IMPACT OF SUBSURFACE SETTING ON CO_2 STORAGE LEAKAGE RISK: IMPLICATIONS FOR FINANCIAL RESPONSIBILITY AND THE INSURANCE INDUSTRY

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ABSTRACT

Geologic carbon sequestration (GCS) is pivotal for reducing greenhouse gas emissions, yet CO_2 and brine leakage, and their environmental and financial impacts, remain critical concerns. This research links technical leakage simulations with financial risk assessments to evaluate how subsurface conditions and reservoir geometries influence leakage behavior and associated costs. Central to the study is the premise that wellbores—particularly unidentified plug and abandoned wells—serve as the most likely conduits for leakage, representing a worst-case scenario when these open pathways connect the reservoir to the surface. An integrated modeling framework was developed using static geological models and dynamic multiphase flow simulations to analyze various aspects of leakage behavior. We examined the variation of CO_2 and brine leakage with distance from the injection well; the percentage of CO_2 leaked and the financial impact with and without detection and remediation; sensitivity to different subsurface settings; the effects of well density; and the influence of reservoir geometry, specifically comparing anticline and dipping structures. Results indicate that rapid pressure propagation drives early leakage, with most incurred costs occurring within the first five years of the project. In scenarios without monitoring and remediation, significant cumulative leakage is observed; however, effective detection and repair strategies reduce cumulative CO_2 leakage to less than 1% of the injected volume—even under extreme high well density conditions. Cost analysis reveals that the injection penalty is the primary expense driver, followed by water remediation capital costs. Among all parameters studied, well density emerged as the most significant driver of financial impact, with higher densities substantially increasing both leakage volume and total financial impact. Furthermore, probabilistic assessments incorporating various well failure probabilities show that, although higher failure rates can increase normalized costs over the project's lifespan, the overall leakage remains minimal, thus reducing financial risk when remediation is applied during injection and post-injection periods. Although different reservoir geometries and subsurface settings affect cumulative leakage, their financial impacts converge to negligible differences when monitoring and remediation measures are implemented. This study provides critical insights into the interplay between reservoir conditions, leakage dynamics, and financial outcomes in GCS projects, offering practical guidance for optimizing monitoring strategies, risk management, and site selection to ensure both environmental safety and economic viability.

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