

Peer Review Report

Review Report on Use of Subsurface Geology in Assessing the Optimal Co-location of CO₂ Storage and Wind Energy Sites

Original Research, Earth Sci. Syst. Soc.

Reviewer: Christopher Lloyd

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EVALUATION

Q 1 Please summarize the main findings of the study.

The paper aims to highlight the CO₂ storage potential of the depleted Pickerill gas field, southern North Sea, that may be utilised to help reach the UK's net zero emission targets. The field is within the geographic boundaries of the Outer Dowsing Offshore Wind Project, and if it goes ahead as planned, will greatly affect the CO₂ storage suitability of the Pickerill field. The authors suggest a holistic approach when dealing with decarbonization techniques so that both CO₂ storage and offshore wind can complement each other. The study makes several findings:

- The Pickerill field reservoir comprises several facies with varying reservoir properties. This combined with internal compartmentalisation has resulted in poor production performance from several of the wells.
- By replacing the produced gas that previously occupied the pore space with CO₂, the storage potential of the Pickerill field is 32 MtCO₂. This capacity is split into three segments, with a combined area smaller than the original field outline, as some areas are deemed unsuitable for storage due to the poor gas production performance from wells.
- The seal comprises the Zechstein Group halites, anhydrites and dolomites, which vary greatly in thickness, but are present laterally (at least 60–70 m thick) across the full field. There are no areas identified where the pre- and post-salt stratigraphy are in connection.
- The advantage of using the area for CO₂ storage as opposed to offshore wind is highlighted through estimation of CO₂ emissions saved via wind energy vs stored CO₂ from natural gas usage.

Q 2 Please highlight the limitations and strengths.

The study is clearly structured, well written and is supported by clear, easy to read figures. It uses a robust methodology to geologically characterise the Pickerill field and provides some interesting statistics to back-up questionable areas. For example, the low Zechstein Group thickness in the centre of the field should not cause an issue as one nearby well showed only a 5 m seal contained a gas column. The most novel aspect was comparing the land use of CO₂ storage to wind farms, which is a key finding in the debate for using certain areas for different decarbonization methods. Overall, this was an engaging paper to read and has explored some interesting points that should be considered in the future.

However, I have four main concerns that should be addressed to increase the impact of this paper upon publication.

1. One of the two main takeaways from this paper is that the current proposed site of the Outer Dowsing Offshore Wind Project is reducing the suitability/capacity of the storage sites below. The Malroy, Galahad and Mordred fields combined offer a comparable capacity to the Pickerill Field and also lie within the ODOWP outline, but their presence and capacities are only mentioned in the final few paragraphs. Including these fields at the start builds a much better story, and a 'cluster of sites with >60 MtCO₂ capacity' is more convincing than a single storage site with 32 MtCO₂. The capacities have already been estimated, so the wells used can be added to Table 1. I do not think a full seismic and well interpretation will be required for the other fields and instead the Pickerill field analysis can be used as an example of how to perform such work in this region. A regional seismic line would be beneficial to show any changes in stratigraphy (primarily the overlying halite etc).
2. There is a sizeable amount of text on background information that is not relating to the main aims of the paper. This is primarily found in the 'regional geological background' (>20% of the current word count and

>50% of this is on stratigraphy above the seal), 'stratigraphy and seismic character' (most of the points are already shown in the informative figure) and 'brief introduction to the Pickerill Field' (interesting points but not really relevant for what you are trying to say). I suggest shortening these sections and possibly using the saved words on information from my first and third concern.

3. There is very little mentioned on uncertainties with your analysis. The main questions that came to mind while reading were: 1) Is all the gas being replaced by CO₂ realistic/ where has this been achieved and what is the evidence? 2) Will the well penetrations be a problem for leakage? 3) Is there an uncertainty range on the estimated storage capacities? 4) Will any of the geology be an issue for CO₂ (e.g. geochemical reactions, subseismic faulting through the salt etc.)? If these are things the authors do not believe would be a problem, they should still be mentioned somewhere with evidence.

4. The title is too broad and does not represent the objectives or findings of the study. The title gives the impression of a review paper, however only single field and a single technique that uses subsurface geology is used (CCS, although wind turbine installations do require geological analysis, this is not mentioned). If you were to consider a full subsurface geological analysis, you would also consider secondary storage sites above and around the field. I understand the advantages of having a broad title, but I feel more information is required. The paper addresses a big topic of land use for two of the main land area competitors (CCS and offshore wind) so I think these should somehow be included in the title.

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.

The following are small suggestions when reading the analysis.

- Have you considered secondary storage sites above the Pickerill Field? You have a structure in the Bunter sandstone, could this be used? Is the seal suitable? It could be targeted with the same well and would add volumes.
- By trying to include all the data you are losing the important details. For example, in figure 10B you show the full salt thickness variability. However, the aim here is to assess the seal, so where salt is more than say 200 m (or whatever number you deem suitable) does not matter for sealing, but 0-200 m thickness does. Therefore I suggest reducing the colour bar so that more variability in the section that does matter (0-200 m) can be observed (high thicknesses are all represented by a single colour).
- In figure 7A it is difficult to see what is low variance and what is low seismic amplitude when they both are shown by light grey, similarly as high variance is black we do not know what the seismic amplitude is. This means it is quite difficult to see the faults IMO. I suggest using a cutoff for both maps (e.g. only show where variance is above 0.8 in green and then where amplitude is between 200-0 in red. Then just make both slightly opaque so that overlaps can be seen). This would show the faults better.
- The location of figure 7, 9, 10 and 13 are not shown on any regional maps. I would suggest adding them somewhere early, and also to figure 14.
- You are using the arithmetic mean for your average permeabilities. This means that the high permeability peaks bring up the average and therefore do not truly represent the average permeability of the sandstone. You can easily tell by putting a vertical line at the average reported permeability, only a small amount of data lies to the right but these are very high numbers so bring up the overall average. Average permeabilities are typically reported using the harmonic mean, which should be used here.
- The faults in the top Rotliegend group tip out in the Zechstein Group but are there any areas where they could be connected? Or the listric faults extend far enough for them to connect to them Rotliegend group faults? Basically, is there any risk of the faults acting as conduits for CO₂ into the overburden? If this is the case or not, I think it should be mentioned somewhere.

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)

Yes.

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)

Yes.

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):

Please see attached PDF with comments

QUALITY ASSESSMENT

Q 6 Originality	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 7 Rigor	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Q 8 Significance to the field	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Q 9 Interest to a general audience	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Q 10 Quality of the writing	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Q 11 Overall quality of the study	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>