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ENHANCED WEATHERING FOR CO2 CAPTURE: ANALYSIS OF OPPORTUNITIES AND CHALLENGES IN INTEGRATED MODELING OF GLOBAL MITIGATION SCENARIOS

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Abstract Summary (Font: Arial Bold, 10).

Enhanced Weathering (EW) is a carbon dioxide removal (CDR) strategy that accelerates the natural chemical weathering of silicate rocks to capture and store atmospheric CO_2. While natural weathering currently removes approximately 1.1 $GtCO_2$/year, enhanced applications could scale up removals to 2–4 $GtCO_2$/year at costs ranging from USD 20–40 per tonne of CO_2. This research critically assesses the opportunities and challenges of EW as a scalable CDR solution and proposes key parameters for its integration into Integrated Assessment Models (IAMs), which are essential tools for long-term climate scenario analysis and policy design.

Introduction

The growing interest in CDR technologies stems from the urgent need to complement emissions reduction strategies with negative emissions solutions. Among emerging approaches, EW offers a promising pathway by leveraging naturally occurring geochemical reactions to sequester CO_2. Its additional co-benefits, such as enhancing soil fertility and mitigating ocean acidification, position EW as a multifaceted solution aligned with both climate and sustainable development goals. However, EW remains underrepresented in global IAMs, with only a few models (e.g., REMIND) including it explicitly. This limits its visibility in policy discussions and scenario planning.

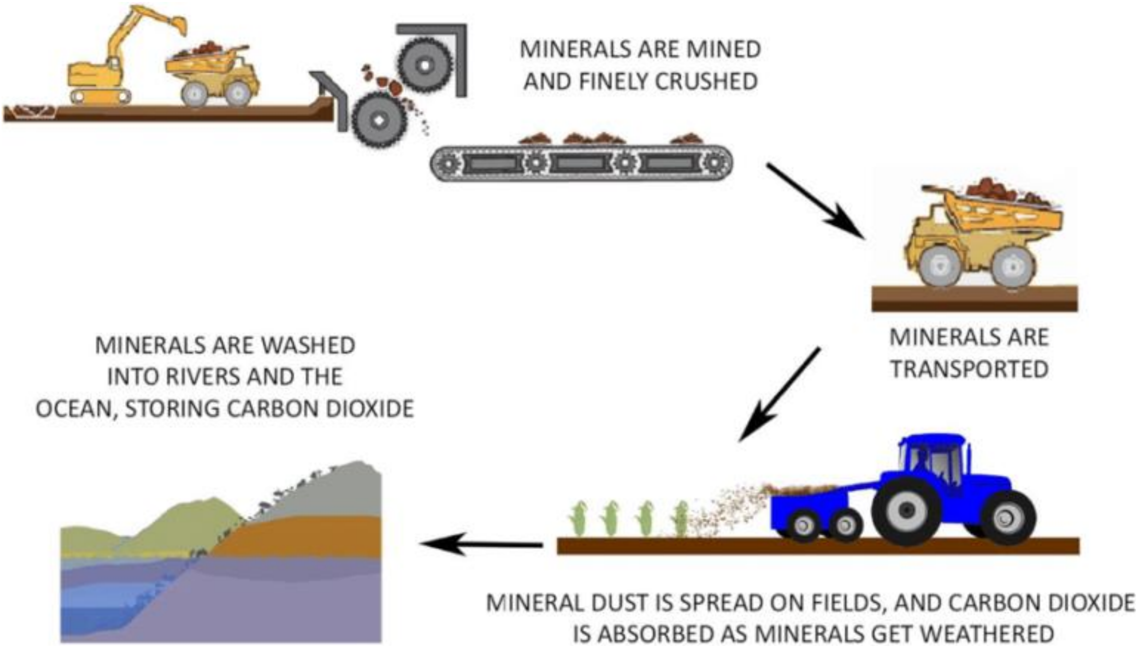

Figure 1: General scheme of enhanced weathering. Source: Spence *et al*. (2021).

Method and/or Theory

The research employs a qualitative meta-analysis based on a systematic review of peer-reviewed literature, modeling documentation, technical reports, and empirical data from pilot initiatives. The methodology focuses on identifying and characterizing seven critical parameters for representing Enhanced Weathering (EW) in Integrated Assessment Models (IAMs), particularly in the context of the COFFEE model developed by PPE/COPPE-UFRJ. These parameters are:

- **Rock Dissolution Rate**: Defined based on mineralogical composition, particle size, and edaphoclimatic conditions, this parameter determines the pace at which silicate minerals react with atmospheric CO_2 in soil environments.
- **Soil Adoption Rate**: Refers to the percentage of arable land where EW can realistically be applied, accounting for land use constraints, local agricultural practices, and technological readiness.
- **Energy Demand**: Includes the energy required for mining, crushing, milling, and transporting the rock powder to application sites, expressed in kWh per tonne of CO_2 removed.
- **Agricultural Effects**: Evaluates co-benefits such as improvements in soil fertility, pH correction, crop productivity, and potential reductions in the use of chemical fertilizers.
- **Temporal CO_2 Capture Profile**: Describes the sequestration dynamics over time, including the lag between rock application and peak carbon uptake, and the saturation period under different climate-soil conditions.

- **Regional Potential**: Assesses geographical variation in EW feasibility and performance, with emphasis on humid tropical countries where weathering kinetics are more favorable.
- **Emission Factor**: Accounts for lifecycle emissions associated with EW deployment, including upstream emissions from equipment use and material transport, which influence the net carbon balance.

Results

The analysis reveals that Enhanced Weathering (EW) holds significant potential for global carbon dioxide removal, with a technical capacity estimated between 2 and 4 $GtCO_2$ per year. This potential is particularly high in humid tropical regions such as Brazil, China, India, and the United States, where climatic and soil conditions accelerate silicate mineral dissolution. Cost estimates for EW deployment vary depending on the type of rock used, logistics, and regional conditions, but typically range between USD 20 and USD 40 per tonne of CO_2 removed. The energy demand associated with EW processes—primarily for rock comminution and transportation—is estimated between 200 and 400 kWh per tonne of CO_2 captured, underscoring the importance of optimizing supply chains and siting strategies.

Beyond its mitigation potential, EW offers notable environmental co-benefits. Its application can raise soil pH, improve nutrient availability, and enhance agricultural productivity, while simultaneously reducing dependence on synthetic fertilizers. Additionally, the export of bicarbonate ions to aquatic systems contributes to ocean alkalinity, potentially mitigating acidification in vulnerable marine ecosystems. However, several challenges remain. These include the limited availability of long-term field data, the potential for ecological side effects such as heavy metal mobilization, and the lack of standardized protocols for monitoring, reporting, and verifying carbon sequestration outcomes.

From a modeling perspective, the integration of EW into IAMs demands the development of robust, region-specific parameterizations. Current models tend to overlook mineral-based CDR strategies, and few offer the resolution necessary to capture the spatial heterogeneity and multipurpose benefits of EW. The COFFEE model, developed by PPE/COPPE-UFRJ, presents a promising platform for EW integration due to its flexible architecture and capacity to model land-energy interactions. Incorporating the seven parameters identified in this study—ranging from dissolution rates and energy demand to emission factors and agricultural effects—would enable more comprehensive representation of EW within long-term mitigation scenarios and support the design of policies that leverage its full potential.

Conclusions

Enhanced Weathering represents a promising, scalable, and cost-effective CDR strategy that could play a pivotal role in meeting high-ambition climate targets. Its integration into

IAMs is both a modeling challenge and a policy opportunity—especially in regions like Brazil, where geological and environmental conditions create a favorable context for deployment. This study provides a foundation for developing EW modules in IAMs and underscores the need for further empirical validation, standardized protocols, and interdisciplinary collaboration to support the inclusion of mineral-based CDR in global mitigation portfolios.

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