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]

* LULUCF: Land use, land use change and forestry

Outline

- Background
- Methodology
- Results
- Summary & Outlook

Adapted from Lütkehus et al. [1]

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Background

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


Methodology – Applied Procedure

1. Identification of salt deposits
2. Suitability assessment of salt deposits
3. Geo-referencing & digitalization of salt deposits
4. Land eligibility of salt deposits
5. Cavern placements
6. Cavern design
7. Capacity estimation


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IEK-3: Institute of Techno-Economic Systems Analysis
Methodology – Suitability Assessment and Georeferencing

- **Suitable salt formation criteria for underground hydrogen storage [1,2]:**
- **Bedded salt formations:**
  - 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
- **Salt domes & pillows:**
  - No criteria on thickness & depth
  - Around the depth of 1,400 m


Georeferencing & digitalization of the suitable salt structures [3,4]
Methodology – Land Eligibility and Cavern Placement

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Excludes</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban areas</td>
<td>&lt;2,500 m</td>
<td>[1]</td>
</tr>
<tr>
<td>Rural areas</td>
<td>&lt;2,000 m</td>
<td>[1]</td>
</tr>
<tr>
<td>Major fault zones</td>
<td>&lt;200 m</td>
<td>[2]</td>
</tr>
<tr>
<td>Natural protected areas, water bodies</td>
<td>&lt;200 m</td>
<td>[1]</td>
</tr>
<tr>
<td>Railway, major roads and gas pipelines</td>
<td>&lt;200 m</td>
<td>[1,3]</td>
</tr>
</tbody>
</table>

Geological correction factor (distance from the salt edge):
- Bedded salt
- Salt domes

Criteria Excludes Source

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 m³
  - Bedded deposits: D=84 m, V=500,000 m³

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

Methodology – Operational Parameters

- Temperature [1]: \( T_{\text{avg}} = 288 + 0.025 \cdot \text{depth} \)
- Operating pressures [2]: \( P = \sum \rho_i \cdot g \cdot h_i \), \( P_{\text{max}} = P \cdot 0.80 \), \( P_{\text{min}} = P \cdot 0.30 \)
- Density [3]: \( \rho_{\text{H}_2} = \frac{P \cdot M}{Z \cdot R \cdot T} \)

Results - Suitable Salt Formations

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

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

Energy densities vary with respect to characteristics:
- Salt domes: $412 \text{ kWh}_H^2 \text{ m}^{-3}$
- For bedded salt formation: $214 - 458 \text{ kWh}_H^2 \text{ m}^{-3}$
- For bedded salt formations, depth of the salt layer plays a major role
Results – National Storage Potential

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

**Remark**

For a 100% renewable based European energy system, estimated need storage capacity for salt caverns is reported as $0.2 \text{ PWh}_\text{H2, LHV}$ [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
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 m³) with larger diameter is used for bedded salt formations
  - A larger cavern (750,000 m³) is used for salt domes

- Storage potentials are derived by thermodynamic relations:
  - Onshore & offshore salt caverns: 84.8 PWh\textsubscript{H2, LHV}
  - Only onshore salt caverns: 23.2 PWh\textsubscript{H2, LHV}
  - Onshore caverns within 50 km of shore: 7.3 PWh\textsubscript{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]!

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Thank you...