Assessing The Potential Of Soil Carbonation And Enhanced Weathering To Sequester Atmospheric CO_2, Through Life Cycle Assessment: A Case Study For Sao Paulo State, Brazil

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1. Introduction

Greenhouse gas (GHG) removal technologies (GGRT) are necessary to limit the increase in global average temperature to 2°C relative to pre-industrial levels [1].

Enhanced silicate rock weathering is defined as the **"process by which CO_2 is sequestered from the atmosphere through the dissolution of silicate minerals on the land surface"** [2], and has considerable potential as a GGRT.

However, the GHG emissions to implement the practice must not exceed its sequestration potential.

Objectives:

- Assess the environmental impacts of the practice in Sao Paulo (SP) state through a Life Cycle Assessment (LCA) approach.
- Assess the potential net CO_2 removal of Sao Paulo agricultural land through soil carbonation and weathering of basalt rock.
- Estimate the uncertainty of the two most sensitive parameters (sequestration potential of basalt and truck emission factor).

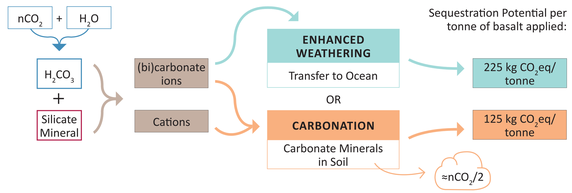


FIGURE 1 | Overview of the rock weathering process and the two pathways (carbonation and EW) considered in this study.

2. Methodology

2.1 System Boundary

Processes within the boundaries are represented in Figure 2. This LCA did not take into account any soil or crop response following the field application.

The functional units (FU) of this LCA are
- Per hectare of SP agricultural land amended by <5mm basalt particles,
- Per tonne of CO_2eq removed.

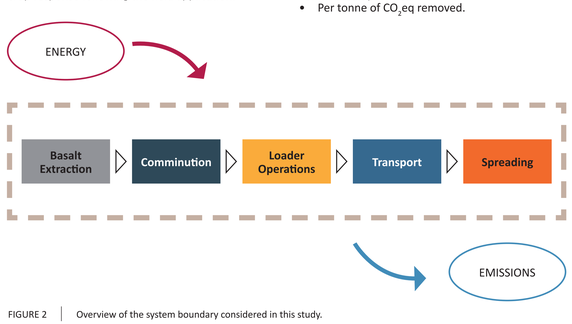


FIGURE 2 | Overview of the system boundary considered in this study.

2.2 Study Area

Sao Paulo was selected as a case study because of:

- Its location on an area with large basalt deposits [3]
- The resulting occurrence of basalt quarries [4]
- The climatic and soil conditions for rapid rock weathering [5]

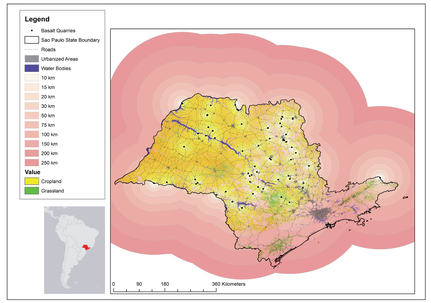


FIGURE 3 | Sao Paulo state with the locations of basalt quarries, cropland, and grassland inside the state. Concentric buffer zones, centred on the quarries, represent straight-line distances between quarries and agricultural areas.

3. Results & Discussion

Enhanced weathering and carbonation respectively emit around 75 and 135 kg CO_2eq per tonne of CO_2eq removed.

Our GHG contribution analysis (Figure 5) indicates that transportation is the most impacting process (considering SP average quarry to field distance of 65km).

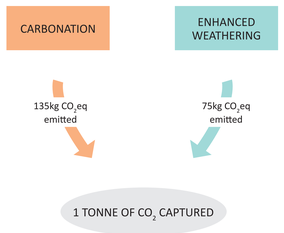


FIGURE 4 | Amount of CO_2eq emitted for the capture of 1 tonne of CO_2eq

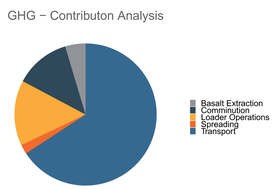


FIGURE 5 | GHG contribution analysis considering SP average quarry to field distance (65 km)

Basalt extraction, comminution and spreading induce fixed emissions while the impact of truck transportation increases with distance.

The offsetting distance refers to the quarry to field distance at which the GHG emissions offset the potential sequestration.

Both the sequestration potential of the basalt rock and the type of truck selected to transport the material have a major impact on the offsetting distance.

Sequestration of one tonne of basalt depends on the CaO and MgO content of rock and on the share of ions that will reach the oceans (ω from 1 to 1.79 for carbonation and enhanced weathering, respectively)

Figure 6 highlights the influence of the truck selected for transportation of the material and the impact of the ω value on the offsetting distance, computed through a Monte Carlo analysis.

Uncertainty on MgO & CaO content, tortuosity ratio, and emissions of fixed processes are taken into account.

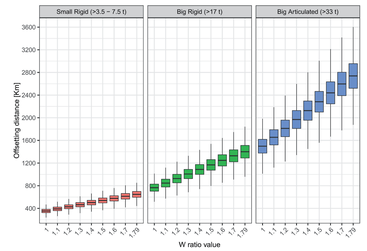


FIGURE 6 | Effect of Emission Factor (from truck type) and ω value on the offsetting distance. The ω value of 1 and 1.79 represent Carbonation and EW, respectively. The error bars shows the uncertainty of emissions associated with all physical processes as well as the uncertainty on sequestration potential according to the ω value.

Using the typical truck in Sao Paulo, the offsetting distance reaches 544 ± 65 and 994 ± 116 km for carbonation and EW, respectively (Figure 7).

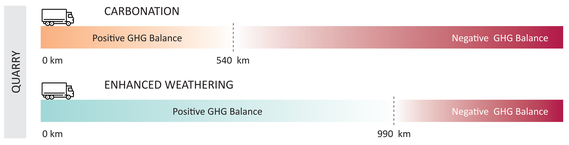
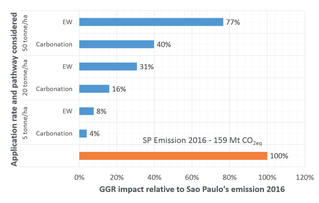


FIGURE 7 | Offsetting distance: distance at which the emissions offset the sequestration potential - SP conditions.



Sao Paulo's sequestration potential remains important, even considering the GHG emissions to implement the practice.

FIGURE 8 | Sequestration potential of the state of Sao Paulo's 12 million hectares of agricultural land

Importance Of The Holistic LCA Approach

- Emissions to implement the practice are usually not considered when assessing the potential of GGRT.

  For instance Kantola et al. (2017)[6] suggest that 1.1 Pg CO_2eq could be sequestered by the application of 50t/ha of basalt on of the corn belt of North America. Our assumptions reduces by 50% this estimate.

- Improvement on vehicle fuel use or use of bioethanol could reduce the GHG impact computed in our case study.
- Increased plant yield suggested after basalt application may also reduce the environmental footprint of the practice.

4. Conculsions

- An existing network of basalt quarries has the potential to supply SP with crushed material suitable for enhanced weathering or carbonation.
- Transportation greatly affects the potential sequestration of the technique. In our case study, the offsetting were 540 ± 65 and 990 ± 120 km for carbonation and EW, respectively.
- Comparisons with a previously published assessment showed transport impacts were underestimated, leading to overoptimistic net sequestration values.
- Applying crushed basalt at 1t/ha on Sao Paulo's 12 million hectares could capture 1.3 to 2.4 Mt CO_2eq through carbonation and enhanced weathering respectively.

As various GGRT are explored as efficient solutions to sequester atmospheric CO_2, we emphasizes the need to quantify all practices in their entirety to show the net efficiency, limiting features and caveats.

5. Acknowledgments

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