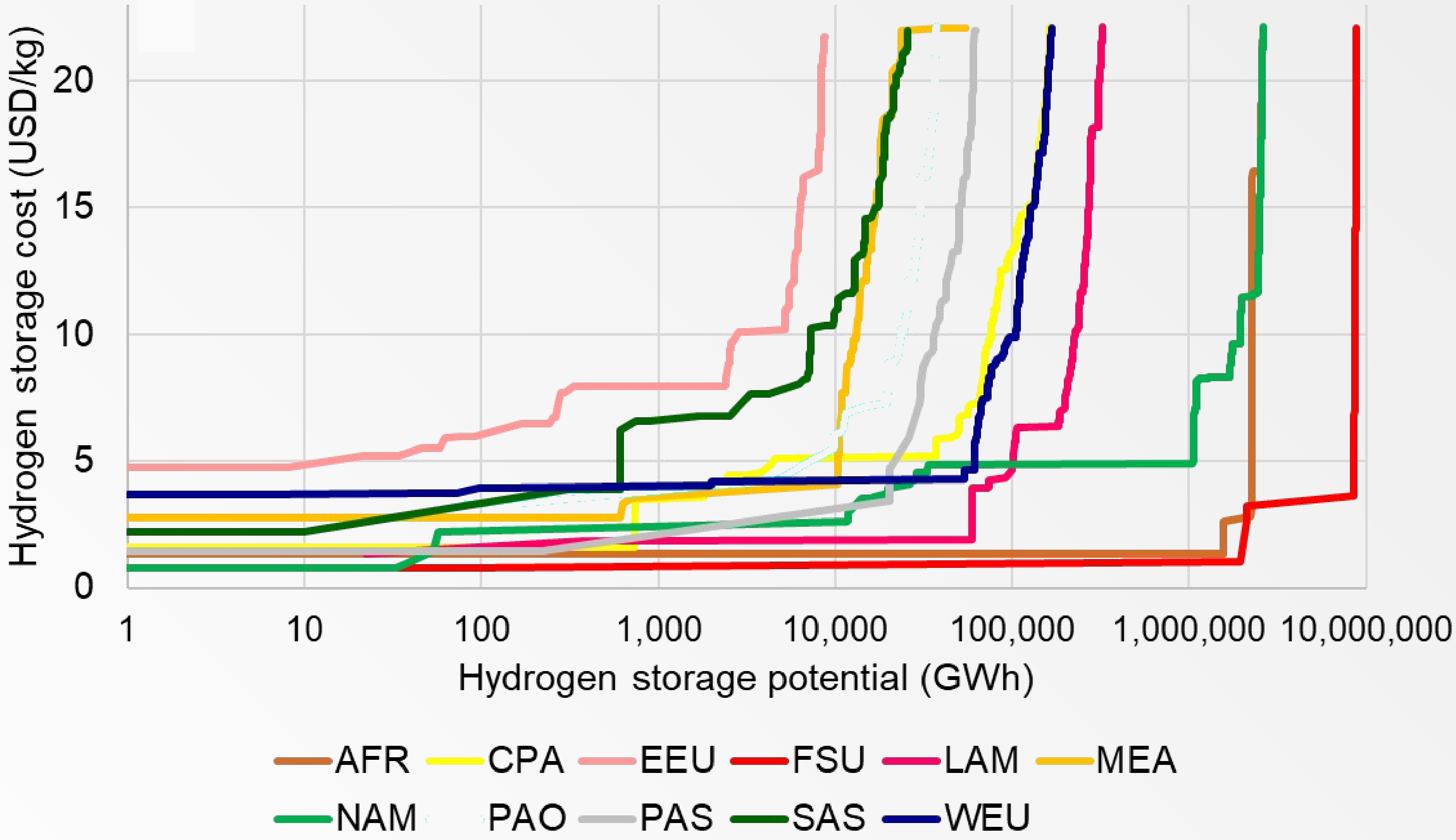


https://www.google.com/maps/d/edit?mid=1EcGvI_Cr-1I-

Global Potential

Lakes and reservoirs H_2 storage global potential organized by cost-curve per region.



AFR is Sub-Saharan Africa, WEU is Western Europe, CPA is Centrally Planned Asia and China, EEU is Eastern Europe, FSU is Former Soviet Union, LAM is Latin America and the Caribbean, MEA is Middle East and North Africa, NAM is North America, PAO is Pacific OECD, PAS is Other Pacific Asia, SAS is South Asia

Future work

- Impact of climate change on hydrogen storage in lakes and hydropower reservoirs:
  - Lakes and reservoir levels directly impact the potential for hydrogen storage.

Conclusion

- Hydrogen storage in lakes and reservoirs consists of storing compressed hydrogen in HDPE pipes filled with desert sand. The pressure in the pipeline is the same as the pressure outside.
- This can be done because hydrogen is insoluble in water.
- The capital cost of hydrogen storage of 3.76 USD/kg at 200 m depth. 5 to 25 times cheaper than storing hydrogen in salt caverns.
- The global hydrogen storage in lakes and reservoirs is 15 PWh.
- Hydrogen storage in lakes and reservoirs is a viable and environmentally friendly technology with great potential in a future hydrogen economy.

Questions?

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