**Response to Reviewer #4:**

Thank you for your feedback. We have made the revisions requested to the manuscript and addressed your comments in this document in blue. We hope this adequately addresses the concerns raised.

**To the editor, here are our responses/explanations based on the email:**

**International Journal of Greenhouse Gas Control**Reviewer's Responses to Questions

Note: In order to effectively convey your recommendations for improvement to the author(s), and help editors make well-informed and efficient decisions, we ask you to answer the following specific questions about the manuscript and provide additional suggestions where appropriate.  
  
1. Are the objectives and the rationale of the study clearly stated?  
  
Please provide suggestions to the author(s) on how to improve the clarity of the objectives and rationale of the study. Please number each suggestion so that author(s) can more easily respond.

Reviewer #4: Yes. See detailed comments for additional input.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

2. If applicable, is the application/theory/method/study reported in sufficient detail to allow for its replicability and/or reproducibility?  
  
Please provide suggestions to the author(s) on how to improve the replicability/reproducibility of their study. Please number each suggestion so that the author(s) can more easily respond.

Reviewer #4: Mark as appropriate with an X:  
Yes [x] No [] N/A []  
Provide further comments here: See detailed comments for additional input.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

3. If applicable, are statistical analyses, controls, sampling mechanism, and statistical reporting (e.g., P-values, CIs, effect sizes) appropriate and well described?  
  
Please clearly indicate if the manuscript requires additional peer review by a statistician. Kindly provide suggestions to the author(s) on how to improve the statistical analyses, controls, sampling mechanism, or statistical reporting. Please number each suggestion so that the author(s) can more easily respond.

Reviewer #4: Mark as appropriate with an X:  
Yes [x] No [] N/A []  
Provide further comments here: See detailed comments for additional input.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

4. Could the manuscript benefit from additional tables or figures, or from improving or removing (some of the) existing ones?  
  
Please provide specific suggestions for improvements, removals, or additions of figures or tables. Please number each suggestion so that author(s) can more easily respond.

Reviewer #4: No. Would only suggest clarifying the existing ones, as described in the detailed comments section.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

5. If applicable, are the interpretation of results and study conclusions supported by the data?  
  
Please provide suggestions (if needed) to the author(s) on how to improve, tone down, or expand the study interpretations/conclusions. Please number each suggestion so that the author(s) can more easily respond.

Reviewer #4: Mark as appropriate with an X:  
Yes [] No [x] N/A []  
Provide further comments here: As presented, the figures and text do not have enough stand-alone information to support the conclusions. See detailed comments for suggested improvements to improve clarity.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

6. Have the authors clearly emphasized the strengths of their study/theory/methods/argument?  
  
Please provide suggestions to the author(s) on how to better emphasize the strengths of their study. Please number each suggestion so that the author(s) can more easily respond.

Reviewer #4: Yes. See detailed comments for additional input.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

7. Have the authors clearly stated the limitations of their study/theory/methods/argument?  
  
Please list the limitations that the author(s) need to add or emphasize. Please number each limitation so that author(s) can more easily respond.

Reviewer #4: Somewhat. The authors clearly describe their methods, which is refreshing. They clearly describe what it can do, but a balanced approach may be in order to better describe some of the method's limitations.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

8. Does the manuscript structure, flow or writing need improving (e.g., the addition of subheadings, shortening of text, reorganization of sections, or moving details from one section to another)?  
  
Please provide suggestions to the author(s) on how to improve the manuscript structure and flow. Please number each suggestion so that author(s) can more easily respond.

Reviewer #4: No.

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

9. Could the manuscript benefit from language editing?

Reviewer #4: No

Author Response: Noted, Thank you. We will address your comments in the “Detailed comments” section below

Reviewer #4:

1. Line 41. To improve clarity, remove the word "only".

Author Response: Edited; we have removed the line based on comments from reviewer #1

1. Reference 1. Although from a reputable source, this reference is only pointing to a news article. Especially for your first citation, I would encourage a more rigorously scrutinized source. Is there also a peer-reviewed source that contains the same information?

Author Response: Edited; we have added a new source.

1. Line 44. Coal, oil and natural gas are the largest used sources of fossil fuels, but not the only ones. Similarly CO2, CH4, and N2O are the largest produced GHGs, but not the only ones. Clarify language by modifying text to read: "The burning of fossil fuels (such as coal, oil, and natural gas) has resulted in the generation of various GHGs, such as carbon dioxide (CO2, methane (CH4) and nitrous oxide (N2O).

Author Response: Edited; thank you

1. Reference 2. Please update reference, preferably to a report or peer-reviewed journal. Reference 2 is pointing to an online webpage from a reputable source that was last updated on 23 February 2024. The webpage does not indicate that the amount of CO2 generated in 2020 to be ~3.11 million metric tons.

Author Response: Edited; we have added a new source.

1. Line 53. CO2 storage can be carried out in a number of different ways, not just the 3 listed. Clarify language by modifying the text to read: "CO2 geologic storage can be carried out in a number of different ways, including via injection into …"

Author Response: Edited; thank you

1. Line 60. This paragraph requires the addition of peer-reviewed journal references.

Author Response: Edited; we have removed the line based on comments from reviewer #1

1. Reference 3. The reference author names and format need to be corrected for this and other references. For this particular reference, correct reference information: "Bauer RA, Will R, E. Greenberg S, Whittaker SG. Illinois Basin-Decatur Project. In: Davis TL, Landrø M, Wilson M, eds. Geophysics and Geosequestration. Cambridge University Press; 2019:339-370."

Author Response: Edited; thank you

1. Line 73. Here and elsewhere, clarify "carbon capture well" terminology. I believe you mean "capture sequestration well", as opposed to something to do with the carbon capturing process itself.

Author Response: Edited; thank you

1. Introduction section. A discussion should be added about CO2 injection rates in general, what drives them, and why their calculation is a somewhat difficult problem for CO2 sequestration. Of deep interest is the calculation of the maximum rate at which CO2 can be injected into the subsurface by human operators. We are interested in the maximum rates of course because current climate models suggest that rather large amounts of CO2 injected at high rates is needed to sequester CO2 as fast as possible to mitigate climate change. Given that operators may want to have as high a rate as possible, what are the factors that actually determine the rate at which the operators are injecting CO2 (e.g., the pressure rise in the aquifer, equipment malfunctions, etc)? This would be directly relatable to what you are predicting. Lastly, there should be a discussion about why AI can become a preferred method: among other things, some existing methods to estimate subsurface injection rates can become complex and/or costly when considering at a basin scale. I'm sure there are other reasons that can be stated as well. What are the other ways in which maximum injection rates are currently calculated? What are the tradeoffs in methods? There is often, no single right way of doing things.

Author Response: A paragraph with regards to optimum CO2 injectivity has been added. In summary, achieving optimum CO2 injectivity relies on various factors, including geological and reservoir properties such as permeability and heterogeneity, effective pressure management, maintenance of injection fluid properties, and appropriate pump and well design. The goal is to determine the injection rate that maximizes volume over time while ensuring the storage reservoir's capacity is not exceeded. This emphasis on optimum rather than maximum injection rate considers the need for sustainable CO2 sequestration. Injecting too rapidly can lead to issues like premature reservoir filling or skin problems, reducing injectivity. Insights and methodologies from the oil and gas industry, such as nodal analysis, can inform our approach. However, further discussion on this topic falls outside the scope of this paper.

1. Line 94. Clarify text: "Within reservoir engineering, the prediction of hydrocarbon and water production rates from geological …"

Author Response: Edited; thank you. This statement simply means that predicting flow rates are a time series problem where future rates are predicted based on historical rates. ~~Instead of machine learning, however, DCA uses simple empirical equation, sometimes incorrectly.~~

1. Equation 2. The text in Lines 95-99 seems to indicate that Equation 2 is discussed in Reference 14. However, this equation is not included in Reference 14, Arps (1945). Additionally, there appears to be mathematical issue with this equation since one option has b=0, but then the exponent 1/b would be 1/0, which is impossible to answer since division by zero is undefined. This equation should be corrected, correctly referenced, each variable should be defined and units stated (including t).

Author Response: Edited; thank you. The reviewer is incorrect; these equations are present in Pg 19, table 5. ~~Also, these decline curves are very standard, fundamental reservoir engineering equations. We did not expect that the simplified forms of the equation to be described since interested readers can always reference the papers. However, we have now done so for this paper at the request of the reviewer.~~ There is no option b =0. b has to be more than 0 and less than 1.

1. Line 118. This sentence is misleading. In the field of CCUS, there are currently well over 100+ fields with data collected. Additionally, "injector production" is confusing as well: An injection well adds fluid to the subsurface, but a production well removes fluid from the subsurface. Which is meant by this term? In general I would say that data has been collected (although data itself is sometimes difficult to share, which is a different issue.) Even in the ML realm, Reference 23 states "ML algorithms have been widely used in CCS research and achieved good effect…". The beginning of this paragraph should be re-written to be in line what the references show as well.

Author Response: Edited; thank you. We have replaced the word “injector production” with “well” performance. We have rewritten the paragraph slightly.

1. Line 123. The Iskander et al sentence is missing the reference number.

Author Response: Edited; thank you

1. Table 1. A description of what the 34 measurements are is needed. For example, what is "Avg\_PLT\_CO2VentRate\_TPH" actually measuring and what are the units? The short names are sometimes not very descriptive. Also, what does "Non-Zero Value" mean?

Author Response: Added, thank you.

1. Line 212. Another plus of LSTMs are that they are "effective at capturing long-term temporal dependencies without suffering from the optimization hurdles that plague recurrent networks", right? (Greff et al., 2015)

Author Response: Reference has been included; thank you

1. Figure 4. Y-axis appears to be truncated. Colorbar needs descriptor.

Author Response: Edited; thank you

1. Line 270. Why were these 6 variables in particular retained?

Author response: Many variables exhibit strong correlations, with coefficients exceeding 0.5 (See correlation matrix). To prevent multicollinearity issues, we retained only one variable from each group of highly correlated variables. Exceptions were made when variables originated from different sources, such as tubing and reservoir pressure at the observation well. Excluding the target injection delta variable, we selected eight variables for the machine learning application.

1. Figure 5. What is the y-axis with units on 5b?

Author response: tonnes per hour. Figure amended.

1. Figure 5 and 6. The 5b and 6b close up comparisons between the actual and LSTM predictions do not match up well. There should be some discussion about why this is okay (or not). Are the larger amplitude variations of greater interest in a real-world setting and is your model capturing those wiggle-for-wiggle? (Can't tell from the figure.) Are these smaller scale variations not of importance in a real-world setting? Is further decimation of the data necessary and/or useful?

Author Response: Fig 5 is just showing one example from a K-fold. It’s a smaller data set, so the match will be poorer, but the model uses these numerous small data sets to ultimately tune the large scale macro model.

1. Line 318. How are you defining an anomaly? How is this useful in a real world example?

Author Response: In a CO2 injection project, we anticipate maintaining a consistent optimum injection rate and injection pressure despite potential fluctuations. This concept parallels Newton’s 2nd law, suggesting that an object in motion will persist in motion unless acted upon by an external force. Anomalies occur when this equilibrium is disrupted.

1. Table 4. A description of the Varied Parameters is needed. For example, what does "Z-Score Inj\_Diff" actually mean? This actually appears to be two tables stitched together, they should be separated and separately described.

Author Response: Noted; we have split the table as requested although we think it makes for a less impactful presentation. We have explained what Z-score means in “Nomenclature”; its just a conventional statistical measurement, like mean or mode.

1. Table 5. Table 5 appears to be truncated. No column headers. Cannot evaluate.

Author Response: Noted; it is not truncated. We have added a new column header (there was a previous header there already) – we hope this is clearer

1. Figure 7. The comparisons do not appear to match up well even though the authors indicate that "all results show small perturbations around the unseeded value". There should be some discussion about why variations up to an order of magnitude difference is okay (or not).

Author Response: We remind the reviewer that the expectation that the results match perfectly when initial conditions change is an unreasonable one to make. Of course, the results will be different. What we want to demonstrate is that it is insensitive to initial seed values because results only change within +/- 10% of a base (unseeded value) case. We are measuring at fractions of a psi, after all.

1. Figure 8. Units needed on y-axis. X-axis units are unclear, is this days? What do the yellow and green boxes represent? Where are the four anomalies described in the text?

Author Response: The box colors distinguish between two distinct events. In the first event, noticeable variations in injection pressure occurred. Initially, there was a reduction in injection pressure, followed by subsequent increases and further reductions, creating four anomalies. These fluctuations directly impacted the CO2 plant vent rate, which ideally should remain at zero to ensure all CO2 is effectively injected into the well. However, the anomalies led to some CO2 being inadvertently vented. Concurrently, these pressure oscillations were reflected in the pressure gauges at the injection well, CCS1, yet no corresponding anomaly was observed at the pressure gauge in the observation well, suggesting minimal impact on the reservoir. Consequently, it can be inferred that this event originated within the well, possibly stemming from valve malfunctions or plugging issues, which were subsequently addressed, as evidenced by the absence of anomalies thereafter.

The second event involves a singular reduction in wellhead pressure at the injection well. This decrease in wellhead pressure triggered an increase in pressure throughout the injection well and elevated pressure readings in the observation well. This significant alteration in pressure dynamics likely signifies a more substantial disturbance, possibly indicating a system-wide anomaly or operational adjustment. Further analysis is warranted to fully understand the implications and potential causes of this event, particularly considering its notable impact on both injection and observation wells.

1. Line 418. Your motivation is important and should also be stated in the introduction to better emphasize the strength of your technique.

Author Response: Noted; we have emphasized this again in the introduction and conclusion.

1. Conclusions. How would a significant equipment failure (or similar event) in the training dataset be represented? Would the data need to be cleaned, or would it be able to cope? What if there was such a failure in the testing dataset? In an operational example? What would happen?

Equipment failure can indeed lead to anomalous readings in the sensor data. For instance, if the pump malfunctions, it would likely affect the injection well's wellhead pressure, which in turn would be detected by the downhole sensors. The model would recognize this deviation from the normal operating pattern as an anomaly, prompting operators to investigate and address the issue promptly. Moreover, such anomalies serve as indicators that the containment of CO2 is intact, providing assurance of safety and operational integrity. On the other hand, if there is a failure in the wellbore, the anomaly would likely manifest in the nearest sensor of the injection well. However, there may not be corresponding changes in the injection pressure or other sensors in the well. Nonetheless, this anomaly would still trigger an alert regarding the injection delta, signaling operations to investigate further. Once confirmed, actions such as shutting in the well and initiating wellbore repair procedures would be taken promptly to maintain operational efficiency and prevent any potential environmental or safety concerns.