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Predictive Modeling of Carbon Dioxide Removal Potential via Enhanced Rock Weathering in Agricultural Soils Using Machine Learning

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While the carbon dioxide removal (CDR) potential of enhanced rock weathering (ERW) has typically been estimated using geochemical reaction modeling tools such as PHREEQC or Geochemist's Workbench (GWB), these have not yet become widely utilized tools in many cases due to the complexity of uncertainty assessment required for large-scale deployments. To address these challenges, this study develops a machine learning (ML)-based high-speed predictive model that incorporates basalt mineralogy, particle size distribution, reaction time, and key soil parameters such as soil pH as input features.

The model was trained on a comprehensive dataset integrating existing literature and batch simulations performed in GWB. Cross-validation results demonstrate that the proposed model significantly enhances computational efficiency while maintaining high consistency with geochemical kinetic calculations. Furthermore, this research quantifies the nonlinear coupling mechanisms between CDR potential and environmental factors, specifically highlighting the dominant roles of basalt rock mineralogy, soil pH, and basalt particle size. The model's validity was further confirmed by comparing predictions with cation release behavior observed in acid extraction experiments on rock samples.

This approach bridges the mechanistic accuracy of process models with the efficiency of machine learning, enabling the identification of boundary conditions for optimal carbon sequestration. The resulting predictive data serve as fundamental inputs for Life Cycle Assessment (LCA) and Techno-Economic Analysis (TEA), allowing for the integrated evaluation of grinding energy consumption, transport costs, and net-negative carbon benefits. Ultimately, this study provides a scientific framework to guide the commercial deployment and decision-making of ERW projects in specific agricultural environments.