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USING AN ANALYSIS OF CONCRETE AND CEMENT EPD: VERIFICATION, SELECTION, ASSESSMENT, BENCHMARKING AND TARGET SETTING

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Abstract.

The carbon embodied in buildings is an important proportion of our emissions and needs to be radically reduced in order to support climate change mitigation. The highest proportion of embodied carbon is usually emitted during the product stage, and within the structural elements. Therefore, reducing the carbon embodied in the structural materials is likely to have a major impact. In most buildings, the majority of embodied carbon comes from steel and concrete. But although there are now hundreds of registered Environmental Product Declarations (EPD) for cements and concretes, there has been very limited independent published information comparing the embodied carbon of different concrete mixes and raw materials. This lack of comparative data limits the potential to make appropriate decisions at early design stages leading to low carbon buildings.

The authors have recently conducted a review of verified EPD for concrete mixes and for concrete's key constituents, including cement, identifying the range of carbon coefficients. This paper provides guidance on making use of the coefficient ranges provided in that research: to support the verification of EPD for concrete and its raw materials; in material selection; in assessing building level embodied carbon; in benchmarking; and in the setting of reduction targets.

Keywords: Benchmarking, embodied carbon, EPD, LCA, methodology.

1. Introduction and theoretical background

The carbon embodied in buildings, from the use of construction materials which produce Carbon Dioxide and other greenhouse gases during their life cycle, is an important proportion of our carbon emissions. International Energy Agency (IEA) estimate that embodied carbon accounted for 11% of global CO_2 emissions in 2017, most of this from cement and steel manufacture [1]. IEA and the World Business Council for Sustainable Development Cement Sustainability Inititive (WBCSD-CSI) estimate the greenhouse gases emissions from cement manufacture are already 7% of our total global emissions [2]. IEA also note that cement demand has nearly doubled between 2000 and 2016, mainly due to increased demand in China, and latterly, India [1]. With almost all cement used in concrete, it is clear that concrete has a major influence on global greenhouse gas emissions.

Environmental Product Declarations (EPD) are standardised presentations of the environmental impact of products. ISO 21930:2007 [3] was widely used by many of the EPD Programmes across Europe, but EN 15804 [4] has been developed following a mandate from the European Commission to harmonise the provision of EPD for construction products across Europe, ensuring that EPD to EN 15804 have a common methodological approach to LCA and provision of environmental impacts. ISO 21930 was updated in 2017 to closely align with EN 15804 [5]. ConstructionLCA's infographic [6] shows that the numbers of EPD using EN 15804 have risen rapidly with over 7000 EPD available globally at the start of 2020.

As a significant construction material, EPD have been produced for both cement and concrete products, including both ready-mix concrete and precast concrete. As detailed in their paper [7], Anderson and Moncaster made a systematic review and analysis of all the published EPD globally for ready-mix concrete and its constituent materials (cement, aggregates and admixtures) at the end of 2019. They found 252 EPD for ready-mix concrete reporting data for over 2000 individual products, 108 EPD for cement and cementitious materials covering 118 products, 88 EPD for aggregates covering 117 products and 9 EPD for specialist aggregates, and 16 EPD for admixtures coming from 25 EPD programmes in total. These EPD all represent products available in the market - including both national and regional industry average data provided by trade associations and manufacturer specific data for both average and specific products, and many of these EPD, especially those for ready-mix concrete, provided individual data for more than one product, in some cases providing data for over 100 individual products in one EPD.

These EPD were reviewed in terms of the data on "cradle to gate" embodied carbon coefficients (the Global Warming Potential Impact Indicator for Modules A1-A3 within EPD) and their embodied energy (the Primary Energy and Secondary Energy Resource Indicators for Modules A1-A3 within EPD), together with other data such as clinker and cementitious content for cements and 28-day strength for concretes, where they are provided. This paper describes how the information reported in the Systematic Review and Analysis can be used in EPD verification, materials selection, Embodied Carbon assessment at building level, in benchmarking and in setting Improvement targets.

2. Previous Studies

Hammond and Jones provided an overview of the embodied energy and carbon coefficients reported in academic and industry literature in their Inventory of Carbon and Energy database (ICE database) [8]. They found 112 datapoints for ready-mix concrete, 92 datapoints for cement and 36 datapoints for aggregate, though in relation to embodied carbon they note that "there is often an absence of such data".

Damineli et al. reviewed 156 randomly selected papers from 1988-2009, 59 from Brazil (covering 604 concretes) and 97 International (covering 981 concretes), considering the embodied carbon of different concretes together with binder content, and 28 day compressive strength [9], and this work was updated by Scrivener et al. including examples of recent developments, including data from concretes formulated with up to 70% replacement of binder by filler [10].

The ICE database was updated in 2011 [11] using only 3 new datapoints for cement, aggregates and ready-mix concrete. the ICE database was updated again in 2019 [12] using embodied carbon data from published EPD. This version used 22 datapoints for ready-mix concrete (16 ready-mix sources listed), 14 datapoints for cement (4 sources listed) and 164 datapoints for aggregate (22 sources listed).

Pomponi and Moncaster reviewed carbon coefficients for cement and concrete in academic literature, identifying 58 coefficients across the two products [13]. Van Den Heede and De Belie similarly identified 12 datapoints for cement [14], Salas et al., reviewed the literature on LCA for cement and identified 16 embodied carbon datapoints [15], Ganassali et al. identified 32 EPD for cement [16], Kurda, Silvestre and de Brito identified 17 cement datapoints and 20 aggregate datapoints [17] and Braga, Silvestre and de Brito identified 16 concrete datapoints [18].

Passer et al. have written about how EPD are being used in the European Market [19] and Jelse and Peerens about how they can be used for Green Public Procurement [20]. Ganassali et al. discuss how they produced benchmark values for cement using 32 EPD, using the median value of the range for the reference value, with limit and target values set using the boundaries of the upper and lower quartiles of the range distribution [16]. Jones has developed embodied carbon benchmarks using the arithmetic mean of datapoints from selected EPD and others sources for each product [12].

3. Description of the Systematic Review and Analysis of EPD and Summary of its Results

3.1. Methodology

The review was conducted at the end of 2019. During the data collection phase, EPD were downloaded from all the known EPD programmes, using EcoPlatform [21] and the North American PCR Catalogue [22] and a general literature search. In the categorisation phase, EPD were categorised into cement, different concrete mixes, aggregates, and dividing the EPD which report multiples into a set of individual results. In the third phase, the data was extrapolated from the EPD cataloguing and tabulating like with like. The data included the embodied carbon coefficients (GWP for A1-A3) together with other relevant data for all the separate products contained within each product group. In the fourth phase, visualisations were developed and in the fifth phase, the results were checked and verified.

3.2. Cement Embodied Carbon Coefficients

Figure 1, taken from Anderson and Moncaster [7] which explains some of the reasons for variation, shows the embodied carbon coefficients for all the identified cement EPD plotted on a graph against clinker content. The types of cement (e.g., CEM I, CEM II etc) are differentiated using colour.

3.3. Ready-mix Concrete Embodied Carbon Coefficients

Figure 2 from the same source [7], shows the ranges for Embodied Carbon coefficients for all the identified products within ready-mix concrete EPD plotted against the 28-day strength where it has been provided. EPD ranges are identified based on the country of concrete production, with average EPD produced by national trade associations highlighted as a shaded range, labelled, e.g., "French Generic".

This clearly shows that the ranges of impact vary significantly between countries, with French and German industry generic EPD having much lower impacts for the same 28-day strength than the corresponding US and Canadian; and all EPD from Mexico and Saudi Arabia having much higher impacts than those EPD from Australia and the U.A.E. for example.

4. Using the Embodied Carbon Coefficient Ranges for Cement and Concrete

In the process of verifying the results, the authors found in several cases datasets which were significant outliers, and in these instances contacted the EPD programmes to check if there were possible errors in the data provided. In these cases, several errors were identified and EPD have been reissued. This led the authors to consider how the data collected in the Systematic Review and Analysis could be used.

4.1. In EPD Verification

The above example clearly illustrates how the Systematic Review and Analysis can be used to check EPD for cement, concrete and aggregates to identify if the results are reasonable.

For cement EPD, Figure 1 can be used to check the clinker content and embodied carbon are within the expected region of the graph, especially for CEM I, II, III and IV cements. The Systematic Review Analysis also provided a box and whisker graph showing the range of embodied carbon for EPD by Country of Production and by type of cement (CEM I, CEM II etc), not included here, allowing verifiers to check the plausibility of embodied carbon results. Additional graphs are provided in the systematic review [7], but not included here, for CEM I and CEM II cement EPD showing the embodied carbon broken down by CO2 from calcination and from fuel use, and the primary and secondary fuels use, broken down by renewable and non-renewable sources, which again can be used to consider the plausibility of data provided in the EPD for verification.

For concrete EPD for verification, we recommend checking them against Figure 3 which provides the embodied carbon ranges (mean and upper and lower quartile) for different countries and 28-day strengths to see that the embodied carbon is in the expected region of the graph. This graph also shows how many EPD results were included in each grouping.

4.2. In Material Selection

Cement selection must be considered alongside the functionality of the concrete that is required. Figure 3 shows that that there is great variation in impact reported for any given strength, but that generally, there is an increase in embodied carbon per m3 as the 28-day strength of the concrete is increased. However Purnell cautions against the selection of low strength concretes over high strength concretes on the basis of their reduced embodied carbon, highlighting that significantly more of a low strength concrete may be required to fulfil a particular function [23]. A similar conclusion was drawn by Damineli et al. who showed that assessing CO_2 per m^3 and per unit of structural performance ($kgCO_2e/m^3/MPa$) suggested that C50 concrete was the optimal choice ide greater savings in embodied carbon (20-35%) than those achieved by replacing cement with pulverised fuel ash (10-25%) for example [23]. Carbon Intensities for ready-mix concretes with 28-day compressive strength over 10 MPa (from [7]) are shown in Figure 4.

Many manufacturers are now able to provide EPD for the range of concretes that they product, for example using national tools such as the French BETie EPD tool [24] or industry association tools such as the CSI EPD Tool developed for WBCSD CSI [25] or that developed for the Norwegian Ready Mixed Concrete Association, FABEKO. There is also the EPD tool developed by BASF for manufacturers to assess concretes [26] and other manufacturer specific EPD tools such as that for Tarmac [27].

Therefore, when selecting a concrete, we recommend that specifiers do the following: (1) consider the range of embodied carbon impacts shown in Figure 3; (2) ask local concrete producers if they are able to provide information on the embodied carbon (carbon footprint or EPD) for their concretes; (3) look for a producer able to provide a concrete at the lower end of the embodied carbon range for its strength; and (4) make sure that any impacts from extended transport distances do not outweigh the benefits of reduced embodied carbon in production - provided in Module A4 of EPD.

4.3. In Building LCA

During early design stages, we recommend using regional generic data for concrete where available, as at this stage in the design this is the type of data recommended by EN 15978 [28]. If generic data is not available for a particular region, then we recommend identifying a region with similar technology for cement and concrete production and using Figure 2 to pick an appropriate embodied carbon value (from an industry generic EPD if available, or from the median of the range otherwise). Ganassali recommends the median as it is not sensitive to the outliers in a sample composed of a small number of data [16].

At later stages of the design, it is recommended to use specific data, e.g., from manufacturer specific EPD based on the products you have chosen to use in the building (see section on material selection).

4.4. In Benchmarking

Benchmarks can be provided for a product generally (e.g., cement or concrete) or for a specific product, such as CEM I cement or C30 concrete. Specifying benchmarks at the more specific level will ensure that the products meeting the benchmark are not just lower carbon products, but products which have lower carbon impacts than other products with similar functionality. For concretes, it is important that the functionality is considered in defining the benchmark. Concretes with lower embodied carbon per m3 may have lower compressive strength, and this may lead to a requirement to use more concrete which could have an adverse environmental impact. For situations where compressive strength is relevant, we recommend using Carbon Intensity ($CO_2eq/m^3.MPa$) as shown in Figure 4 to set benchmarks.

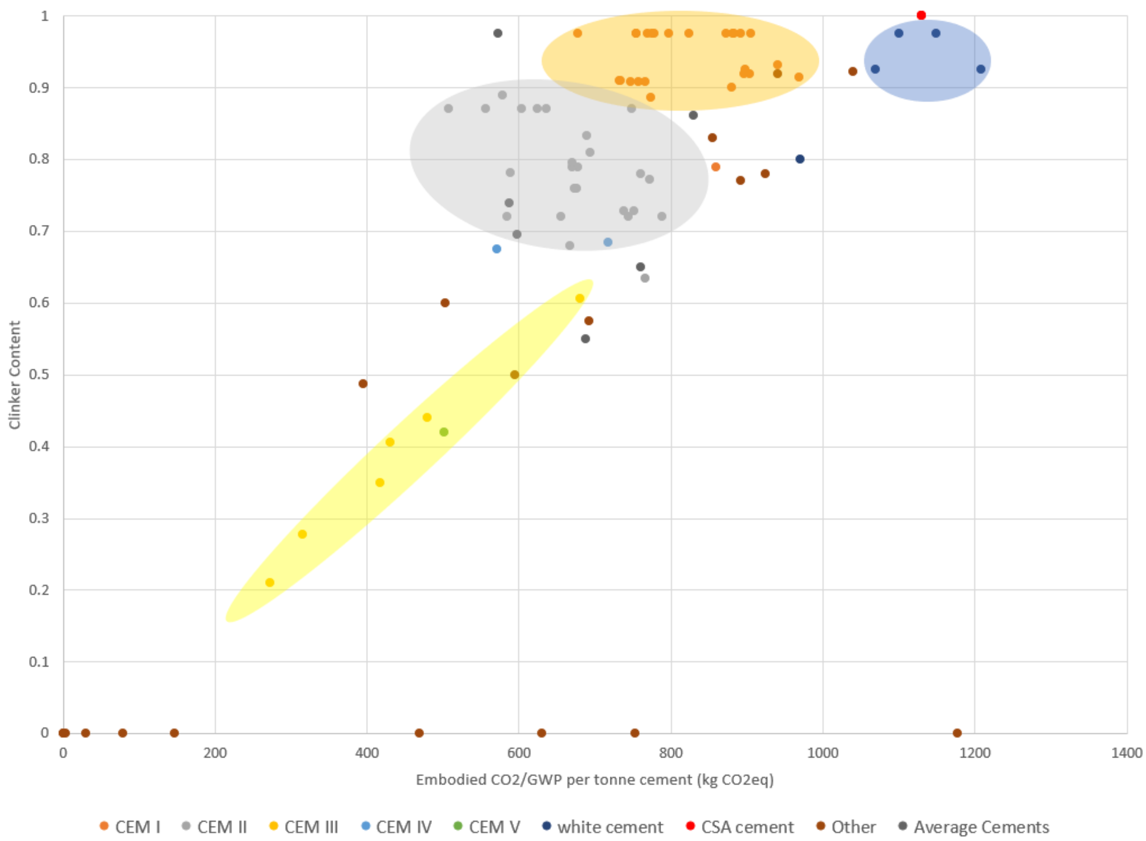

FIGURE 1. Graph showing relationship of Embodied Carbon for cements by clinker content, source [7].

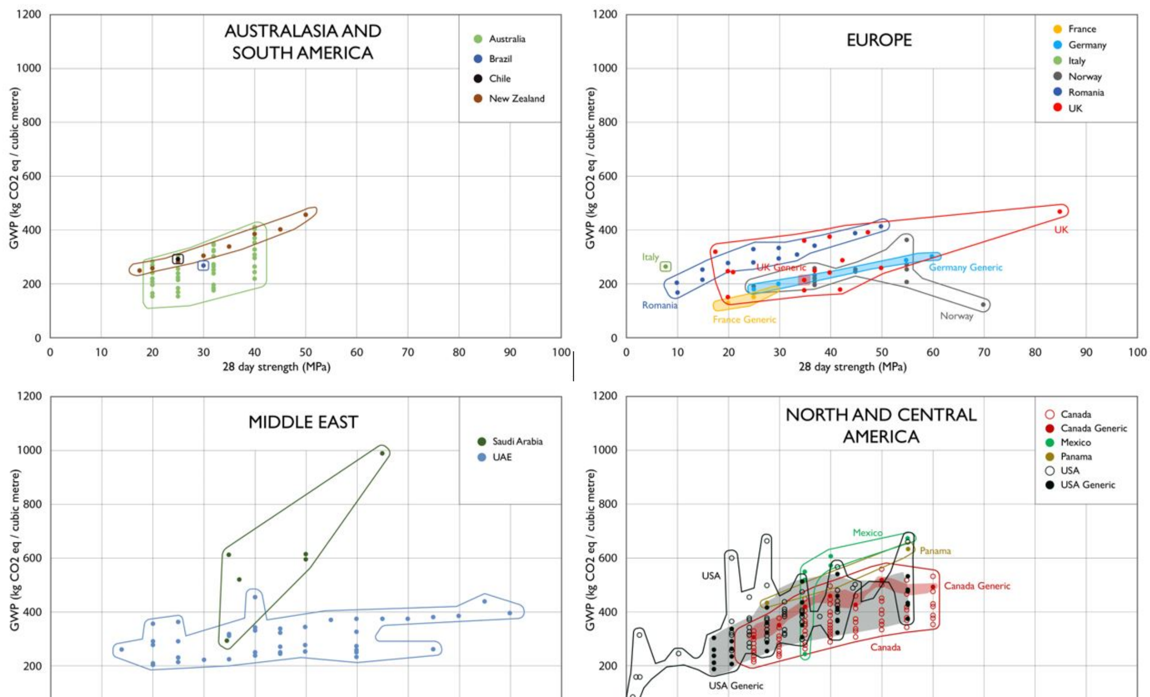

FIGURE 2. Embodied carbon per m^3 concrete by compressive strength, shown for each country, source [7].

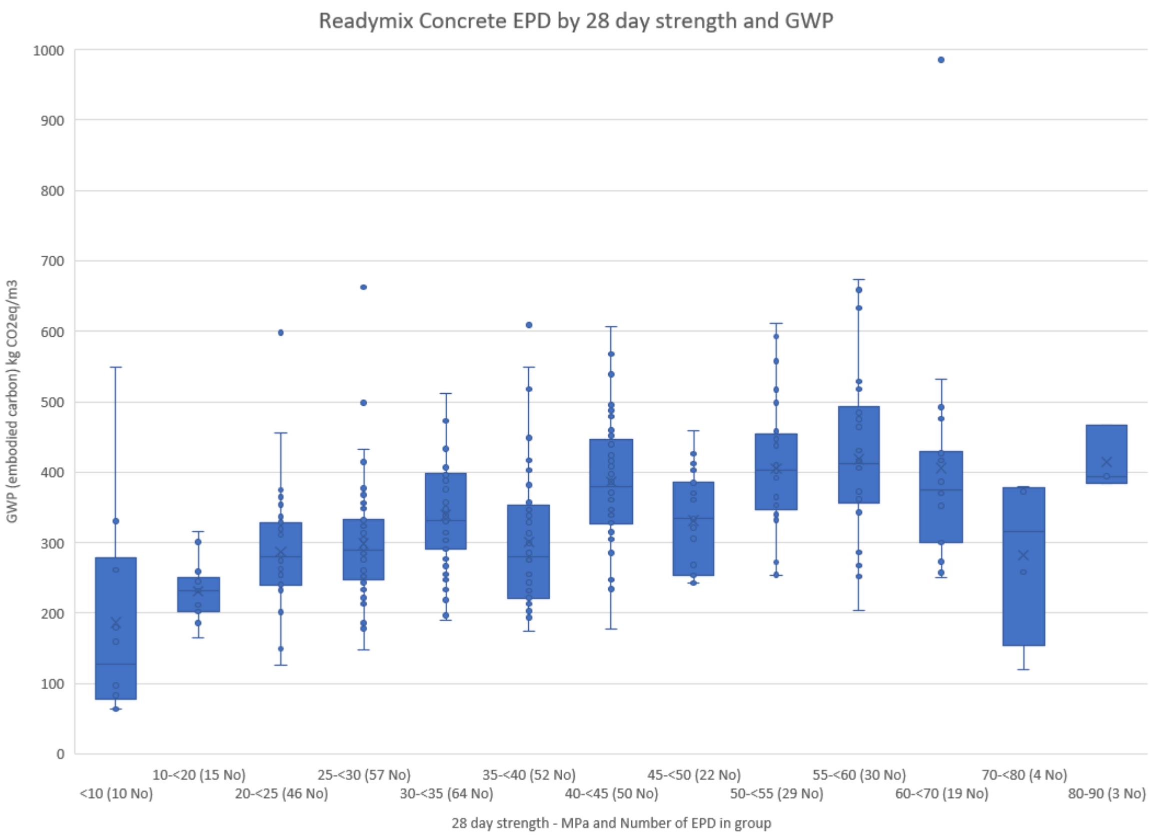

Figure 3. Box and Whisker graph showing mean, upper and lower quartiles of Embodied Carbon for ready-mix concretes from concrete EPD, by 28-day strength, source [7].

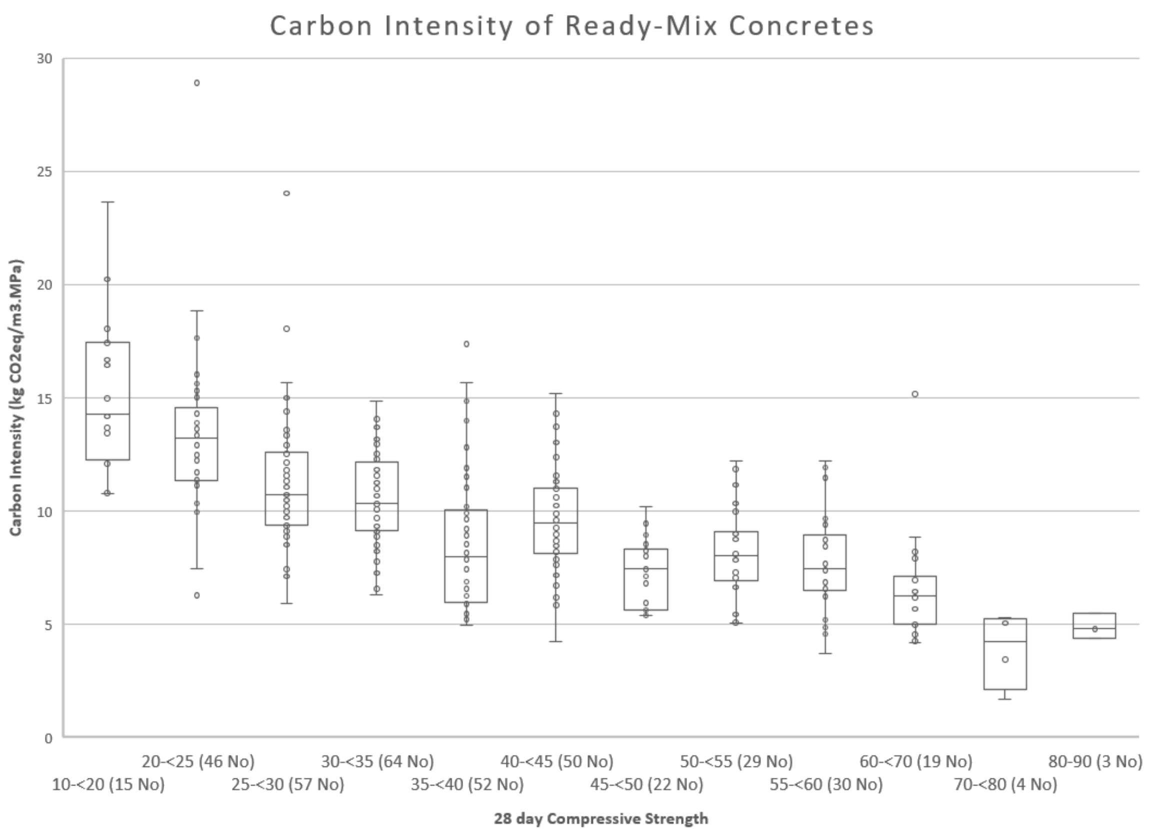

Figure 4. Box and Whisker Graph showing mean, upper and lower quartiles for Carbon Intensity ready-mix concretes, source [7].

In setting benchmarks, the geographical and related technological situation should also be considered - ideally a regional benchmark should ensure that at least some of the production achieves the benchmark, whilst also stretching producers adopting "business as usual".

4.5. In Setting Reduction Targets

The lower quartile ranges in Figure 3 and Figure 4 show the best performance shown by 25% and 50% of products with existing EPD, and therefore what should be achievable in setting long-term reduction targets for the majority of the market. This is also important information for manufacturers who wish to stay competitive in the carbon-aware market.

5. Conclusion

This paper has demonstrated how the analysis of existing EPD for cement and concrete can provide multiple useful information for Verifiers, Specifiers, Designers, Building Assessors and Manufacturers, including for EPD verification, material selection, building LCA, benchmarking and target setting. A similar detailed analysis of many other products groups from the construction sector, particularly other materials and products with major impacts, would be useful for the construction industry as a whole.

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