Quantifying geological CO₂ storage security to deliver on climate mitigation

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Abstract

Carbon Capture and Storage (CCS) can help nations meet their Paris CO₂ reduction commitments cost-effectively. However, lack of confidence in geologic CO₂ storage security remains a barrier to CCS implementation. Leak rates of 0.01% yr⁻¹, equivalent to 99% retention of the stored CO₂ after 100 years, are referred to by many stakeholders as adequate to ensure the effectiveness of CO₂ storage¹⁻³. Secure storage must allow global average temperatures, driven by excess CO₂, to decrease well below 2°C; these timescales are typically modelled to be 10,000 years⁴. Thus, leakage rates must remain below an average linear rate of 0.01% yr⁻¹ for that timespan.

Many studies that assess global industry-wide risk of subsurface gas leakage do not specifically consider subsurface CO₂ retention mechanisms⁵,⁶, despite experimental measurements showing that residual trapping may immobilise a significant proportion of the CO₂ almost immediately on injection⁷. The published studies that incorporate subsurface CO₂ retention into their risk assessments are for site-specific, real or hypothetical, hydrogeological models⁸,⁹, rather than industry-wide, regional, or global scenarios.

Here, we present a numerical program that calculates CO₂ storage security and leakage to the atmosphere over 10kyr. This links processes of geologically measured CO₂ subsurface retention (residual and dissolution trapping), and CO₂ leakage estimates (based on measured surface fluxes from appropriate analogues). We model 12 GtCO₂ of cumulative storage based on the EU’s 2050 target¹⁰, commencing injection in 2020, and calculate CO₂ retention for well-regulated onshore and offshore scenarios, and for a hypothetical onshore, poorly regulated scenario.

Simulations using base-case, expert chosen values for model input parameters give total leakage after 10,000 years of between 2 and 23% of the stored CO₂, equating to simplified time-averaged linear leak rates of between 0.0002% yr⁻¹ and 0.002% yr⁻¹, respectively. Uncertainty on the results, introduced through uncertainties in the input parameters, is quantified using Monte Carlo analysis. These Monte Carlo results show that CO₂ storage in regions with moderate abandoned well densities and that are regulated using current best practice will retain 96% of the injected CO₂ over 10,000 years in more than half of the cases, and will lose 9.6% of the injected CO₂ in fewer than 5% of cases. An unrealistic unregulated case, with unknown and inadequately abandoned wells shows a 50% probability that leakage is below 0.003% yr⁻¹ over 10kyr, meaning more than 70% of the CO₂ is securely retained over 10kyr.
Sensitivity analysis indicates that well density (frequency of wells per until of area) is a key control on storage security. Sensitivity tests also highlight that the most significant uncertainty in the model is how the leakage rate evolves over time; the leakage rate is expected to decrease over time once injection ceases, as the mass of mobile CO$_2$ in the reservoir decreases via residual and chemical trapping, and leakage. We have modeled this based on measured and simulated removal of gases (via leakage or production) from underground reservoirs, but data remains limited and we suggest that this should be a target of future research.

Our new multi-parameter program can, for the first time, successfully simulate the storage of Gt of CO$_2$ regionally across multiple sites. As expected, we find that poorly regulated storage is less secure. Here, however, over 10,000 years, only 27% of injected CO$_2$ will leak in half of cases, with the possibility that up to 34% of the injected CO$_2$ could leak in 5% of cases. This leakage is primarily through undetected and poorly abandoned legacy wells, and could be reduced through identification and remediation of leakage if a comprehensive site screening and monitoring program is deployed. Importantly, natural subsurface trapping mechanisms mean that this leakage will not continue indefinitely. Consequently, even with mitigation actions restricted solely to repair of abandoned wells that blow out, regions with a legacy of poorly regulated subsurface operations can reliably and robustly store and retain 73% of injected CO$_2$. Our calculated leakage values are well below 0.01% yr$^{-1}$. We therefore show geological storage of CO$_2$ to be a secure, resilient and feasible option for climate mitigation even in poorly regulated storage scenarios. Hence, deployment of carbon capture and storage can be recommended to all governments as part of their actions to comply with the Paris 2015 target of keeping the global mean temperature well below 2°C.

References:


