Peer Review Report

Review Report on Capturing geological uncertainty in salt cavern developments for hydrogen storage

Original Research, Earth Sci. Syst. Soc.

Reviewer: Edward Hough
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EVALUATION

Q 1 **Please summarize the main findings of the study.**

Appraisal of cavern storage volumes of Southern North Sea using different scales and resolutions of geological models.
Overall a nicely presented study.

Q 2 **Please highlight the limitations and strengths.**

Consistent appraisal technique applied, although several areas of suggested improvement. Some terminology requires amendment (e.g., modelled caverns are not "viable" but are theoretical).

Q 3 **Please comment on the methods, results and data interpretation. If there are any objective errors, or if the conclusions are not supported, you should detail your concerns.**

Method is well described but multiple points of clarification are recommended.

Q 4 **Check List**

Is the English language of sufficient quality?
Yes.

Is the quality of the figures and tables satisfactory?
Yes.

Does the reference list cover the relevant literature adequately and in an unbiased manner?
Yes.

Are the statistical methods valid and correctly applied? (e.g. sample size, choice of test)
No answer given.

If relevant, are the methods sufficiently documented to allow replication studies?
Yes.

Are the data underlying the study available in either the article, supplement, or deposited in a repository? (Sequence/expression data, protein/molecule characterizations, annotations, and taxonomy data are required to be deposited in public repositories prior to publication)
No answer given.

Does the study adhere to ethical standards including ethics committee approval and consent procedure?
Yes.

If relevant, have standard biosecurity and institutional safety procedures been adhered to?
Yes.

Q 5 **Please provide your detailed review report to the editor and authors (including any comments on the Q4 Check List):**

Overall this is a well-written manuscript that describes an evaluation method that could be widely applied to other salt basins internationally. It also uses the Zechstein of the UK as a case study- this is a highly relevant topic currently given the interest in this evaporite resource (hydrogen/compressed air energy/natural gas/other hydrocarbons and even temporary storage of CO2). As such this paper should be considered for publication, either in ES3 but it may be more relevant for GeoEnergy. However, there are a few points that should be clarified/better explained or included that would improve the manuscript. Please see suggested edits on the uploaded marked up copy.

General comments:

Use of "viable" when describing cavern locations. As the study has not considered engineering design then I recommend using terms such as "potential" or "Theoretical" rather than "viable", which could indicate some level of confidence that a cavern could be successfully engineered at a particular location.

Consistency in spelling and capitalisation: Montecarlo/Monte Carlo; Supergroup (should be capitalised); Stassfurt Halite (halite should be capitalised);

A discussion on the likelihood of all caverns being developed would be useful- in practice I don't think anyone would expect all caverns mapped out would be developed, but the study does give an idea of maximum storage values that may be available (contingent resources);

Use of "required energy storage capacity"- e.g., line 516, 527 but also elsewhere. Can you caveat this with what the requirement is for? I assume it is to meet net-zero targets but this is not clear as currently written.

Some other specific points for consideration before acceptance are:

- Fyfe and Underhill (2003) seems like an omitted reference which could be cited in the introduction.
- Conflict of use of the subsurface. There will be multiple demands on use of the subsurface in this general area- some utilising evaporite, some not. Adding this consideration to the discussion would be useful just as a way of flagging that (1) not all evaporite may be suitable used for cavern storage but also (2) suitable evaporites to host cavern storage schemes may be screened out as they may lie in areas being developed for other technologies (e.g., offshore wind; CO2 storage)
- Did you specify a maximum cavern height? I see from Section 4.3.1.1. that they used 750 m as a maximum height, can this be made explicit in the text?-
- Insoluble calculation seems to assume all halite is 100% soluble (although insoluble are discussed in the Sensitivity analysis section). What about clay content within the evaporite layers? This could lead into a discussion of bulking factors and the associated volume reduction between gross cavern volume and net storage realised. Apologies if I have mis-understood, if so then perhaps this can be made clearer?
- Data should be plural whereas you consistently state 'the data was'.
- The Allsop (2023) paper should probably be cited in Section 3.3.1.-
- Did you manage to generate good bounding surfaces for the Z2 halite based on the seismic data? A discussion on challenges in mapping out this horizon by way of introducing difficulties of mapping out cyclic evaporite successions would be useful if the method is applied by others to similar successions elsewhere.
- Line 89: Coarse resolution of previous studies is noted, but the current work also employs coarse-resolution models- so the work does not illustrate an improvement in that- contrast with lines 192, 353.
- Line 167: Applying method of Caglayan (500 m depth cut-off) does not acknowledge shallower caverns in UK Cheshire; Why the 500 m depth constraint on shallow caverns? I think this requires some level of justification, especially as there are operational caverns in the UK for natural gas storage at depths shallower than this. Is it, for example, based on operating temperatures? If so then could you expand on that?
- Line 185: Lack of a shape/morphology correction factor- their method seems to assume all caverns will be ellipsoid or pill-shaped.
- Line 316/340: Depth surfaces used are from Barnett et al 2023. States using Stassfurt top and base as horizons. Reflection example shown in Figure 3 is very simplistic of the Stassfurt Top and Base geometries across the SNS region. How were these input surfaces modelled? Unclear from Barnett 2023.
- Line 345: Clarify why necessary to use three depth conversion models? 10%/5%/7% depth uncertainty.
- Section 3.3.2: Discussing Layered Evaporite Salt Depth Model, states Top and Base Stassfurt reflections were chosen. Yet, appendix Table B: lists Top and Base Zechstein used for Layered Evaporite model. Should clarify which Layered evaporated depth model referring to…. Variable cavern/fixed cavern/Basin Wide Data?

- Line 569: Also needs to take consideration of higher solubility salts; See my earlier comment, appears that you've considered all halite to be 100% soluble?
- Paragraph commencing at Line 589; Section 4.5. The Williams study showed that increasing distance between caverns has quite a high impact on the overall capacity which would be worth summarising here. A simple scaling solution allows this to be calculated based on distance between cavern centres. A discussion on cavern spacing/geomechanical envelope and how that varies with stress gradient/overburden would be useful here.
- Line 621: evidence for potential collapse needs to be included- as far as I am aware there have been no documented cavern collapses of engineered gas storage caverns (e.g. ref HSE 605 report or Crotogino et al SMRI paper). OK, I accept some earlier, poorly designed brine caverns have suffered chimney collapse but that would be mixing up engineered gas storage caverns with brine caverns.
- Line 659. A difference of 29.5% seems rather large – can this difference be further discussed? (e.g., where are the main points of uncertainty?)
- Figure 3: Polarity indicator hard to read; please make clearer.
- Figure 10 – base of Target salt in layered Evaporite model goes below base Zechstein in Basin Wide. To better compare the models the Base target should be clipped at the Base Zechstein. Otherwise Layered Evaporate model is overestimating.
- Table 1: Can cushion gas be added to this as well as working gas- to give an idea of "sunk cost" of cushion gas?
- Table D: Need reference for overburden Pressure Gradient used for Zechstein in SNS.

QUALITY ASSESSMENT

Q 6	Originality	■■■■□
Q 7	Rigor	■■■■□
Q 8	Significance to the field	■■■■□
Q 9	Interest to a general audience	■■■□□
Q 10	Quality of the writing	■■■■□
Q 11	Overall quality of the study	■■■■□