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Comparative Life Cycle Assessment of Composite Portland Cement Incorporating Bauxite Residue

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ABSTRACT

Great global benefits can be obtained by decreasing the cumulative environmental burden throughout concrete's life cycle due to its estimated annual worldwide consumption of ca 30 billion tonnes. The contribution of cement to this environmental burden is significant, since CO_2 is emitted from limestone decomposition, and clinkerisation occurs under high temperatures (1400-1450 °C). Bauxite residue (BR) is a by-product of the aluminium industry with an estimated annual generation rate of ca 170 million tonnes and has the potential to be recycled as a supplementary cementitious material (SCM). This study explores the changes in various environmental impacts that may be expected when BR is used as a potentially low-impact substitute for clinker.

A comparative cradle-to-gate life cycle assessment (LCA) model was developed in Activity Browser software version 2.8.0, based on a functional unit of 1 m^3 of concrete structure. BR-based composite Portland cements were compared with Portland composite cement – CEM II/A-M (0.2 wt% natural pozzolans, 1.3 wt% fly ash, 4.6 wt% granulated slag as SCMs) on the basis of equivalent functional performance in concrete. The BR-based cements contain 30 wt% treated BR. The comparison was performed based on the ReCiPe life cycle impact assessment method involving 18 impact categories assessed at midpoint level and using the hierarchist perspective. Two types of BR were considered: (i) BR co-calcined with kaolinite (at 750 °C) and (ii) vitrified BR (at 1200-1300 °C). The region of concrete production is Europe, which is the geographical region selected for the background processes such as electricity generation, heat production, and transportation in the Ecoinvent database version 3.9.1.

The results show that burden shifting in the concrete life cycle occurs in some impact categories due to use of BR-based cements instead of CEM II/A-M. The burden shifting arises from the BR treatment processes, despite several impacts showing considerable reductions (Figure 1). For example, compared to CEM II/A-M concrete, the global warming potential (kg CO_2-eq m^{-3}) of the BR-based concretes changes by -17.7% in the co-calcination case, and -12.0% in the vitrification case. However, the change is +2.5% (co-calcined BR-based concrete), and +45.9% (vitrified BR-based concrete) for the ionising radiation potential (kg Co-60-eq m^{-3}), which reveals that artificial radioactivity elevates due to emissions from BR treatment. In this regard, at the unit process level, the highest contribution (~93%) to the ionising radiation potential stems from the share of nuclear power generation in the chosen electricity mix, more specifically emissions due to treatment of the uranium milling tailings. Thus, to avoid burden shifting in ionising radiation potential impacts, BR could be treated in regions where there is less nuclear energy and more renewable energy. Also, other strategies can be chosen to mitigate burden shifting in other impact categories, e.g., water consumption potential (WCP).

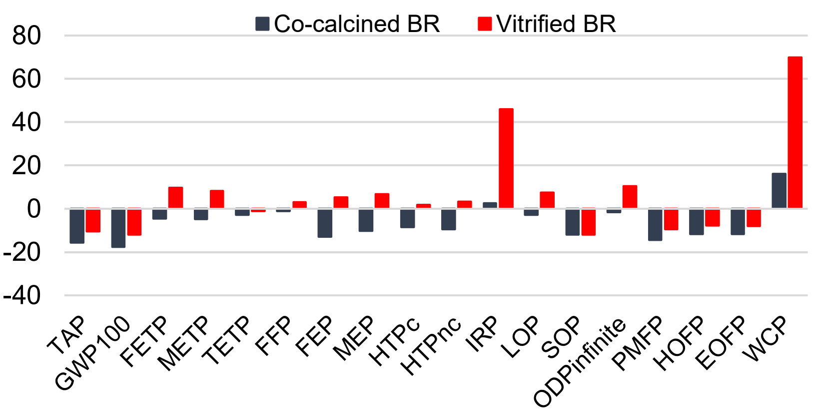

Figure 1. Percent change in impacts of concrete involving treated BRs relative to CEM II/A-M, based on Recipe Midpoint (H) LCIA method

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