# LIFE CYCLE ASSESSMENT OF EMERGING PROCESSES TO VALORIZE MINING WASTE

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## Introduction

The notion of transforming waste as secondary resources for substituting materials in the current economy is getting more popular[1]. Besides limiting environmental consequences[2], copper mining residues such as waste rock has been viewed as one of the promising materials for valorisation due to its resource availability. A particular product such as alternative cementitious binders can be made out of this waste, after which the raw waste undergoes treatment processes to achieve the desired mechanical properties. Attempts to replace ordinary Portland cement require an array of mechanochemical activation methods[3] to the original waste, thereby leveraging the values of original materials. While the concept of recycling waste may sound beneficial at first, one must showcase the environmental benefits following the life cycle thinking approach including all processes. Various inputs and outputs that come along the novel value chains imply the introduction of resources into the system. Moreover, the maturity and scale of emerging and conventional technologies have shown to be important in the assessment. In this study, we demonstrate the first steps towards understanding the potential for environmental savings through prospective life cycle assessment of geopolymer-based concrete. To account for process changes, we implement upscaling strategies to the life cycle stages of geopolymer production. Analysing this systematically can help us pinpoint environmental bottlenecks and trade-offs, as well as justifying the benefits of substituting common concrete with a more sustainable material.

## Materials and Methods

A life cycle assessment (LCA) was conducted to quantitatively assess environmental impacts of concrete production through three valorisation pathways of waste. This product is intended to substitute standard cement concrete in the market. The five cases developed in Table 1 also serve as comparisons between the novel routes (i.e., geopolymer derived from waste rock) and the conventional one (i.e., Portland cement), in which the latter needs clinker processing. Therefore, we defined the functional unit as the supply of ‘1 $m^3$ concrete with 40 MPa mechanical strength’.

**Table 1.** Processes involved to manufacture 1 $m^3$ concrete, 40 MPa and the data source

| **Route** | **S1: Precursor** | **S2: Binder** | **S3: Concrete** | **Data source** |
|---|---|---|---|---|
| Lab scale geopolymer concrete | Jaw crushers and double-roller crushers | Recipes based on own experiments. (Mixing precursors with alkali activators) | Geopolymer concrete mix designs obtained from literature reviews[4] | In-house[3], expert inputs, process simulation, and calculated inventory |
| Geopolymer concrete, route 1 | Thickener only | | | |
| Geopolymer concrete, route 2 | Pressure filters with water saving | | | |
| Geopolymer concrete, route 3 | Double sieving with water saving | | | |
| Standard concrete | Portland cement concrete via hi-temperature calcination | | | ecoinvent 3.6[5] |

The first route comprises inventory data from the performed experiments developed in-house, which entails the direct measurement at the laboratory[3]. Basing on the first route, we created three upscaled routes that represent the adjusted life cycle inventory data at large scale operation in Europe, next to the mining area. This was done by simulating the step 1 (S1) in a mineral process simulator HSC Sim[6] that entails scale changes, synergies, and efficiency improvement, following frameworks suggested by Tsoy et al[7]. The three different cases were made to examine the effect of altering critical equipment in the precursor grinding configuration and how it will impact the overall results. Meanwhile, the use phase and end of life of concretes manufactured were all excluded in this study. The overall scheme is depicted in Figure 1.

The environmental performances for all cases were calculated for three impact categories, namely 1) climate change, 2) cumulative energy demand, 3) water scarcity footprint (AWARE). This was done to evaluate trade-offs across different categories.

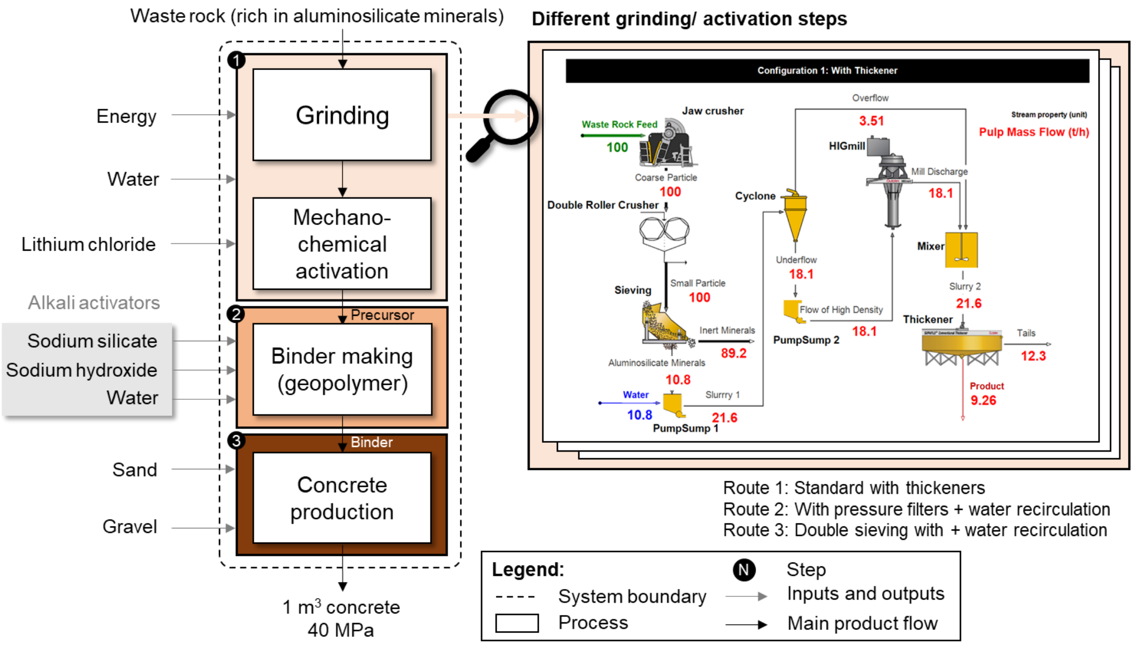

Figure 1. The scheme for geopolymer concrete production

## Results and Discussion

The upscaling efforts for three simulated cases in the precursor and the binder making step reduce climate change impacts between 85 – 88% of the original value (see Figure 2, part A). These environmental gains come from two factors. First, the economies of scale play a major role in reducing grinding electricity input in the initial stage. At large scale, high intensity grinding mill is installed to replace lab pulverisers with higher electricity per mass input. This proves that producing geopolymer at commercial scale is not only feasible, but also favourable in terms of climate change and cumulated energy demand. Once the precursor making is assumed to reach the standard industrial throughput (i.e. 100t/h, according to the high intensity grinding mill technical spec[6]), the environmental impact is significantly reduced. The geopolymer concrete emits even lower $CO_2$ emissions than common cement concrete in the market, as it avoids the high temperature calcination process that is replaced by mechanochemical activation.

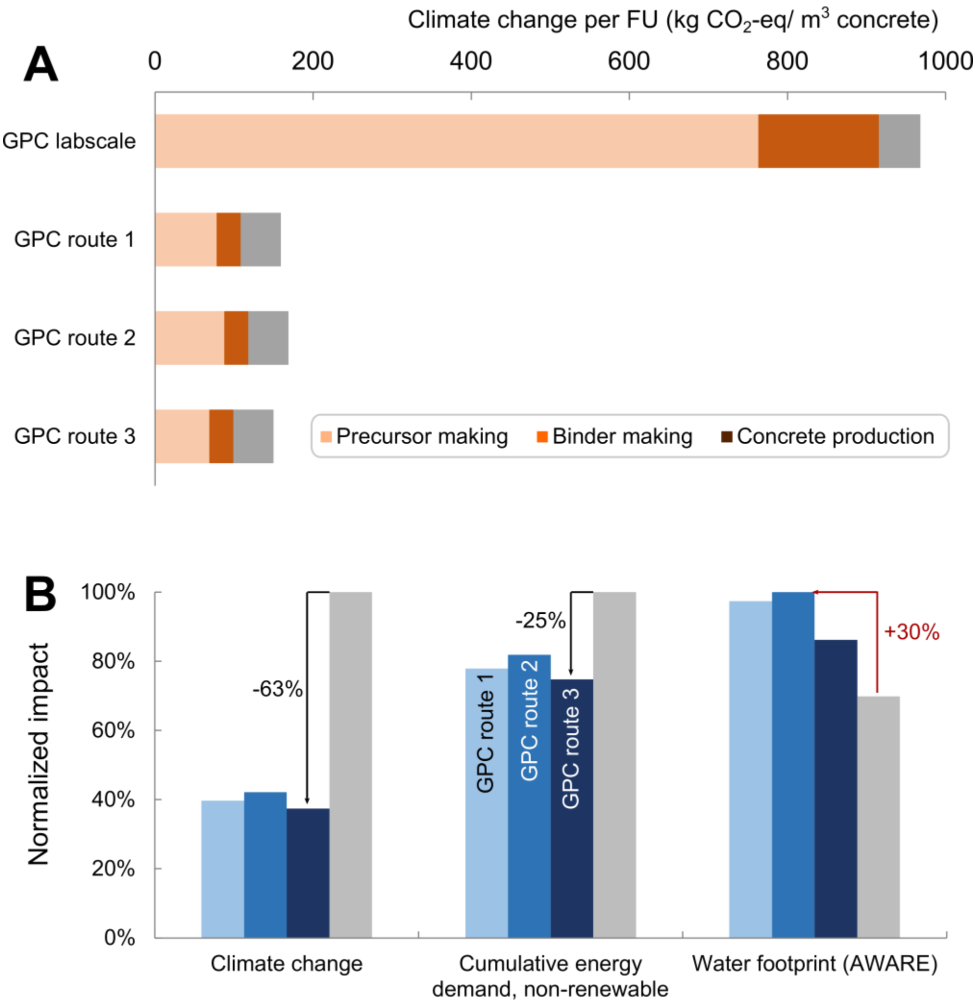

Figure 2. Part (A) compares climate change impacts of geopolymer concrete in lab scale and upscaled cases. Part (B) shows the potential savings/ losses compared to ordinary Portland cement concrete (grey bars) across different categories

Second, process synergies in the circuit might reduce water and reagents consumption. For instance, the choice of configurations from route 1 to route 2 and 3 enables water recirculation to be installed and thus minimize tap water intake. This parameter may not affect the results drastically in this study, but when production is planned in regions with high water scarcity, then it would amplify the benefit of one route to another. Even though the recirculation strategy might be worthy for the climate change and cumulative energy demand impact category, it is the opposite for the water scarcity footprint. One may further decrease these impacts by sourcing alkali activators and lithium from side-stream based materials[8] and less resource-consuming productions. However, in most cases, climate change impacts are more important than water scarcity for concrete production.

## Conclusion

The combined upscaling and life cycle assessment approach are able to detect energy and environmental hotspot and to provide feedback for process designers, especially concerning preparation of alkali activator chemicals from more sustainable alternatives such as sodium carbonate, calcium hydroxide and even underutilized alkaline residues. Different configurations matter in terms of environmental performance when there are open technological routes to upscale bench-scale experiments to industrial ones. Beyond the specific case, this study can be replicated to prospective LCA studies for other mine waste valorisation opportunities[9]. As an outlook, multiple scenarios with different future trajectories[10] and technological routes can create more holistic forward-looking studies, investigated in terms of ecological benefits and practical applications.

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