Getting scope 3 right: how building life cycle analysis enables more complete greenhouse gas accounting for materials producers

MIT CSHub Research Brief

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Key Takeaways

- Present protocols for greenhouse gas (GHG) accounting lack clear guidelines for materials producers, particularly producers of intermediate goods
- All stages of building life cycle relevant to organizational environmental footprint (OEF) of cement producers, including scopes 1-3
- Use phase comprises the majority of building life cycle emissions, hence is a major contributor to OEF of cement producers

Growing momentum around greenhouse gas reporting

In the U.S., federal and state initiatives—such as Buy Clean[1]—prioritize materials producers which publicize **greenhouse gas (GHG)** emissions by promoting the use of low-emission materials for specific products used in public projects. Although Buy Clean bolsters market demand for low-emission materials, such initiatives are less applicable to GHG reporting at the firm level (as reporting at this level relies on considering the entire breadth of products that intermediate goods like cement are incorporated into). On the firm level, several cement producers have pledged to develop and follow organizational guidelines for reporting and lowering emissions[2].

With the growing momentum around lowering emissions, public and private entities need clear guidelines for reporting emissions and setting targets for emission reduction and neutralization efforts. The current best practice for doing so is known as **organizational GHG accounting** to estimate an **organizational environmental footprint (OEF)**[3].

Present protocols for organizational accounting define three scopes of an entity's environmental footprint: **scope 1** or direct emissions, **scope 2** or indirect emissions associated with the generation of purchased electricity, and **scope 3** or any other indirect emissions in the entity's **upstream** (preceding its direct activities) and **downstream** (following its direct activities).

The definition of scope 3 is broad, including 15 emission categories which span activities from extraction of raw materials for production of an entity's product to the processing of wastes at its product's end-of-life (a complete list can be found in Appendix I and emission categories in the scope of this study will be discussed in the following section). However, for materials producers, and particularly for producers of intermediate goods like cement, present protocols deem several of these emissions categories "too difficult" to measure and "too complex" to model[4].

Cement is mixed into **cement-based products (CBPs)** (e.g., ready-mixed concrete) which in turn are fashioned into end-use applications (e.g., buildings). Present protocols omit most downstream scope 3 emission categories from required reporting for cement producers by stating that cement producers lack complete information on cement's end-uses[i], such as the operational energy usage of each individual building with CBP components.

The goal of this research is to create a more complete picture of the OEF of cement producers by coupling information on cement's end-uses with industrial ecology tools such as life cycle analysis (LCA) and life cycle inventory (LCI) databases.

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[i] Organizational accounting for cement producers is governed by (1) Science-Based Targets Initiative's (SBTi's) cement guidance for target setting, (2) World Business Council for Sustainable Development's (WBCSD's) cement guidance for GHG reporting, and (3) Greenhouse Gas Protocol (GHGP).

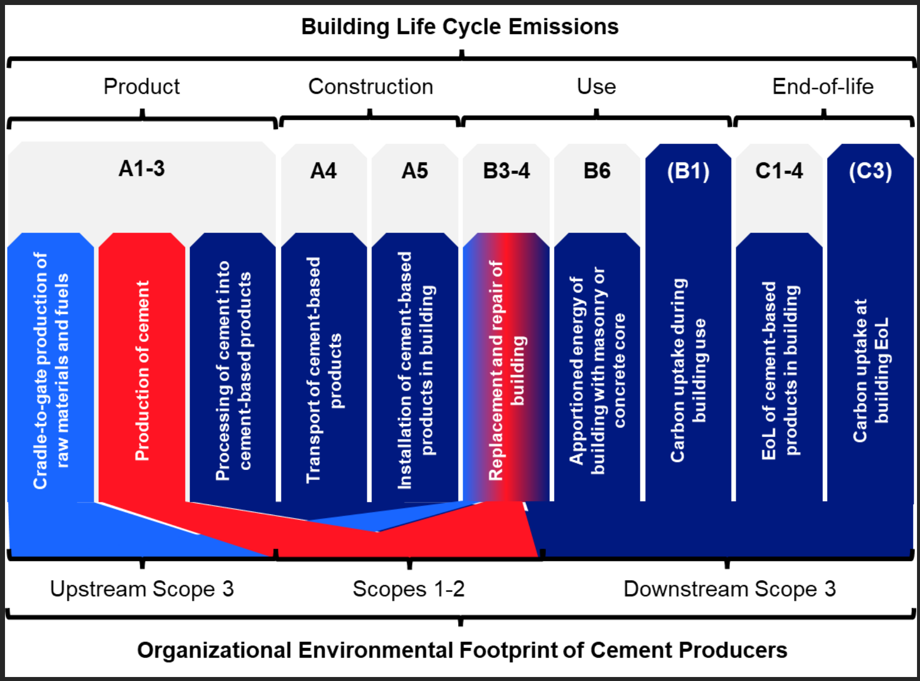

Figure 1 (Above). Outline of how building life cycle emissions map onto the organizational environmental footprint of cement producers; all building life cycle stages are relevant to cement's value chain, however only a portion of emissions in each building life cycle stage is relevant to report in the organizational environmental footprint of cement producers.

Defining cement's value chain and scopes 1-3 in this study

This document presents an abbreviated framework mostly focusing on scope 3. To simplify the presentation, we assume that scope 1 activities include calcination and on-site combustion of raw materials and fuels for clinker production only. We consider any other blending, grinding, bagging, and transportation and distribution (T&D) beyond the factory gate as part of the downstream of cement's value chain[ii].

In addition to scope 1 activities, present protocols require reporting on scope 2 activities, which includes off-site combustion of fuels for generation of purchased electricity, as well as a selection of scope 3 activities. Required upstream reporting is limited to cradle-to-gate and T&D activities associated with purchased goods, services, and fuels (burned in scope 1 or 2). Required downstream reporting is limited to T&D activities associated with sold goods (i.e., clinker).

Bridging greenhouse gas accounting and industrial ecology tools

Previous research at the **MIT Concrete Sustainability Hub (CSHub)** had developed tools for estimating building life cycle impacts[5] and hazard-related damages[6]. These tools allow us to estimate the full life cycle of a building's GHG emissions while accommodating any level of design information.

We propose updates to present protocols by describing how building **life cycle analysis (LCA)** and **life cycle inventory (LCI)** databases can supplement organizational accounting for emission categories currently ruled out for being "too complex" to model[4]. We demonstrate this in a case study of CBPs used in single-family homes (as detailed in the following section).

Combined with housing stock analysis, building LCA allows us to model the full scope of reportable emissions associated with the material production, construction, use, and end-of-life of CBPs used in buildings.

[ii] Limiting scope 1 activities to clinker production simplifies system boundaries while covering the single-most carbon-intensive process in cement production as well as a process cement producers are required to report on regardless of whether they purchased clinker or produce their own.

Capturing building life cycle emissions in cement's value chain

The objective of this case study is to estimate the contribution of CBPs used in single-family homes to the OEF of cement producers. In this context, cement is the intermediate good, CBPs are the primary good, and single-family homes are the final product.

Building life cycle emissions consist of embodied and operational emissions. **Embodied emissions** relate to material production, construction, and end-of-life emissions associated with materials consumption. **Operational emissions** relate to fuel and electricity emissions associated with energy usage during the use phase. Both embodied and operational emissions vary based on building design, material characteristics, energy composition, and user behavior around activities like repairs and energy usage.

To identify which building embodied emissions map onto the OEF of cement producers [see Figure 1], we first identify which CBPs are used in which building components. Ready-mixed concrete may be used in exterior walls, slab foundations, or footings, and concrete masonry units (CMUs) may be used in exterior or basement walls, among other materials used in wall and foundation systems[iii].

To identify what portion of building operational energy (B6) emissions (B6) map onto the OEF of cement producers [see Figure 1], we define **apportioned energy** to represent heating and cooling demands relevant to CBP components. Hence, B6 emissions are apportioned by a fraction representing CBPs' contribution to thermal conductivity (as higher thermal conductivity leads to higher heating and cooling demands).

In our estimates, apportioned energy covers roughly 20% (for concrete homes) to 50% (for masonry homes) of B6 emissions. (B6 emissions of wood homes are assumed out-of-scope. If reporting on the OEF of loggers, apportioned energy covers roughly 30% of B6 emissions associated with wood homes.)

In this study, reportable emissions include all building life cycle emissions relevant to the OEF of cement producers. In addition to required upstream reporting, we also consider cradle-to-gate and T&D activities associated with capital goods, which we allocate based on information found in LCI databases. In addition to required downstream reporting, we also consider activities associated with processing clinker into cement and cement into CBPs, as well as construction, use, and end-of-life activities of buildings (as described above).

[iii] We assume that product, construction, and end-of-life emissions associated with CBPs used in initial construction, repair, and replacement are in-scope, while the same for other (non-CBP) goods are out-of-scope.

Throughout this research, we create building archetypes to represent building characteristics pertinent to evaluating embodied and operational emissions. These building archetypes differ based on factors including, but not limited to

- Exterior wall core (i.e., concrete, masonry, or wood)
- Number of stories
- Living area
- Roof shape
- Roof cover
- Window area

Along with locational characteristics (e.g., climate), these building characteristics help estimate material and energy demands.

Use-phase comprises majority of building life cycle emissions

In this section, we evaluate building life cycle emissions for Florida homes built in 2022. Figure 2 shows building life cycle emissions and Figure 3 shows only the portion of building life cycle emissions which map onto the OEF of cement producers (i.e., reportable emissions).

All stages of the building life cycle are relevant to cement's value chain. However, only a portion of emissions associated with each building life cycle stage falls within the OEF of cement producers.

Repair (B4) emissions and initial construction (A1-5) emissions track a similar order of magnitude [see Figure 2], particularly in Florida where homes are exposed to high levels of hurricane wind loading and damages. However, reportable B4 emissions are much lower than reportable A1-5 emissions [see Figure 3]. This is because hazard repairs rarely occur in building components containing CBPs (that is to say they occur in components like windows and roofing which do not contain CBPs rather than components like the foundation which do).

Operational energy (B6) emissions comprise the largest portion of building life cycle emissions [see Figure 2]. Similarly, apportioned energy (i.e., reportable B6 emissions) comprise the largest, though relatively smaller, portion of reportable emissions [see Figure 3].

Thus, the use phase, which includes energy usage as well as repair and replacement is a major contributor to both building life cycle emissions and reportable emissions.

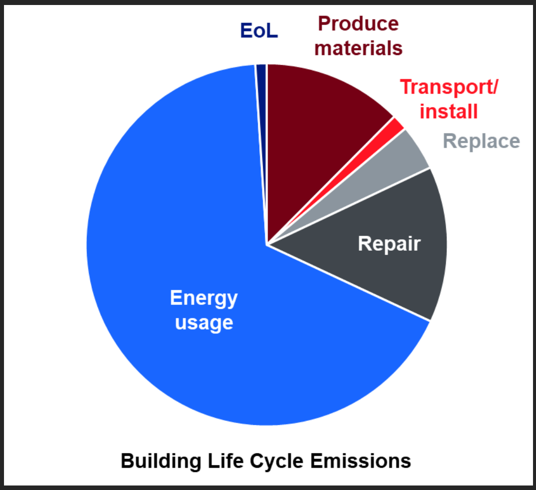

Figure 2 (Above). Breakdown of building life cycle emissions; Florida homes built in 2022, mean of 5000 simulations. Replacement based on industry standards for wear-and-tear; repair based on median of 100 wind loading scenarios.

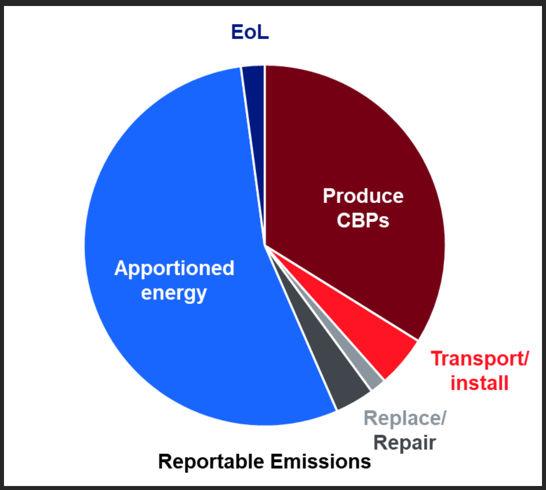

Figure 3 (Above). Breakdown of building life cycle emissions which map onto the organizational environmental footprint of cement producers; Florida homes built in 2022, mean of 5000 simulations.

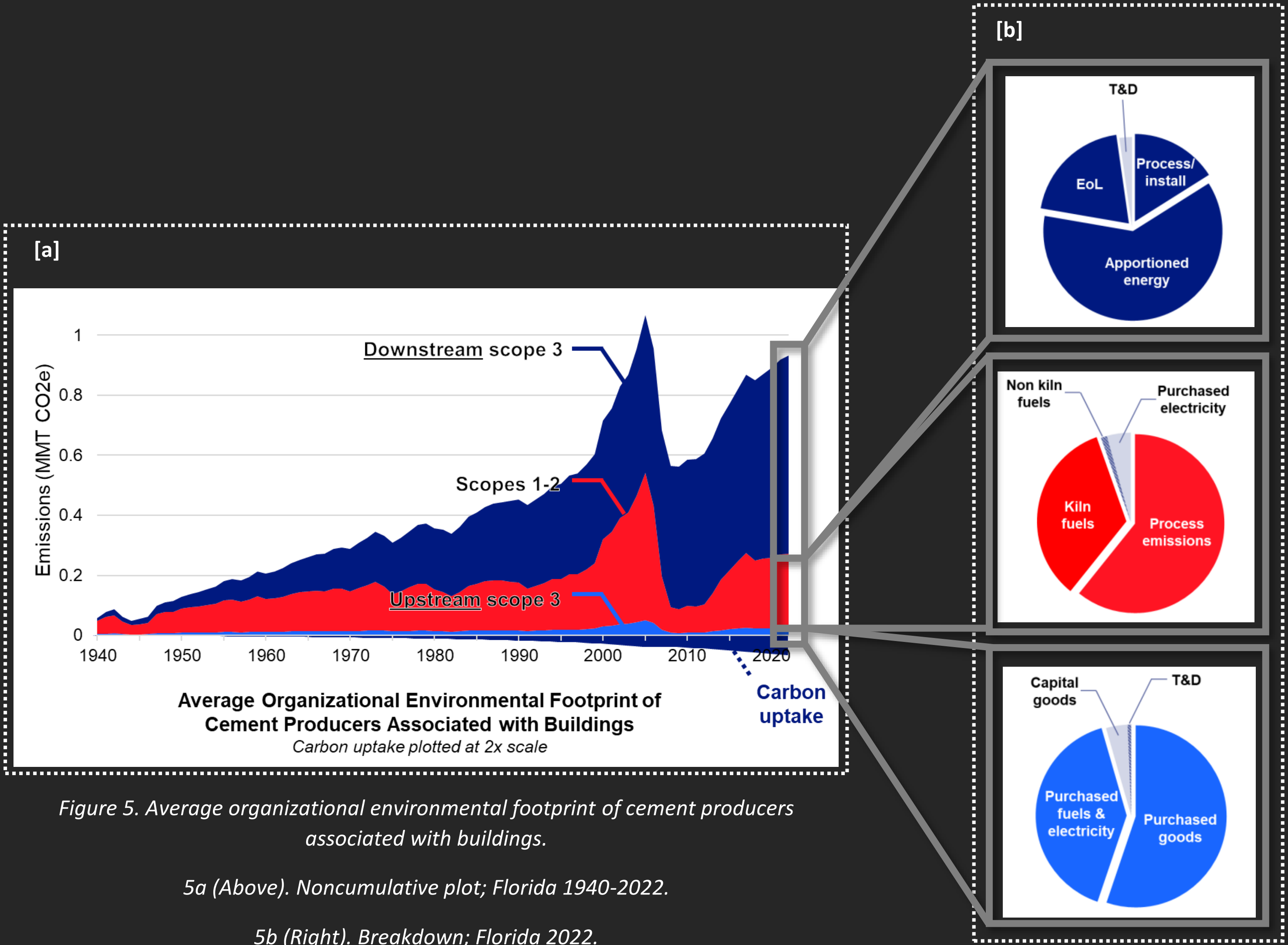

Figure 5. Average organizational environmental footprint of cement producers associated with buildings.

5a (Above). Noncumulative plot; Florida 1940-2022.

5b (Right). Breakdown; Florida 2022.

Use-phase: major contributor to footprint of cement producers

In this section, we evaluate reportable emissions associated with CBPs used in Florida homes built in 1940 through 2022 to capture the OEF of cement producers averaged across 9 Florida plants[7]. Figure 4a shows reportable emissions associated with CBPs over the analysis period. Figure 4b shows a snapshot of reportable emissions in 2022.

Reportable emissions grow over time, not only because the new construction rate goes up, but because the existing housing stock grows, contributing to a larger number of homes creating operational energy emissions, or reaching the end of their service life and creating end-of-life emissions. Downstream scope 3 emissions comprise a smaller portion of reportable emissions in earlier analysis years compared to the latter ones [see Figure 4a]. Towards the end of the analysis period, downstream scope 3 emissions comprise the largest portion of reportable emissions.

Scope 1-2 comprises 26% of reportable emissions in 2022, upstream scope 3 comprises 3%, while downstream scope 3 comprises the remainder and majority 72% [see Figure 4b]. The majority (>95%) of upstream arise from the production of raw materials, fuels, and electricity. The majority (>99%) of downstream emissions arise from the construction, use, and end-of-life of buildings.

Working towards emission reduction and neutralization strategies

Present protocols for organizational accounting for cement producers are mostly limited to emissions which occur in the material production stage of building life cycle. However, the majority of building life cycle emissions derive from the construction, use, and end-of-life stages that occur well after the material production stage.

In this research, we demonstrate that the contribution of latter-stage building life cycle emissions to the OEF of cement producers is pronounced towards the end of the analysis period, as a growing number of homes create operational energy and end-of-life emissions, separately. In addition to lowering emissions directly within their control, cement producers are encouraged to consider the efficiency of their products in lowering downstream emissions.

This study explores opportunities for building LCA to inform the OEF of cement producers, especially through defining and estimating emission categories currently ruled out for being "too complex" to model[4]. The direction of this research is to assist the cement sector in developing effective strategies for GHG reduction and neutralization throughout their entire value chain.

References

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