Technical Potential of Salt Caverns for Hydrogen Storage in Europe

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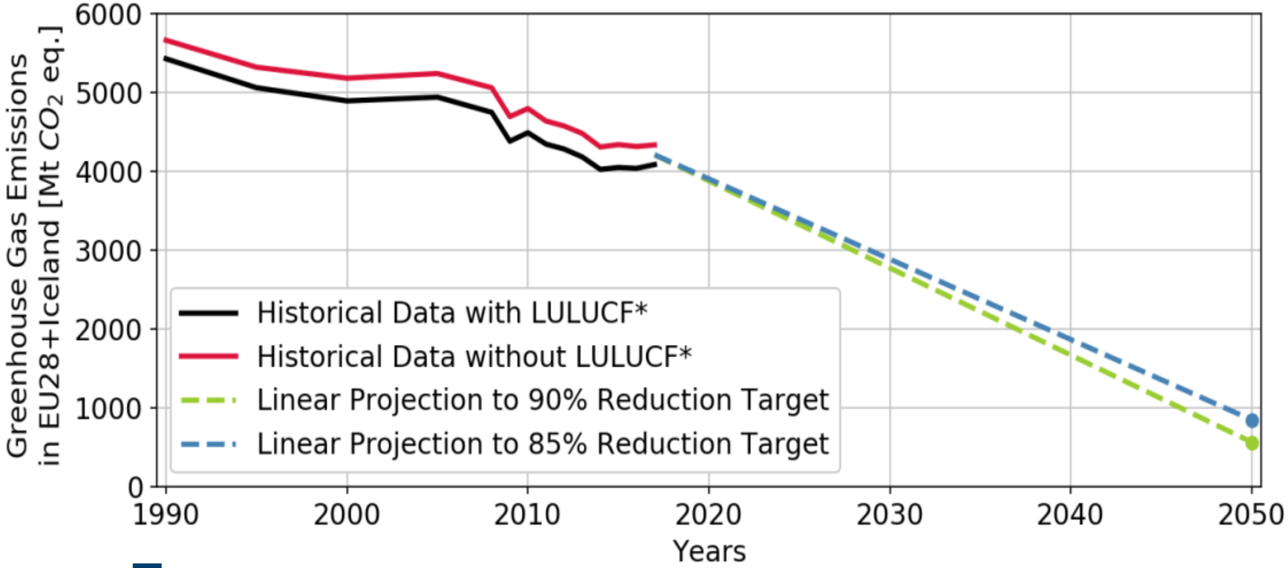
Techno-economic Energy Systems Analysis (IEK-3)

Motivation

Greenhouse gas emissions in the EU-28 and Iceland with reduction targets in 2050 (in reference to the values in 1990) [1]



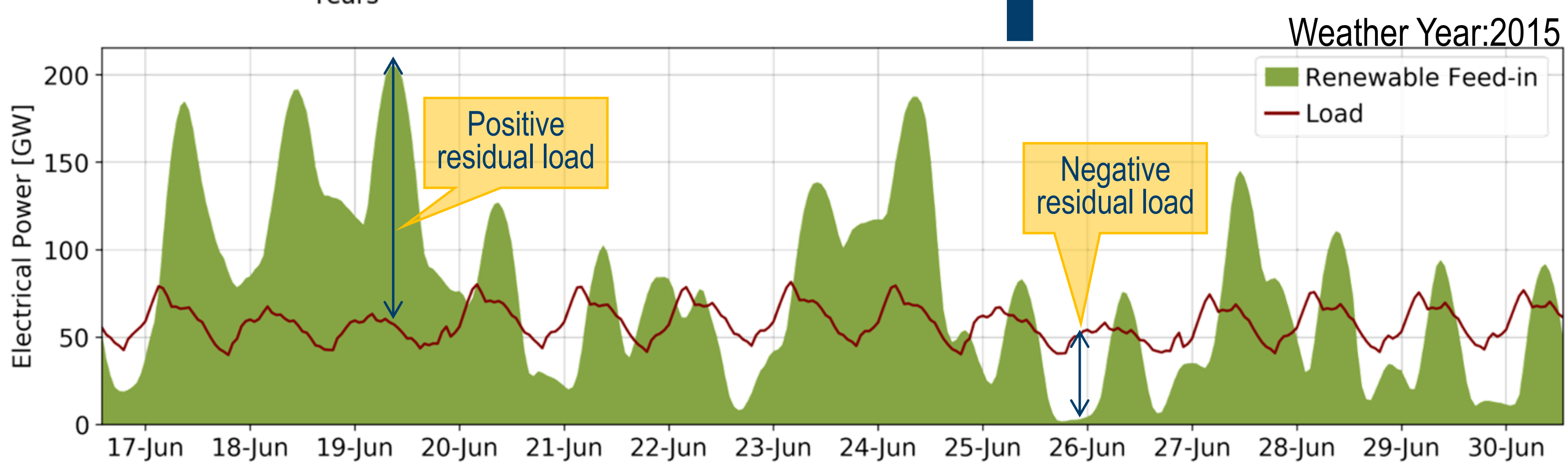
Question

What is the storage potential of hydrogen across Europe? Where can we store it?

Seasonal storage required!
(Power-to-hydrogen)

Pathway

Higher renewable energy sources

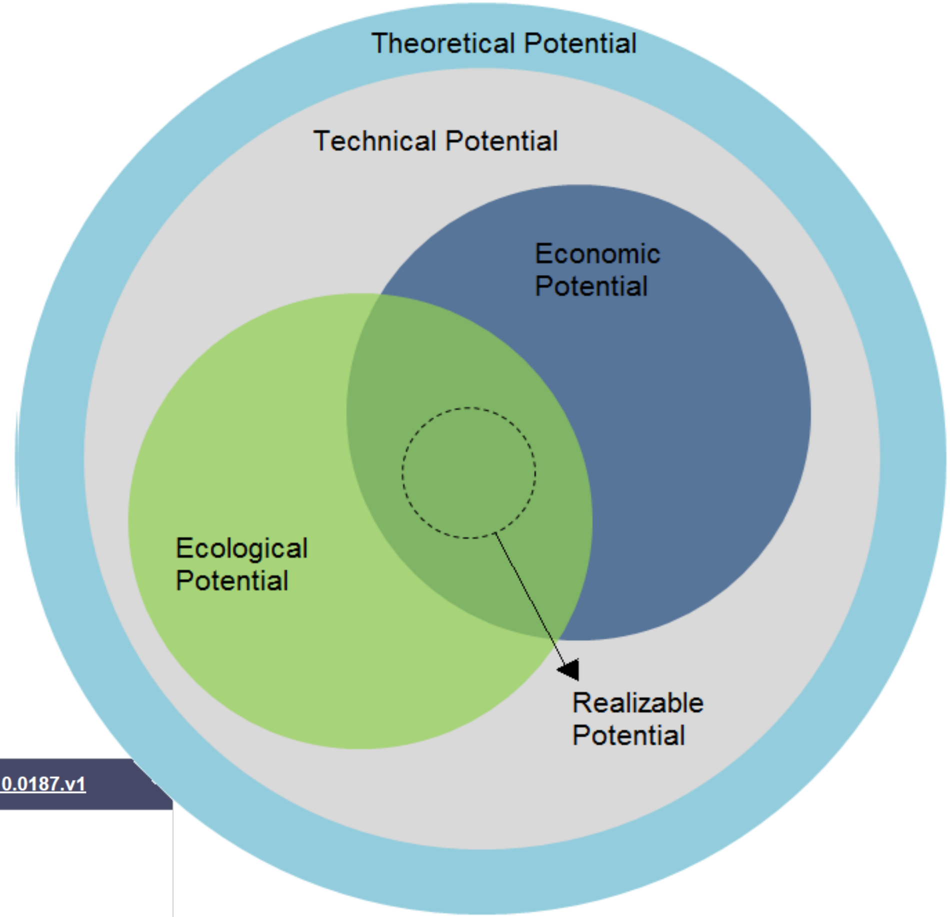


* **LULUCF:** Land use, land use change and forestry

[1] EEA. Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019. Copenhagen: 2019.

Outline

- Background
- Methodology
- Results
- Summary & Outlook



Adapted from Lütkehus et al. [1]

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Technical Potential of Salt Caverns for Hydrogen Storage in Europe

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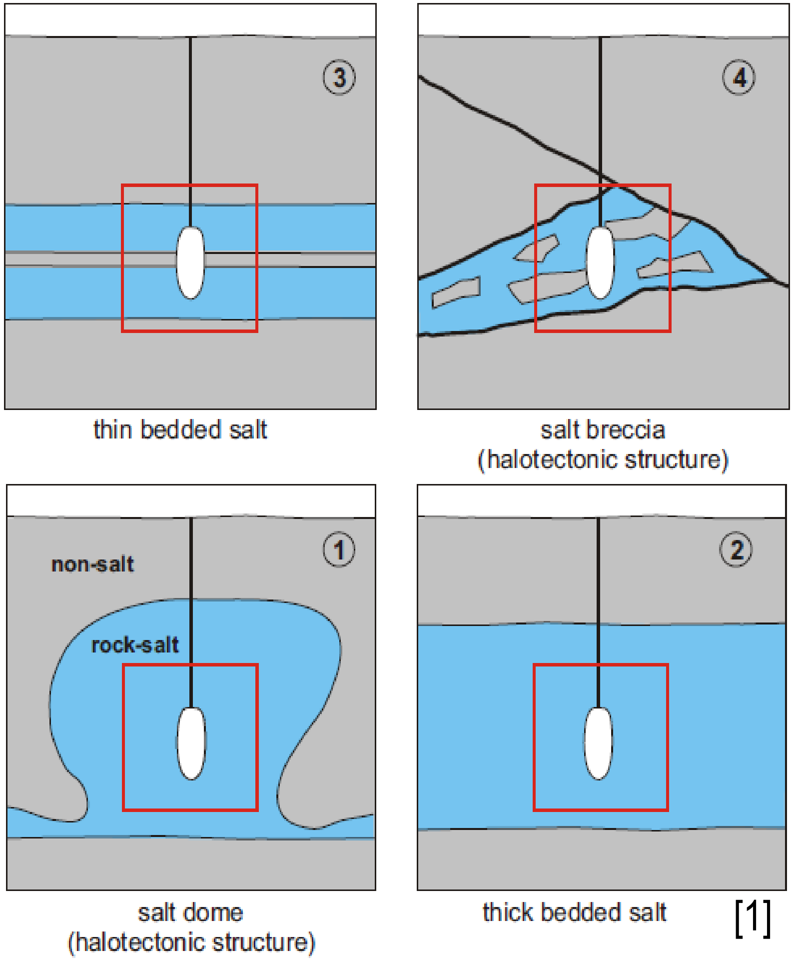
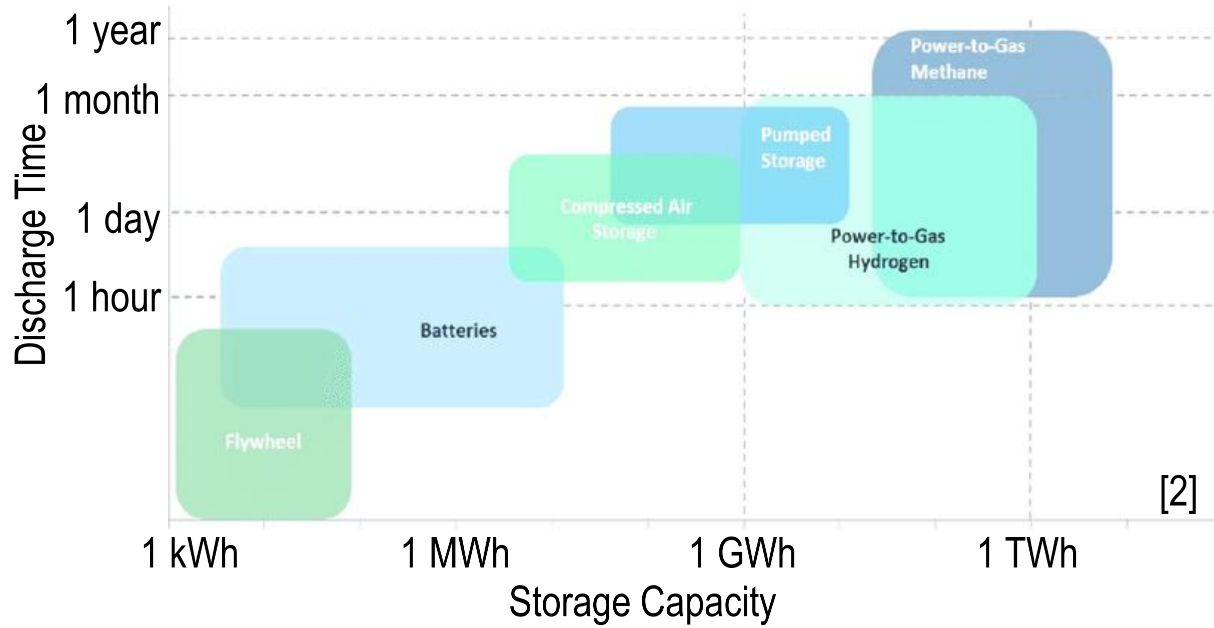
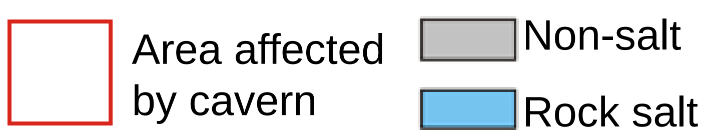
[1] Lütkehus et al. Potenzial der Windenergie an Land: Studie zur Ermittlung des Bundesweiten Flächen-und Leistungspotenzials der Windenergienutzung an Land. Dessau-Roßlau: 2013.

Background

- Seasonal storage is necessary in highly renewable energy systems
- For higher storage capacity, chemical energy storage is more suitable







[1] Kepplinger et al. (2011) Present Trends in Compressed Air Energy and Hydrogen Storage in Germany: SMRI Fall Technical Conference, October 3-4, 2011. KBB Underground Technologies GmbH, IVG Caverns GmbH **[2]** Moore & Shabani. A Critical Study of Stationary Energy Storage Policies in Australia in an International Context: The Role of Hydrogen and Battery Technologies. Energies 2016;9:674. doi:10.3390/en9090674.

Methodology – Applied Procedure

Identification of salt deposits

Suitability assessment of salt deposits

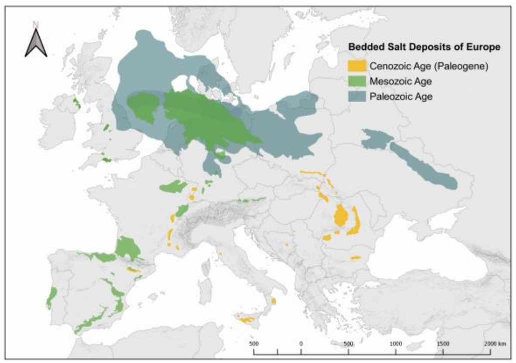
Geo-referencing & digitalization of salt deposits

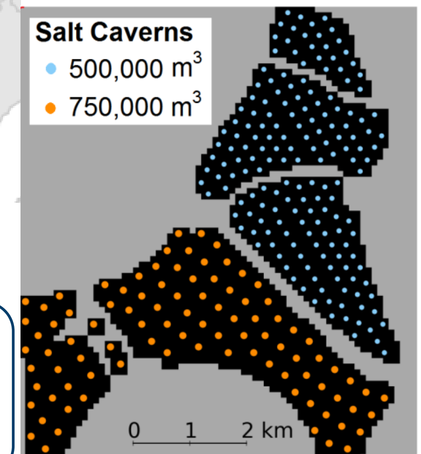
Land eligibility of salt deposits

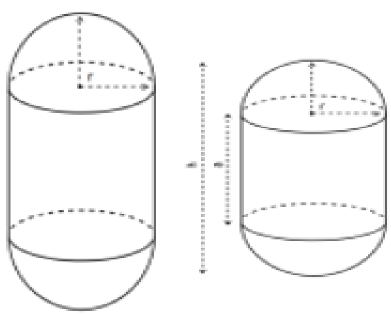
Cavern placements

Cavern design

Capacity estimation







Caglayan et al. ***Preprints*** 2019, 2019100187 (doi: 10.20944/preprints201910.0187.v1).

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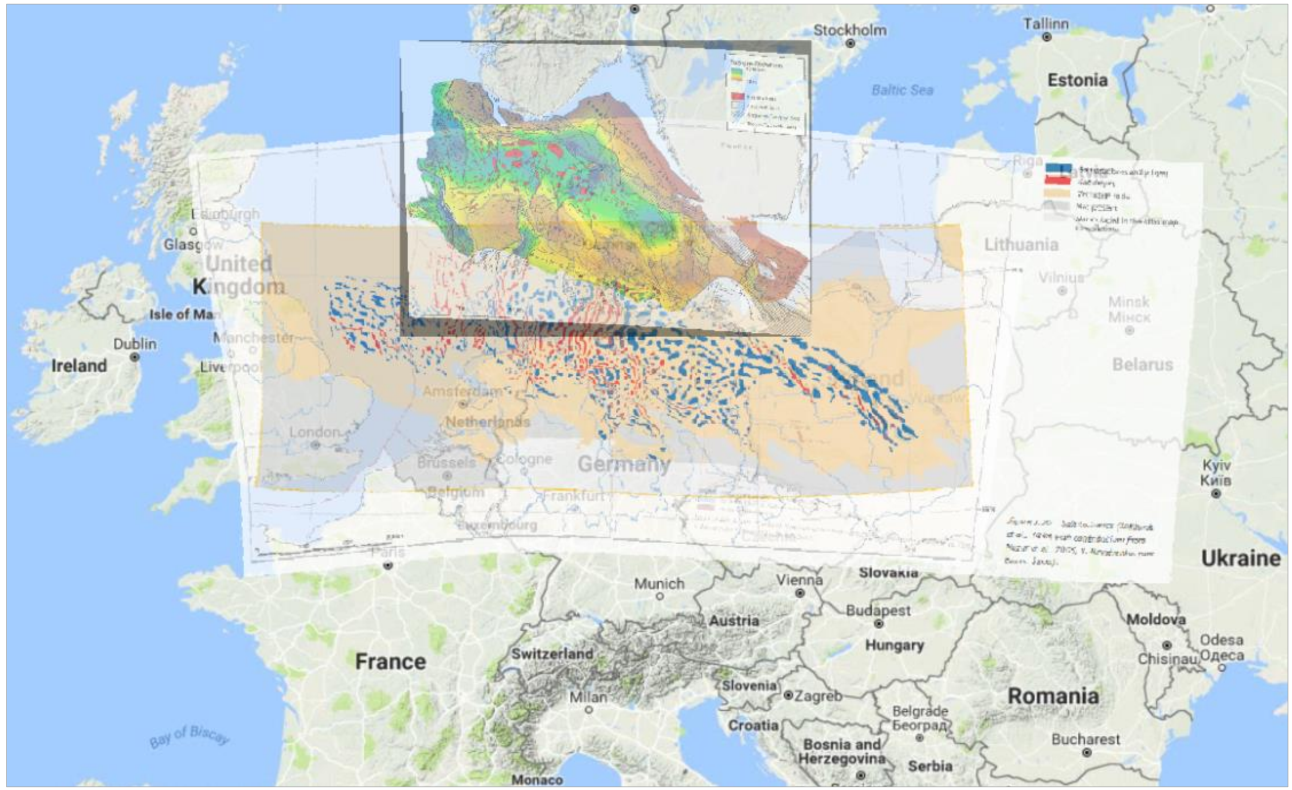
Methodology –Suitability Assessment and Georeferencing

- ***<u>Suitable salt formation criteria for underground hydrogen storage [1,2]:</u>***
- *<u>Bedded salt formations:</u>*
  - Last cemented casing (LCC) depth: Min. 500 m - Max. 1,800 m
  - Optimal depth range: LCC at 800-1,400 m
  - <20% insoluble sulfates
  - Minimum salt thickness: 200 m
  - No strong deformation
- *<u>Salt domes & pillows:</u>*
  - No criteria on thickness & depth
  - Around the depth of 1,400 m



Georeferencing & digitalization of the suitable salt structures [3,4]

[1] Barron TF (1994) Regulatory, Technical Pressures Prompt More U.S. Salt-Cavern Gas Storage. Oil & Gas Journal(Vol. 92)
[2] Doornenbal H (ed) (2010) Petroleum geological atlas of the southern Permian Basin Area. EAGE, Houten
[3] Nordic CCS Competence Centre: Geology and Stratigraphy. https://data.geus.dk/nordiccs/geology.xhtml.
[4] www.maps.google.com.

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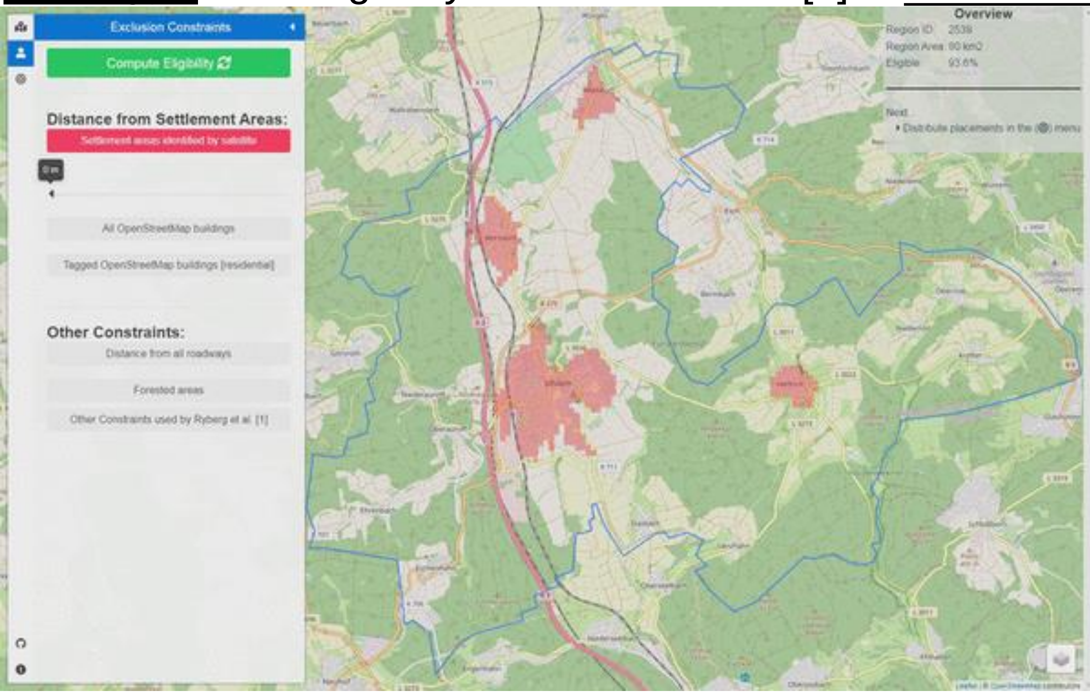
Methodology – Land Eligibility and Cavern Placement

Criteria	Excludes	Source
Urban areas	<2,500 m	[1]
Rural areas	<2,000 m	[1]
Major fault zones	<200 m	[2]
Natural protected areas, water bodies	<200 m	[1]
Railway, major roads and gas pipelines	<200 m	[1,3]
Geological correction factor (distance from the salt edge): - Bedded salt - Salt domes	<2,000 m <500 m	Own data

Application of the constraints on individual salt formations

Analogy: Land eligibility for wind turbines [1]



- Eligible locations are estimated on each salt formation
- Salt caverns are distributed by 4 times cavern diameter:
  - Salt domes: D=58 m, V=750,000 m^3
  - Bedded deposits: D=84 m, V=500,000 m^3

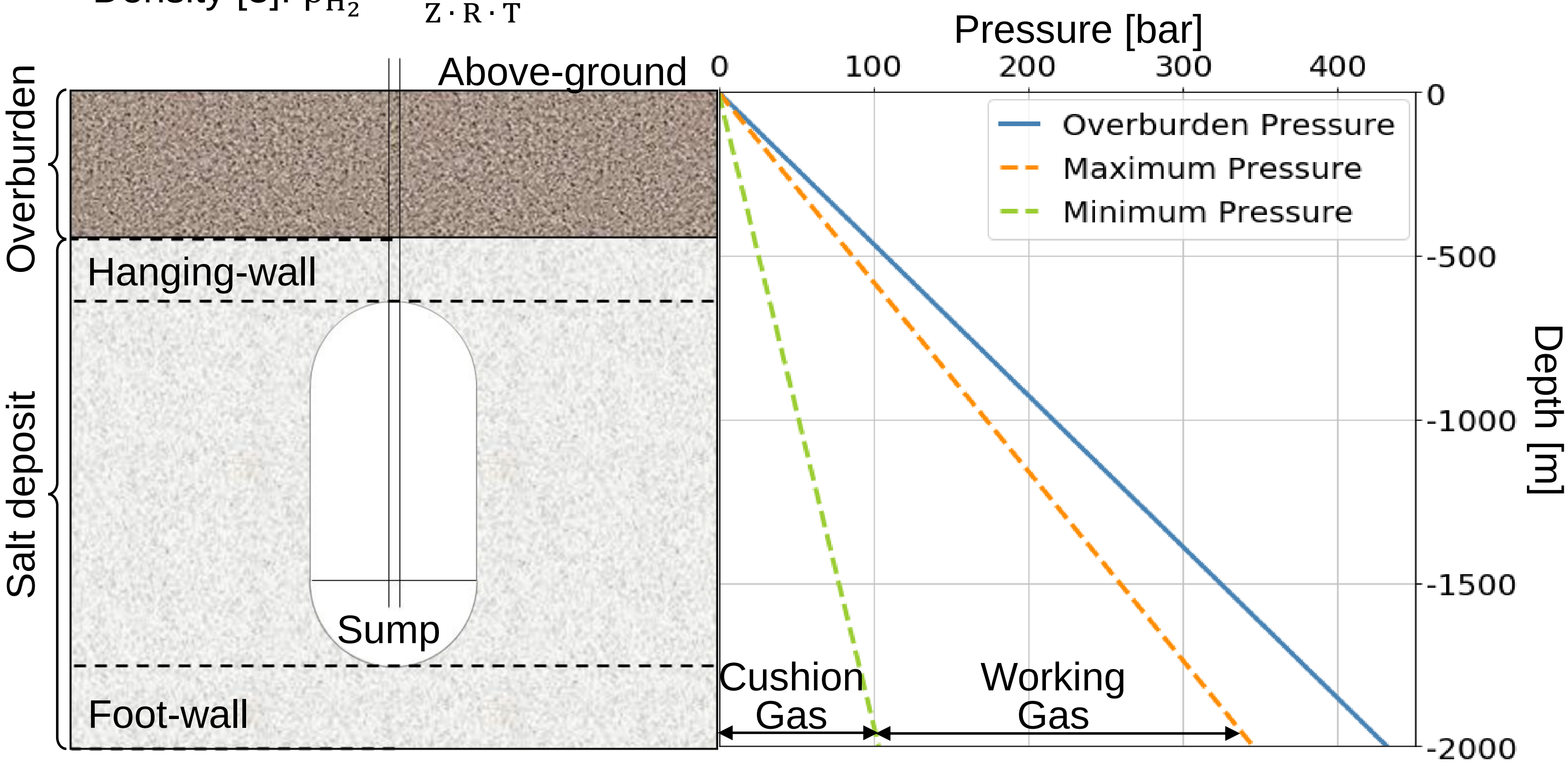
Remark

Why the diameter of smaller cavern is larger? Thickness of salt layer is a limitation in bedded formations.

[1] Ryberg et al. Evaluating Land Eligibility Constraints of Renewable Energy Sources in Europe. Energies 2018;11:1246. doi:10.3390/en11051246.
[2] European database of active faults and seismogenic SHARE. http://www.share-eu.org/node/70.
[3] Natural Gas Pipelines in Europe Africa & Middle East A. Harvard WorldMap.

Methodology – Operational Parameters

- Temperature [1]: $T_{avg} = 288 + 0.025 \cdot depth$
- Operating pressures [2]: $P = \sum \rho_i \cdot g \cdot h_i, \ P_{max} = P \cdot 0.80, \ P_{min} = P \cdot 0.30$
- Density [3]: $\rho_{H_2} = \frac{P \cdot M}{Z \cdot R \cdot T}$

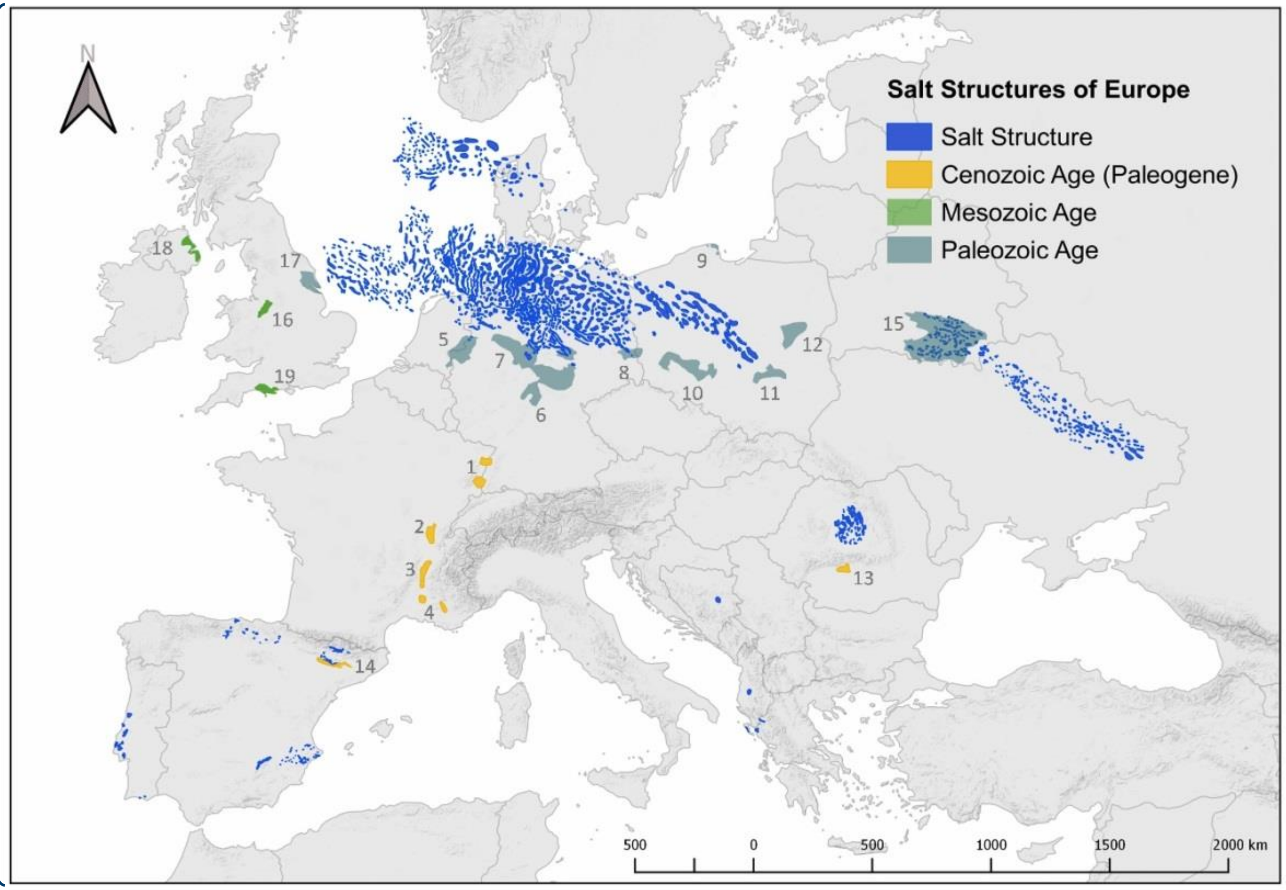


[1] DiPietro JA. Landscape Evolution in the United States: An Introduction to the Geography, Geology, and Natural History. Landsc. Evol. United States An Introd. to Geogr. Geol. Nat. Hist., 2012. **[2]** Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Long Term Storage of Renewable Electricity by Hydrogen Underground Storage in Europe (2014) HyUnder Project **[3]** Bell et al. Ind Eng Chem Res 2014; 53:2498–508. doi:10.1021/ie4033999.

Results - Suitable Salt Formations

Suitable European salt formations for underground hydrogen storage [1-14]:

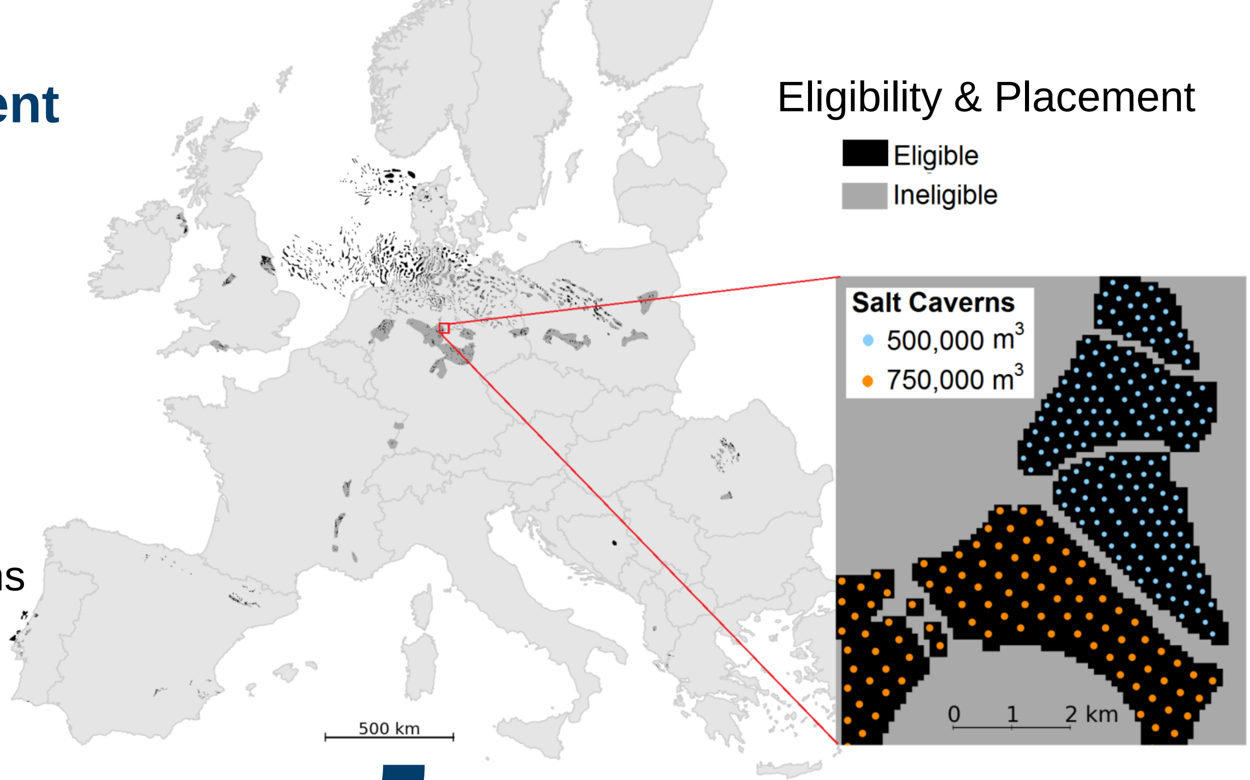
1. Alsace Basin; 2. Bresse Basin; 3.Greoux Basin; 4. Valence Basin; 5. Lower Rhine Basin; 6. Hessen Werra Basin; 7. Sub-Hercynian Basin; 8. Lausitz Basin; 9. Leba Salt; 10. Fore-Sudetic Monocline; 11. Carpathian Foredeep; 12. Lublin Trough; 13. Ocnele Mari; 14. Cardona Saline Formation; 15. Pripyat Basin; 16. Cheshire Basin; 17. UK Permian Zechstein Basin; 18. Larne Salt Field; 19. Wessex Basin).

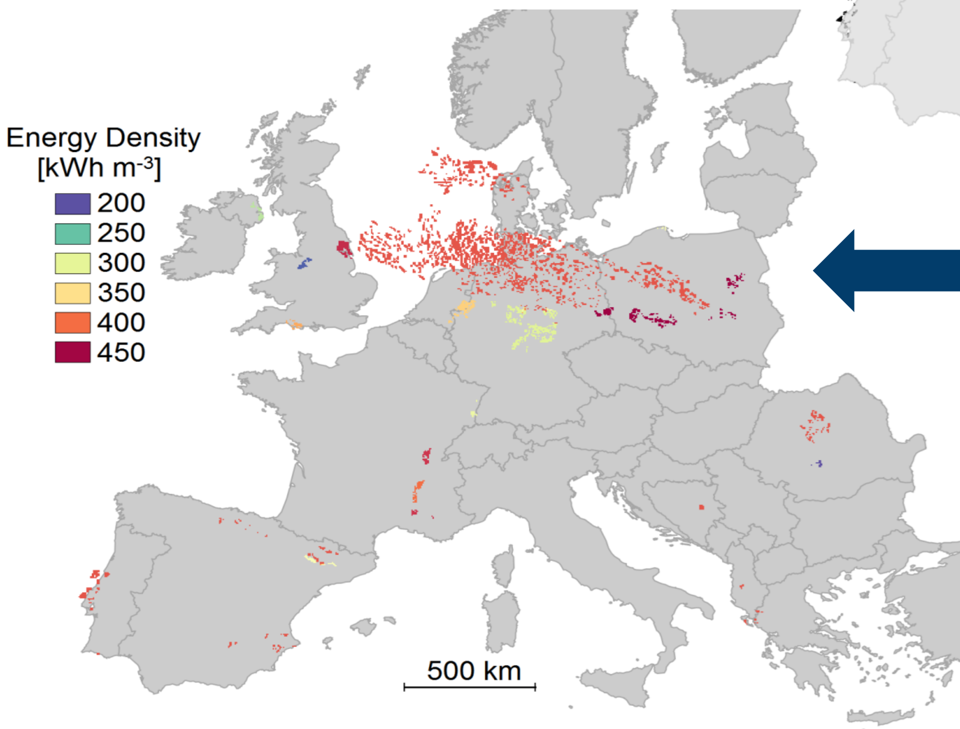


[1] Gillhaus et al. Solut Min Res Insitute KBB Undergr Technol GmbH 2006;2006:257. **[2]** Le Duigou et al. Int J Hydrogen Energy 2017;42:22987–3003. doi:10.1016/j.ijhydene.2017.06.239. **[3]** https://data.geus.dk/nordiccs/geology.xhtml#s2. **[4]** Doornenbal H. Petroleum geological atlas of the southern Permian Basin Area. Houten, the Netherlands: EAGE Publications BV; 2010. **[5]** BGR. Geoviewer (InSpEE Salzstrukturen) **[6]** Ślizowski et al. J Nat Gas Sci Eng 2017;43:167–78. doi:10.1016/j.jngse.2017.03.028. **[7]** Bukowski. Salt Sources and Salt Springs in the Carpathian Zone: Explorations in salt archaeology in the Carpathian zone. Archaeolingua 2013:9. **[8]** Krézsek & Bally. Mar Pet Geol 2006;23:405–42. doi:10.1016/j.marpetgeo.2006.03.003. **[9]** Cocker et al. Geology and Undiscovered Resource Assessment of the Potash-Bearing Pripyat and Dnieper-Donets Basins, Belarus and Ukraine. US Geol Surv 2010:130. **[10]** Stovba & Stephenson. Mar Pet Geol 2002;19:1169–89. doi:10.1016/S0264-8172(03)00023-0. **[11]** Velaj. J Pet Explor Prod Technol 2015;5:123–45. doi:10.1007/s13202-015-0162-1. **[12]** Gillhaus. Underground Salt Deposits of Portugal and Spain - Geological Potential to Meet Future Demand for Natural Gas Storage? Solut Min Res Insitute 2008:20. **[13]** Lopes et al. Am Assoc Pet Geol Bull 2012;96:615–34. doi:10.1306/08101111033. **[14]** Fernandes et al. Mar Pet Geol 2013;46:210–33. doi:10.1016/j.marpetgeo.2013.06.015. **[15]** Soto et al. 1st ed. Elsevier; 2017. doi:10.1016/C2015-0-05796-3.

Results - Eligibility Assessment

- Eligibility constraints are applied on salt layers from bird-eye view
- Offshore caverns in the North Sea area are analyzed (Power-to-hydrogen)
- Separation distance varies:
  - Large caverns in domal salt
  - Small caverns in bedded formations





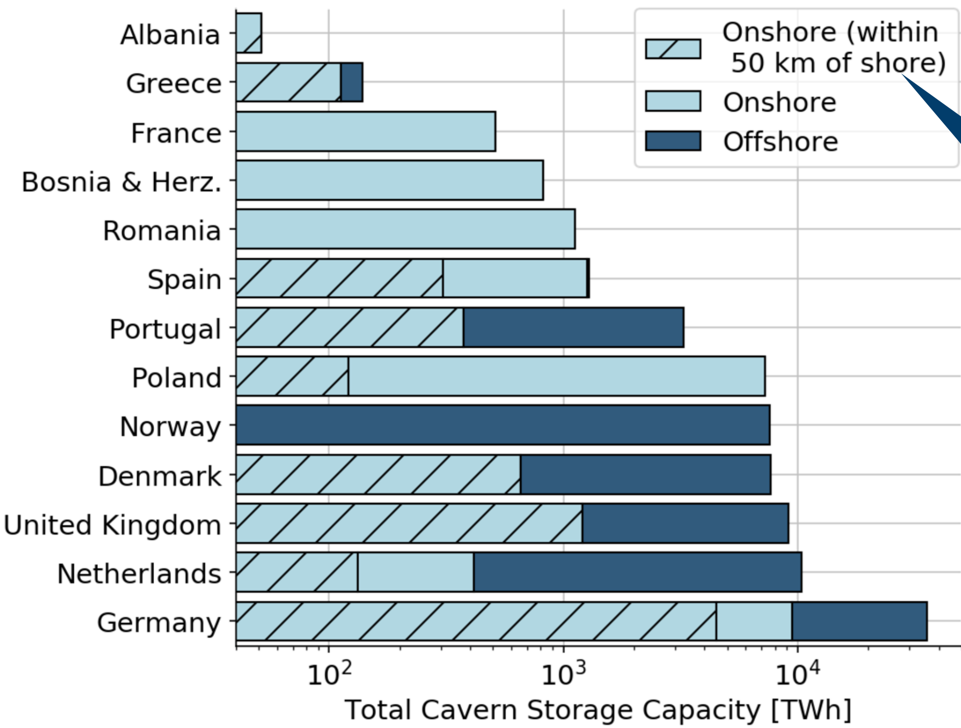
With estimated cavern capacities…

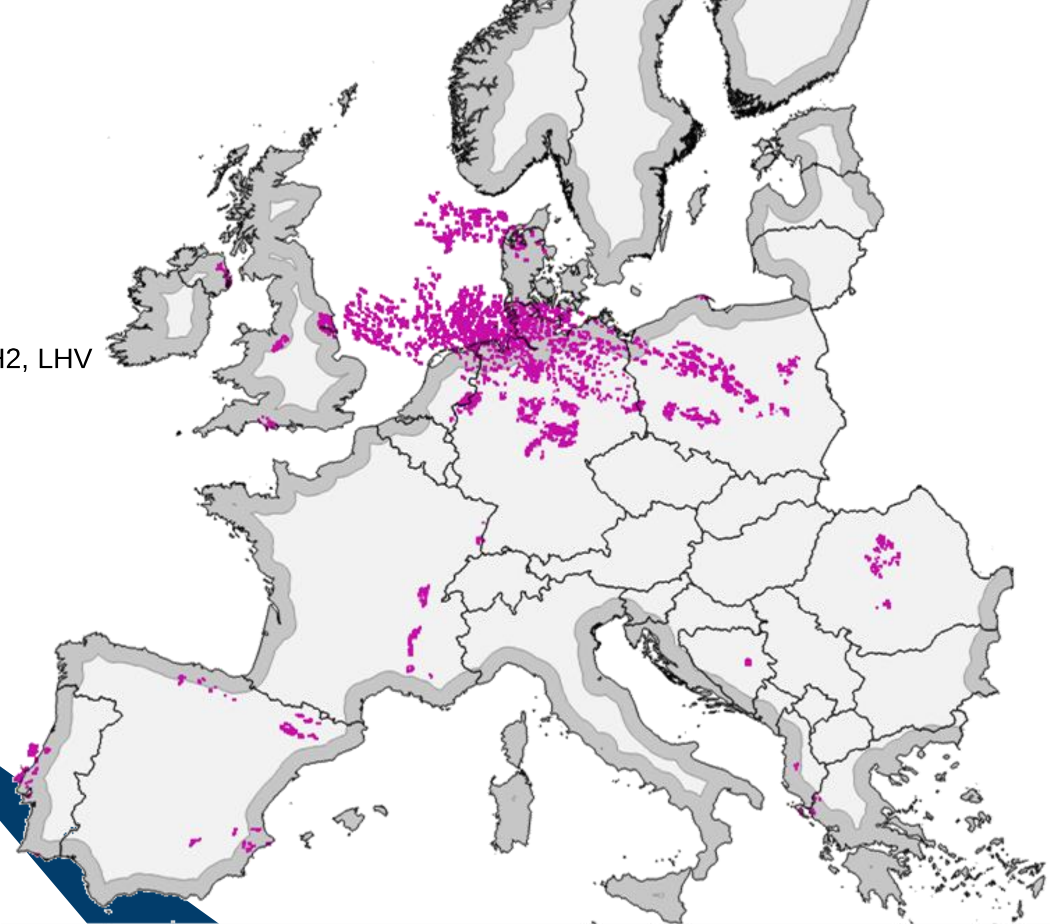
- Energy densities vary with respect to characteristics:
  - Salt domes: 412 kWh_{H2} m^{-3}.
  - For bedded salt formation: 214 - 458 kWh_{H2} m^{-3}.
- For bedded salt formations, depth of the salt layer plays a major role

Results – National Storage Potential

- Onshore & offshore salt caverns: 84.8 $PWh_{H2, LHV}$
- Only onshore salt caverns: 23.2 $PWh_{H2, LHV}$
- Onshore caverns within 50 km of shore: 7.3 $PWh_{H2, LHV}$

Remark
For a 100% renewable based European energy system, estimated need storage capacity for salt caverns is reported as 0.2 $PWh_{H2, LHV}$ [1]





Exemplary scenario (50 km) to consider economic aspects (i.e. brine disposal)

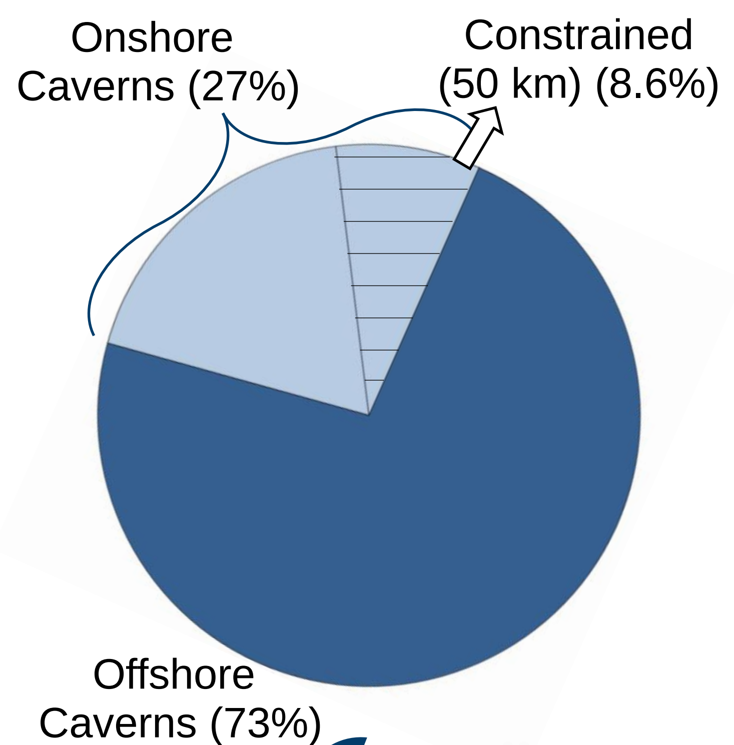
Closest caverns to the shore:

- France 65 km
- Bosnia & Herz. 140 km
- Romania 340 km

[1] Caglayan et al. ***Preprints*** 2019, 2019100150 (doi: 10.20944/preprints201910.0150.v1).

Summary & Outlook

- Land eligibility of suitable salt structures are assessed in Europe
  - Salt structures consist of **salt domes** and **bedded salt formations**
  - Availability assessment prevents cavern construction in settlements, protected areas or fault zones
  - A small cavern (500,000 m^3) with larger diameter is used for bedded salt formations
  - A larger cavern (750,000 m^3) is used for salt domes
- Storage potentials are derived by thermodynamic relations:
  - Onshore & offshore salt caverns: 84.8 $PWh_{H2, LHV}$
  - Only onshore salt caverns: 23.2 $PWh_{H2, LHV}$
  - Onshore caverns within 50 km of shore: 7.3 $PWh_{H2, LHV}$
- Storage potential can be used in an energy system design to identify storage requirement



Concluding remark

Reported storage capacity is nearly 1% of the estimated technical potential [1]!

[1] Caglayan et al. ***Preprints*** 2019, 2019100150 (doi: 10.20944/preprints201910.0150.v1).

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Thank you…