Peer Review Report

Review Report on The Geobattery Concept: A geothermal circular heat network for the sustainable development of near surface low enthalpy geothermal energy to decarbonise heating.

Original Research, Earth Sci. Syst. Soc.

Reviewer: Sean Watson
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EVALUATION

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

The study aims to address the question of the sustainable management of shallow geothermal resources by introducing a new geothermal circular heat network concept, named the 'geobattery'.

With a focus on ensuring the long-term sustainability of closely spaced borehole heat exchangers (BHEs), the geobattery concept harnesses recycled or renewable heat to thermally recharge the shallow geothermal resource via abandoned mine workings or other permeable aquifers and transport the heat to end users.

The authors show that the modelled concept can prevent heat mining as well as reduce the impacts of thermal interferences between closely spaced BHEs. This results in efficiency improvements in terms of thermodynamic work of the heat pumps, and importantly, stable subsurface temperatures that ensure the long-term sustainability of the shallow geothermal resource, irrespective of the relative timing of the BHE installations and geobattery development.

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

Strengths:
The literature review is robust and thorough. The introduction to the manuscript successfully describes the current energy landscape of the UK, and the opportunities for developing BHEs and mine water geothermal schemes in the UK. The literature review also sets out the problem which the study seeks to address (the sustainable management of shallow geothermal resources) and how the geobattery concept may prove to be a solution to this.

The analysis and results produced by the generic model were extensive. The authors considered a number of model scenarios, such as the inclusion of geobattery recharge within the model, the different heating system temperatures, sinusoidal heat loads, varying the timing of the BHE installation in relation to the geobattery, and the intermittency of the heat source. Each of these considerations are relevant to the real-life application and development of the concept, and as such the authors should be commended for exploring each aspect.

The authors should also be commended for synthesising the available information on the workings at Burghlee, Ramsay, Roslin and Bilston Glen collieries. Figures 7, 8, 9 and 11 were particularly informative and illustrate the proximity of potential heat users, the resource, and opportunities to incorporate/develop existing energy supply points and heat networks into the overall system.

The authors also make a pertinent point (lines 678-688) regarding the need for a just transition and the socio-economic benefits to de-industrialised former mining communities that the development of low-carbon heating solutions such as the geobattery concept may bring.

Furthermore, in lines 611-616, the authors state that the development of the geobattery does not preclude the development of a mine-water scheme that targets the mine-water itself for heat extraction. This is a point that could possibly be emphasised earlier in the manuscript. The fact that the geobattery concept may enhance

heat extraction from deeper mine workings, whilst utilising shallow workings for heat transport (that may not have suitable temperatures for heat extraction themselves), is an effective use of legacy mine workings.

Limitations:
Please see the response to question (5) for discussion on aspects of the manuscript which may require further clarity and explanation. In summary, the manuscript could benefit from:
(1) a clearer link between the generic model and the case study, and whether the model input data is representative of subsurface conditions relating to the case study,
(2) further evidence (if possible) in support of the assumed groundwater flow direction in the case study, and
(3) confirmation on whether varying the porosity, thermal conductivity, thermal diffusivity, or temperature has an influence on the model solutions.

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 model parameters were set out and, on the whole, justified in their use. As described previously, the analysis of the generic model conducted by the authors was thorough and explored various scenarios which were relevant to the real-life application and management of the geobattery concept. The authors present the results of each modelled scenario, and then evaluate the benefits of the geobattery. The conclusions drawn from this work are supported by the sensitivity analysis and results.

The study then presents the case study in Midlothian to show three main components of the geobattery; the potential recyclable heat source, connected abandoned mine workings, and the potential users. The authors bring together publicly available data to detail the mined seams at the Burghlee, Ramsay, Roslin, and Bilston Glen collieries, and neatly show the extent of the mine workings throughout the case study area. The authors then estimate the heat source available in the mine workings and go on to identify potential locations in which the geobattery concept could be developed, highlighting the proximity of the ACF to mine workings, and potential heat users.

Overall, the methodology and analysis are robust, the results are clear and support the discussion and conclusion, and the discussion itself is well-considered, covering a number of important points and emphasising the benefits of the geobattery concept within the context of the UK energy landscape.

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?
Not Applicable.

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

Overall, this manuscript presented an interesting, novel concept which warrants further investigation. The analysis of the generic model was thorough, and the results support the points raised in the discussion and the conclusions presented. However, there are occasions within the manuscript which would benefit from further clarity. In lines 348-350, the authors note that the geobattery concept aims to supply heat to shallow geothermal resources at a much larger scale than a single development, and as such will not be developed at the same time as all infrastructure development. This may be outside the scope of the study, but at this project scale could the authors comment on who they envisage being best placed to finance and then manage a demonstrator of the geobattery system (i.e., local government, community funded, private company, or other)? In lines 447-450, the authors refer to the mine-water temperature measured in Bilston Glen colliery at a depth of 670 m as 15?C (Gillespie et al., 2013). Then, supplemented by the heat removed from the cooling system (15?C), the temperature of the mine water is raised to 30?C. It is then stated that this is the estimated mine temperature used in the modelling. This was a helpful clarification which linked the case study to the generic model. With this in mind, could the authors comment on whether the input parameters used in the generic model for the porosity (10%) and thermal conductivity (2.2 W/m?C) also relate to subsurface conditions at the case study site? If not, have the authors attempted to model parameters representative of the case study site? Furthermore, could the authors clarify which value of thermal diffusivity was used in the generic model? Could the authors also comment on the effect that changing the thermal conductivity, thermal diffusivity, porosity, or temperature would have on the results obtained from the generic model? For example, if the temperature of the mine water was increased to c. 23?C or c. 32?C at 700 m depth, as shown for areas in the east and west of the Midland Valley of Scotland (MVS) on the Coal Authority's interactive map, would this have an effect on the model output? In addition to the case study site in Midlothian, could the authors comment on whether they have identified alternative locations within the MVS, or further afield, where the geobattery concept could be implemented? In lines 515-521, the authors state that in the absence of specific hydrogeological data for the mined unit, it is reasonable to assume that the groundwater flow direction in this area is aligned with the regional groundwater flow direction. Could the authors comment on whether they are aware of any updated references or data which support the Robins (1988) assumption relating to the regional groundwater flow regime in the Midland Valley of Scotland (MVS)? Furthermore, could the authors suggest how they might validate the assumption that the groundwater flow direction in the case study area is south-west to north-east as shown on Figures 7 and 8, to ensure that the recycled heat will be transported to the identified heat users? Finally, the manuscript requires a few minor edits, consisting of: Lines 319-321: change "its true value to lies in maintaining the ground temperature to at environmentally sustainable levels" to its true value lies in maintaining the ground temperature at environmentally sustainable levels"?. Line 651: the Glasgow Geothermal Energy Research Field Site (GGERFS) is located in Dalmarnock and Shawfield in Glasgow's East End, not Clydebank. Line 764 and 768: these references include the first names of authors which is inconsistent with the remainder of the reference list. Figure 10: The labelled text for the energy supply points is quite difficult to read. This could be improved if text could be repositioned to avoid crossing the outline of the mine workings or the spine roadways. It may also help the clarity of the heat demand layer if the spine roadways were a different colour to red.

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	■■■■□

REVISION LEVEL

Q 12 What is the level of revision required based on your comments:

Minor revisions.