Decoding concrete's environmental performance: A detailed analysis of global EPDs across the entire life cycle

Sophie Viktoria Albrecht [1*], *Merve* Karamara[2], and *Charlotte* Thiel[1]

[1]OTH Regensburg, Construction Materials, 93053 Regensburg, Germany
[2]OTH Regensburg, Digital Construction, 93053 Regensburg, Germany

Abstract. Environmental Product Declarations (EPDs) for concrete are essential tools to quantify the environmental impact of this versatile building material throughout its life cycle, supporting sustainable choices in construction. Concrete is made up of raw materials like cement, water, aggregates, additives, and admixtures, which can be mixed in diverse ways. This variability often necessitates site-specific EPDs, as emissions and environmental impacts depend greatly on cement type, transport routes, and specific production processes. This study analyses various data sources, focusing on EPDs according to ISO 14025 and EN 15804. The life cycle phases A1-A3, B1-B7, C1-C4 and D are considered and compared. The results demonstrate that factors such as scenario assumptions, methodological choices, and allocation procedures significantly influence concrete's environmental impact. Transparent EPDs improve assessment reliability, while allocation methods, especially in phases D and end-of-life, significantly influence reported benefits, underscoring the importance of careful allocation for accurate impact evaluations. Improved standardisation, transparency, and alignment with EN 16757 would enhance EPD comparability and reliability. Overall, the study identifies key parameters such as recycling potential, production stage and allocation methods as substantial factors in the environmental performance of concrete.

1 Introduction

1.1 Background

Sustainable construction is essential for mitigating the environmental impact of the built environment, particularly due to the predominant use of concrete in the industry. As the most extensively utilized building material, concrete significantly contributes to global carbon emissions, with cement – its primary binding component – responsible for approximately 7 % of total emissions [1]. Over the past 65 years, the consumption of concrete and cement has increased by a factor of ten [2]. To reduce its environmental footprint, the construction industry must implement advanced decarbonisation strategies, including reducing the clinker-to-cement ratio, integrating renewable energy sources into production processes, and developing modular concrete systems optimized for reuse. Moreover, enhanced accessibility to high-quality, transparent data and comprehensive lifecycle assessments are crucial for enabling stakeholders to make scientifically informed decisions, thereby facilitating the transition to a low-carbon built environment [1].

1.2 Relevance of Life Cycle Assessment (LCA) and Environmental Product Declarations (EPDs)

Life Cycle Assessment is essential for evaluating concrete's environmental impact by analysing all life cycle stages to prevent burden shifting. Unlike assessments focused solely on climate change, LCA considers multiple environmental factors, enabling a comprehensive comparison of materials and processes [3]. It systematically compiles and evaluates the input and output flows of a product system, along with its potential environmental effects throughout its entire life cycle [4]. This quantitative approach identifies major emission sources and informs sustainable choices [3]. Environmental Product Declarations are essential for evaluating a products environmental impact, as they provide quantified, science-based data on its life cycle performance. In the construction sector, they serve as a key tool for comparing materials and identifying options with lower environmental impacts, supporting more sustainable decision-making in building design and material selection [5].

1.3 Objectives

Existing research on cement and concrete EPDs provide valuable insights into the environmental performance of these materials across different regions and methodologies. The study analysing ready-mix concrete EPDs in the USA has examined the distribution of compressive strength, product composition, and developed scripts for systematic data analysis [6]. Anderson et al. [7, 8] assessed global cement and concrete products focusing on the life cycle phases A1 – A3 (raw material supply, transport and manufacturing), with

* Corresponding author: sophie.albrecht@oth-regensburg.de

environmental impacts normalized per kilogram of CO_2 per cubic meter and megapascal to enhance comparability. Similarly North American ready mix concrete EPDs have been analysed, reflecting the common limitations in current EPD datasets [9]. These studies highlight the need for a more comprehensive and standardised approach to life cycle assessment, ensuring that data beyond the production phase is adequately reported and evaluated.

By analysing global EPDs of normal-strength concrete with the same compressive strength class, this study aims to identify key parameters that significantly impact the environmental footprint across different datasets. A particular focus is placed on the comparability of EPDs from different regions and data sources, highlighting potential inconsistencies and methodological variations. Additionally, the study conducts a comparative analysis of the life cycle phases A to D of concrete, covering the production stage (A1 – A3), construction processes (A4 – A5), use phase (B1 – B7), end-of-life scenarios (C1 – C4) and potential benefits and loads beyond the system boundary (D).

2 Materials and Methods

2.1 Environmental Product Declarations (EPDs)

The ISO 14025 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. It specifically establishes the use of the ISO 14040 series of standards in the development of Type III environmental declaration programmes and Type III environmental declarations [10]. While ISO 14040 regulates the principles and the framework ISO 14044 regulates the requirements and the guidelines of environmental management and Life Cycle assessment [4, 11].

EN 15804 is a European standard that defines the core rules for environmental product declarations (EPDs) of construction products. It provides a consistent methodology for assessing the environmental impact of building materials and products throughout their life cycle, ensuring transparency and comparability in sustainability evaluations. EN 15804 serves as a crucial basis for sustainable construction and green building certifications across Europe [5].

EN 16757 specifies product category rules (PCR) for EPDs of concrete and concrete elements. It complements the general principles established in EN 15804:2012+A2:2019. The standard provides specific guidelines for modelling the environmental performance of concrete products, ensuring consistency and comparability in LCAs [12].

2.2 Scope Definition

The analysis follows the framework of ISO 14025 and EN 15804 and focuses on a single strength class of unreinforced normal-weight concrete, excluding lightweight and heavy-weight concrete. According to EN 206, normal-weight concrete has a density ranging from 2000 to 2600 kg/m³ [13]. The functional unit (FU) is defined as 1 cubic meter (1 m³) of concrete, ensuring consistency in environmental impact assessment. The study does not include concrete elements. Additionally, each Environmental Product Declaration (EPD) includes only one strength class, avoiding mixed classifications to maintain clarity and comparability. The system boundaries align with the life cycle stages outlined in EN 15804, ensuring standardized assessment across all included data.

2.3 Data Sources

A total of 1259 EPDs were identified across 28 international free EPD databases. These EPDs align with the defined scope of the analysis, focusing on unreinforced normal-weight concrete within a single strength class. However, in 14 of these databases, no EPDs were found that met the specified criteria. A detailed overview of the distribution of relevant EPDs across the databases is presented in Table 1.

Table 1. EPDs from free databases that align with the analysis scope.

EPD database	Number of concrete EPDs
International EPD/environdec	465
IBU (Germany)	356
Ökobaudat	220
EPD Norge (Norway)	168
Rakennustieto (Finland)	10
RTS EPD (Finland)	9
KIWA	7
UL Environment (US)	6
EPD Danmark (Denmark)	5
EPD Italy	5
FDES (France)/inies	4
DAPcons (Spain)	2
EPD Belge (Belgium)	1
NSF (EN15804)	1
IFT Rosenheim	1
Bau EPD (Austria)	0
EPD Ireland	0
Cenia database (Czech)	0
ZAG (Slovenia)	0
DAPHabitat (Portugal)	0
PEPecopassport (France)	0
BRE EN 15804 EPD (UK)	0
MRPI (Netherlands)	0
ITB (Poland)	0
Cemsuisse	0
Eurima	0
Cembureau	0
SUGB	0
Stora Enso	0

2.4 Analytical Approach

To ensure better comparability and avoid mixing strength classes ranging from 8 MPa to 80 MPa, only a single strength class was selected for analysis. After comparing the EPD Identifiers with each other to eliminate duplicates, 1259 EPDs were identified. Among the various strength classes, C25/30 was found to be the most frequently represented, with 181 EPDs overall. This strength class was therefore selected as the focus for further analysis. This approach enhances the consistency and reliability of the findings. The distribution of EPDs across different countries is presented in Fig. 1, with Germany contributing the largest number of EPDs within the defined scope (102 datasets), followed by Australia with 49 datasets.

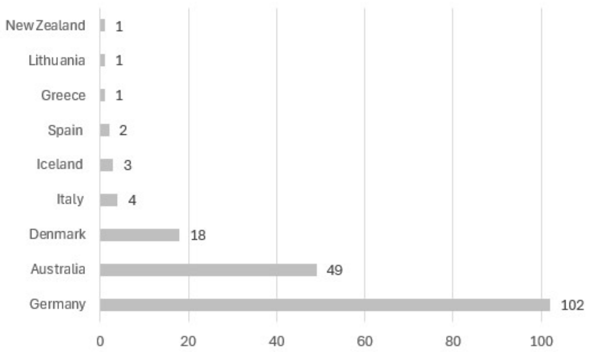

Fig. 1. Distribution of C25/30 fitting the research scope across different countries.

Phases A1-A3 are analysed collectively, as the majority of EPDs do not provide separate data for these phases. Additionally, the life cycle phases A4, A5, B1, C2, C3, C4, and D are examined. The analysis is conducted using EPDs that include the relevant data, acknowledging that not all EPDs provide information for every life cycle phase mentioned. For each life cycle phase, a box plot is generated to represent the distribution of data, including the minimum, maximum, median, first quartile, and third quartile. This visualization provides a comprehensive statistical overview of the variability within the dataset.

The allocation rules applied in Phase D and end-of-life scenarios vary across EPDs and must be assessed individually. For the analysis of Phase D, each EPD is examined to determine the specific allocation methods used, ensuring consistency and comparability in the interpretation of potential benefits and burdens beyond the system boundary.

To streamline the analysis, only a single environmental impact indicator, the total Global Warming Potential (GWP-tot), was considered.

3 Results and interpretation

3.1 Boxplot of the different LCA phases

3.1.1 Phase A1-A3: Product stage

For the life cycle phases A1-A3, which encompass raw material supply, transport, and manufacturing, all 181 EPDs provide data for these stages.

The statistical analysis of the data indicates a maximum value of 580.00 kg CO_2-eq. and a minimum value of 126.00 kg CO_2-eq. The lowest value is associated with the EPD identified as *IBU-CEI-HOL-2205120-DE2023000626-1SUG001-DE*, originating from Germany, while the highest value corresponds to the EPD *EPD-IES-0014748:00,* which is based in Australia.

The first quartile (Q1) has the value of 146.00 kg CO_2-eq., and the third quartile (Q3) is 203.94 kg CO_2-eq. The median distribution is 159.00 kg CO_2-eq., and the mean value is 178.72 kg CO_2-eq. Fig. 2 provides a graphical presentation of the values for the life cycle phases A1-A3.

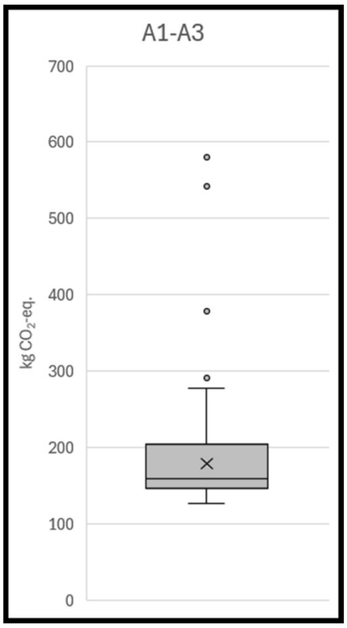

Fig. 2. Box plot of life cycle phase A1-A3 for C25/30 EPDs based on the defined scope.

The minimum value and the maximum value show a significant contrast in carbon missions between different EPDs, reflecting potential differences in raw materials, production processes, and regional factors. The mean is slightly higher than the median, suggesting a slight right-skew in the data caused by the EPDs with significantly higher carbon footprints pulling the average upward. This data suggests that while a large portion of the products have relatively low carbon footprints, there are outliers with much higher values, possibly due to factors such as location, production methods, and material choices.

3.1.2 Phase A4 and A5: Construction process

For the life cycle phase A4 the Transport 141 EPDs were considered as 40 did not declare a value for that phase.

The minimum value of 0.23 is associated with the EPD *EPD-IES-0014696:001* from Australia, while the maximum value of 5.11 kg CO_2-eq. corresponds to the EPD *NEPD-8779-8441* from Denmark.

The first quartile (Q1) has the value of 3.25 kg CO_2-eq., and the third quartile (Q3) is 3.34 kg CO_2-eq. The median distribution is 3.3 kg CO_2-eq., and the mean value is 3.29 kg CO_2-eq. Fig. 3 provides a graphical presentation of the values for the life cycle phases A4.

The tightness of the box plot indicates that 95 of the datasets fall within the narrow range of 0.09, with 91 of these datasets originating from the same company in Germany. This concentration suggests a high degree of uniformity within this subset. The observed variation between the datasets, seen in Fig. 3, is attributed to differences in transport distance, which is determined by the owner of each EPD. This factor significantly influences the environmental impact of the transport phase, contributing to the observed range in values.

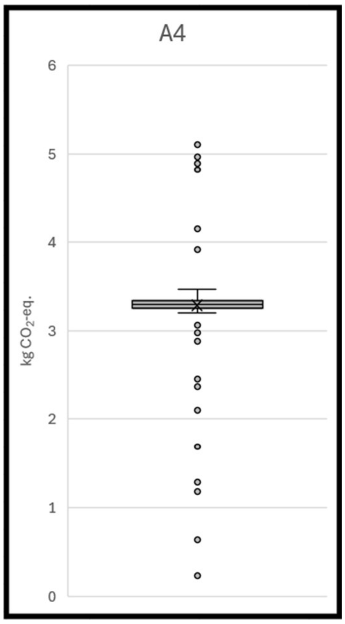

Fig. 3. Box plot of life cycle phase A4 for C25/30 EPDs based on the defined scope.

For life cycle phase A5, which covers construction/installation, 116 EPDs were considered as they provided relevant data.

The minimum value of 0.87 kg CO_2-eq. is associated with the EPD *EPD-IZB-20230421-IBA1-DE* from Germany, while the maximum value of 14.30 kg CO_2-eq. corresponds to the EPD *EPD-IES-0014748:001* from Australia.

The first quartile (Q1) is 1.56 kg CO_2-eq., and the third quartile (Q3) is 6.14 kg CO_2-eq. The median value is 2.26 kg CO_2-eq., with a mean of 4.24 kg CO_2-eq. (seen in Fig. 4).

The median of 2.26 kg CO_2-eq. reflects the central tendency of the dataset, while the mean value indicates a slight skew toward higher values, due to the outliers with significantly higher carbon impacts, such as 14.30 and 13.90 kg CO_2-eq. The minimum value of 0.87 kg CO_2-eq. corresponds to an energy consumption of 0.285 kWh of German electricity mix. In contrast the value of 10.50 kg CO_2-eq. from the EPD *IBU-CEI-HOL-2205120-DE2023000553-1SUG001-DE* includes multiple contributing factors, such as 0.46 kWh of energy consumption, 8.34 MJ of other energy carriers, and 123 kg of material loss.

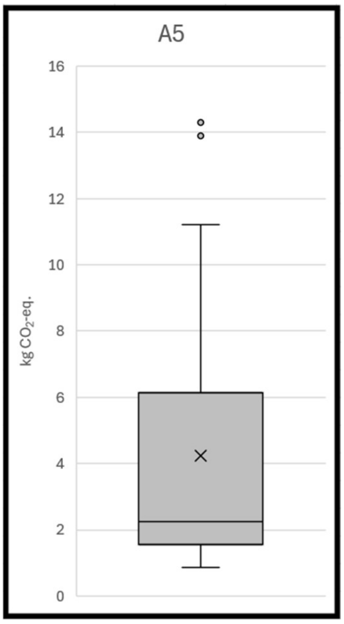

Fig. 4. Box plot of life cycle phase A5 for C25/30 EPDs based on the defined scope.

These factors collectively contribute to the significantly higher carbon footprint observed in this particular EPD. This EPD was selected as it provides a clear breakdown of the factors contributing to its A5 phase, whereas the higher value EPDs lack detailed explanations regarding the specific contributions to their environmental impact in this phase. The significant variation may be attributed to factors such as differences in contributing factors, construction methods, and regional variations in electricity mixes, which are likely to influence the overall environmental footprint of the construction/installation phase.

3.1.3 Phase B1: Use

For life cycle phase B1, the use phase, 119 EPDs were considered as they provided relevant data.

The minimum value of -16.30 kg CO_2-eq. is associated with the EPD *MD-22066-DA* from Denmark, while the maximum value of -0.17 kg CO_2-eq. corresponds to the EPD *S-P-03786* from Spain.

The first quartile (Q1) is -3.36 kg CO_2-eq., and the third quartile (Q3) is -3.07 kg CO_2-eq. The median value is -3.25 kg CO_2-eq., with a mean of -3.69 kg CO_2-eq. (seen in Fig. 5).

The significant negative value of -16.30 kg CO_2-eq. is calculated from the scenario of carbonation in a ceiling/floor element with a thickness of 20cm. This scenario assumes a high degree of CO_2 uptake over time, contributing to the substantial reduction in the GWP.

In contrast, the value of -0.17 kg CO_2-eq. is based on a carbonation scenario in which only one face of a 1 m³ concrete element is exposed to air, while the remaining three faces are not in contact with the atmosphere. The amount of carbonation is calculated with equation 1 [14].

$$CO_2\ uptake = k * \left(\frac{\sqrt{t}}{1000}\right) * Utcc * C * Dc \quad (1)$$

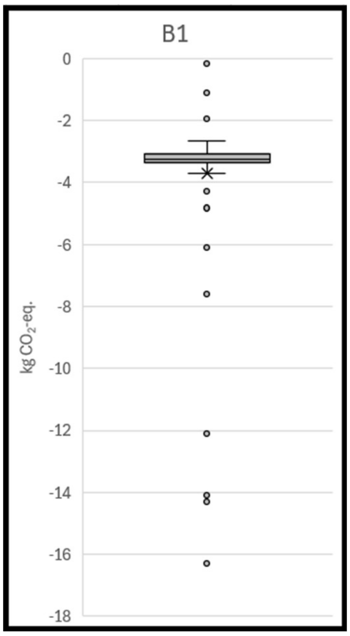

Fig. 5. Box plot of life cycle phase B1 for C25/30 EPDs based on the defined scope.

A total of 62 EPDs fall within the interquartile range, with 59 of these EPDs originating from the same company in Germany. The carbonation potential has been quantified in accordance with EN 16757, using a concrete structure within a building as the reference scenario. The environmental conditions assume exposure to outdoor elements, including rainfall, which influences the carbonation rate. A reference service life of 50 years is applied. Additionally, a surface-to-volume ratio of 5 m²/m³ is used to account for the exposure of the concrete element to air. The weight per unit area value is adjusted based on the specific characteristics of each concrete type to ensure accurate assessments of carbonation effects. accordance with EN 16757, considering a concrete structure within a building as the reference scenario. These factors are used for the calculation of CO_2 uptake seen in equation 2 [15].

$$CO_2\ uptake = \left(\frac{k * \sqrt{t}}{1000}\right) * A_i * D_c * C_{factor} \quad (2)$$

3.1.4 Phase C: End-of-Life

For life cycle phase C1, which covers the demolition/decommissioning, 180 EPDs were considered as they provided relevant data.

The minimum value of 0.63 kg CO_2-eq. is associated with the EPDs *61c0c795-7116-407d-8635-68fe422f76a9* and *a71e60a5-b64b-4715-ae8a-c8c8819149d2* both from Germany, while the maximum value of 27.50 kg CO_2-eq. corresponds to the EPD *EPD-Kiwa-EE-165874-EN* from Germany.

The first quartile (Q1) and the median value are the same with 8.64 kg CO_2-eq., and the third quartile (Q3) is 9.1125 kg CO_2-eq. The mean value is 9.48 kg CO_2-eq. (seen in Fig. 6).
The maximum recorded value of 27.50 kg CO_2-eq. is attributed to a scenario in which demolition is carried out using two hydraulic excavators. Operating for 0.240 and 0.284 hours, respectively. Conversely, the minimum recorded value results from a scenario where mechanical dismantling using an excavator is specified, but no further details on fuel consumption or duration are provided. This lack of specific input parameters likely results in an underestimation of the environmental impact compared to more detailed scenarios.

A significant proportion of the analysed EPDs (97 out of 180) originates from the same company in Germany, all reporting an identical C1 value of 8.64 kg CO_2-eq., which substantially impacts the boxplot distribution. The underlying scenario for these EPDs assumes a diesel consumption of 2.9 liters per cubic meter during demolition activities. Additionally, the amount of recovered demolition material is considered equivalent to the total weight of the concrete per cubic meter, adjusted based on its density. In accordance with current industry practices, the deconstruction of concrete and reinforced concrete structures is predominantly carried out u sing long-front excavators equipped with demolition shears, which represents a standardized demolition approach influencing fuel consumption and material recovery assumptions [15].

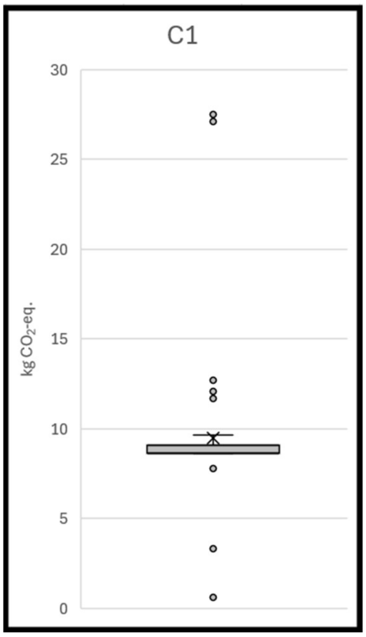

Fig. 6. Box plot of life cycle phase C1 for C25/30 EPDs based on the defined scope.

These findings highlight the strong dependency of phase C1 emissions on scenario definitions, including the type of equipment used, fuel consumption, and the assumed handling of demolition materials.

For life cycle phase C2, which covers transport, 180 EPDs were considered as they provided relevant data.

The minimum value of 4.82 kg CO_2-eq. is associated with the EPD NEPD-8426-8098-EN from Denmark, while the maximum value of 19.10 kg CO_2-eq. corresponds to the EPD *EPD-IES-0016171* from New Zealand.

The first quartile (Q1) is 9.33 kg CO_2-eq., and the third quartile (Q3) is 9.97 kg CO_2-eq. The median value is 9.56 and the mean value is 10.21 kg CO_2-eq. (seen in Fig. 7).

The boxplot for life cycle phase C2 reveals a relatively narrow interquartile range, indicating that a significant number of EPDs are clustered within a small value range. A substantial proportion of these EPDs originates as mentioned earlier from the same company in Germany, with 92 falling within this range. The scenario assumed for these EPDs includes a transport distance of 50 km to a crushing facility via truck, though no further details on fuel consumption or vehicle specifications are provided.

Similarly, the EPD from New Zealand with the highest value for C2, assumes a transport distance of 50 km to waste processing, but lack additional specifications. In contrast, Denmark represents the lowest end of the dataset, with a transport scenario involving a truck (over 32 tonnes, Euro 6 – Europe standard), operating with a capacity utilization of 53.30 % (including return trips). The fuel energy consumption is reported at 0.023 l/tkm, resulting in a total fuel consumption of 0.58 l/t for the transport process [16].

The outliers in the datasets are likely due to extended transport distances, lower vehicle efficiency, or differing assumptions regarding capacity utilization and fuel consumption.

For life cycle phase C3, which covers the waste processing, 180 EPDs were considered as they provided relevant data.

The minimum value of 0.00 kg CO_2-eq. is associated with the EPD *EPD-IES-0016171* from New Zealand, while the maximum value of 16.70 kg CO_2-eq. corresponds to the EPD *EPDITALY0391* from Italy.

The first quartile (Q1) is 3.49 kg CO_2-eq., and the third quartile (Q3) is 4.93 kg CO_2-eq. The median value is 3.69 and the mean value is 4.40 kg CO_2-eq. (seen in Fig. 8).

The maximum value of 16.70 kg CO_2-eq. is explained in the selective EPD as covering activities related to the collection and crushing of concrete debris as part of the recycling process. Conversely, the minimum value of 0.00 kg CO_2-eq. results that no activities are performed under phase C3, leading to a value of zero.

The variability in the dataset highlights significant differences in the assumed waste processing scenarios across different EPDs. While some EPDs include extensive processing activities, others assume minimal or no processing at all, directly impacting the reported environmental impacts.

For life cycle phase C4 (disposal), 178 EPDs were analysed, each providing relevant data. The minimum value of -6.86 kg CO_2-eq. is associated with the EPD *S-P-04711* from Greece, while the maximum value of 13.90 kg CO_2-eq. corresponds to the EPD *EPD-IES-0016171* from New Zealand.

The first quartile (Q1) and median value are both 0.00 kg CO_2-eq., while the third quartile (Q3) is 1.11 kg CO_2-eq. The mean value is 0.75 kg CO_2-eq., indicating a right-skewed distribution (seen in Fig. 9).

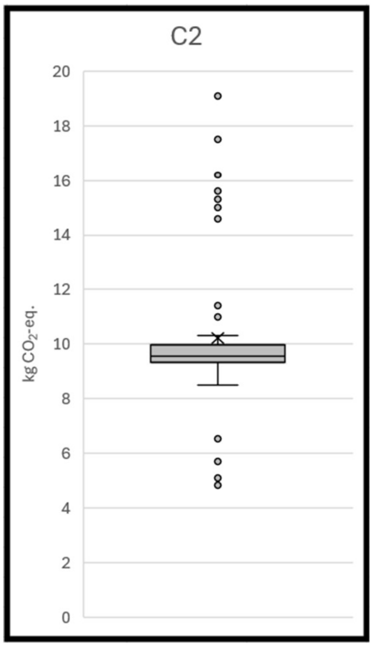

Fig. 7. Box plot of life cycle phase C2 for C25/30 EPDs based on the defined scope.

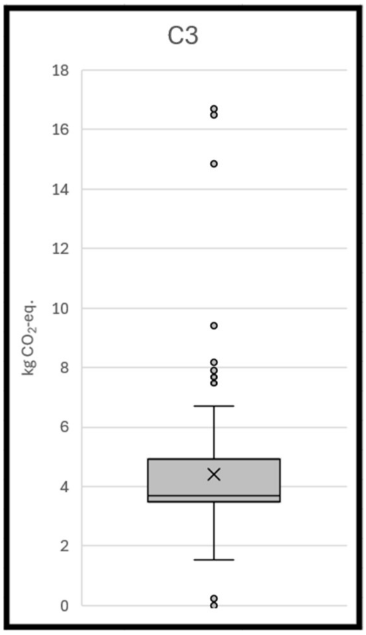

Fig. 8. Box plot of life cycle phase C3 for C25/30 EPDs based on the defined scope.

The maximum value of 13.90 kg CO_2-eq. is attributed to and end-of-life scenario where disposal is the only considered pathway for concrete waste. This results in a high impact for phase C4, while the corresponding EPD discussed earlier records the minimum value for phase C3, as no recycling processes are included. Conversely, the minimum value of -6.86 kg CO_2-eq. is associated with a scenario in which 50% of the product is landfilled.

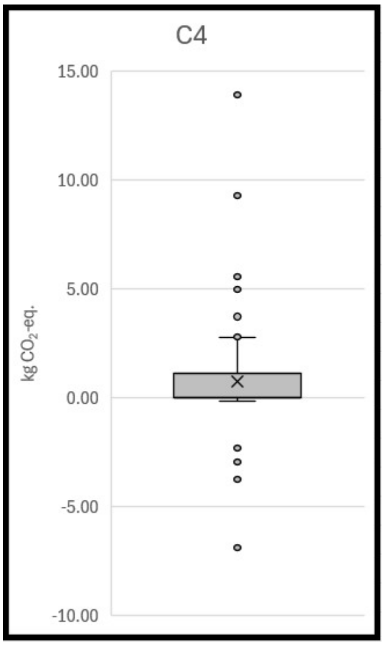

Fig. 9. Box plot of life cycle phase C4 for C25/30 EPDs based on the defined scope.

Notably, 98 out of the 178 EPDs report a C4 value of 0.00 kg CO_2-eq., leading to both the first quartile and the median being 0.00 kg CO_2-eq. This is due to the end-of-life scenario of 100 % recycling of the material for all of the EPDs.

The results highlight the high variability in disposal assumptions, with some datasets considering complete landfilling and others assuming partial or full recycling, which significantly influences the environmental impact values.

3.1.5 D benefits and loads beyond the system boundary

For life cycle phase D (benefits and loads beyond the system boundary), a total of 180 EPDs were analysed, each providing relevant data. The minimum value of -24.7 kg CO_2-eq. is associated with the EPD *EPD-Kiwa-EE-165874-EN* from Germany, while the maximum value of 9.60 kg CO_2-eq. corresponds to the EPD *EPD-IES-0014748:001* from Australia.

The first quartile (Q1) -9.81 kg CO_2-eq., while the third quartile (Q3) is -7.69 kg CO_2-eq. The median value is -9.55 kg CO_2-eq, while the mean value is -8.86 kg CO_2-eq., indicating a negative skew in the dataset (seen in Fig. 10).

The minimum value of -24.70 kg CO_2-eq. is linked to a scenario in which 93.80 % of the concrete waste undergoes recycling, while 6.20 % is landfilled. This results in significant environmental benefits, as recycling reduces the demand for virgin raw materials and their associated emissions. On the other hand, the maximum value of 9.60 kg CO_2-eq. lacks detailed scenario information, making it unclear what assumptions contribute to its significantly higher impact. The absence of detailed end-of-life treatment explanation suggests a scenario where minimal or no material recovery is accounted for, leading to higher emissions.

A total of 92 datasets falls within the interquartile range, with 91 of them originating from the same company in Germany as before. These datasets follow a consistent scenario in which output materials from the crushing process replace primary raw material such as sand, gravel, and crushed stone. The net output flows used for these calculations account for secondary materials derived from aggregates, while contributions from cement, additives, and admixtures are excluded. Credits for replacing primary raw materials are allocated in phase D.

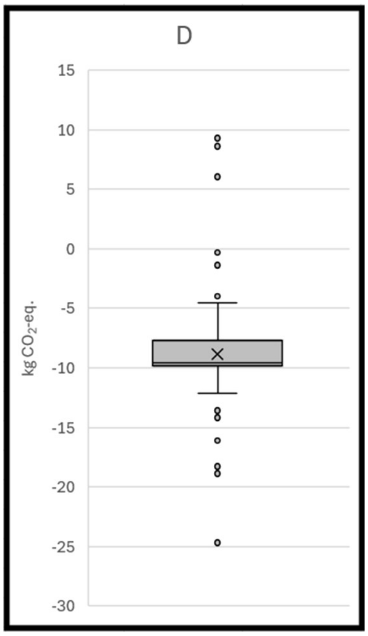

Fig. 10. Box plot of life cycle phase D for C25/30 EPDs based on the defined scope.

The results indicate a strong influence of recycling assumptions on the overall environmental benefits attributed to phase D. The variability in phase D results suggests that EPD methodologies and assumptions regarding material recovery and recycling rates have significant impact on the reported benefits.

3.2 EN 16757 adherence

Out of the 181 datasets, adherence to the EN 16757 standard is as follows, with some limitations: 65 datasets fully comply, while 16 datasets do not adhere to the standard. Two datasets are applicable only to the C3 and C4 phases, and one dataset follows the D Carbonation process. Additionally, 97 datasets are modelled using the B1 Carbonation guidelines and the carbonation of concrete construction waste at the end of life.

The variability in dataset adherence to the EN 16757 standard provides one explanation among others for the significant variation observed across the life cycle phases. The differing compliance levels, particularly in terms of carbonation modelling in the life cycle phases B1, C4 and D, introduce inconsistencies.

This highlights the complexity of comparing datasets that adhere to the standard to varying extents, emphasizing the need for careful consideration of these discrepancies when interpreting the results and assessing the overall environmental impact.

3.3 Influence of Cement Type

Out of the 181 analysed datasets, only 24 explicitly specify the type of cement used. Among these, 21 datasets provide distinct values for phase A1, making them suitable for assessing potential correlations between cement type and the GWP of this life cycle phase. However, due to the limited availability of data, meaningful conclusions remain challenging. Remarkably, only a single dataset includes CEM IV cement, rendering it statistically irrelevant for comparative analysis. The dataset comprises six records for CEM I, all originating from Denmark, and 14 records for CEM II, of which 11 also stem from Denmark. Despite this dataset being relatively small, Danish EPDs demonstrate higher level of transparency by specifying the cement type, which enhances their reliability for further analysis. The graphical representation in Fig. 11 does not indicate a clear correlation between cement type and GWP for phase A1. Additionally, the use of various types of CEM II has introduced further complexity into the analysis of CEM II, complicating the interpretation of the results. Furthermore, the six datasets for CEM I are specifically based on CEM I 52.5 N. Nevertheless, an increase in the number of EPDs that disclose cement composition is necessary to improve the robustness and significance of future analyses.

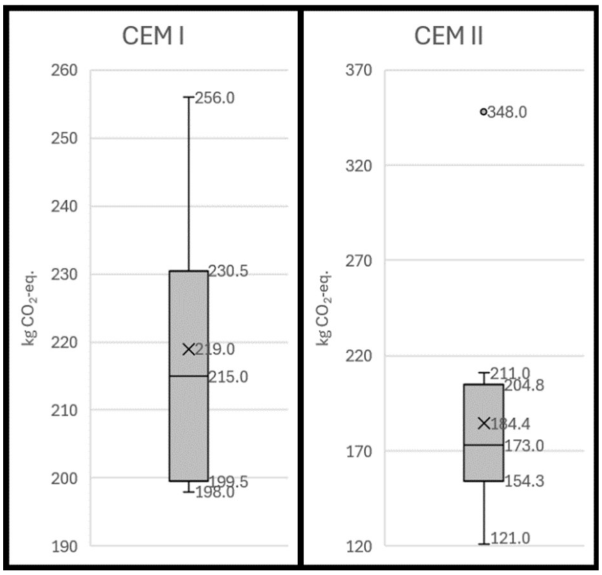

Fig. 11. Distribution of Global Warming Potential for life cycle phase A1 of C25/C30 EPDs containing CEM I and CEM II cement.

3.4 Actuality of the datasets

Out of 181 EPDs analysed, 179 explicitly state their issue date, while two datasets from the oekobaudat database reference the year 2023 but do not specify an exact issue date. The majority of the EPDs are relatively recent, with most issued in 2023 (Fig. 12), ensuring that the underlying process data reflects current industry practices.

The dataset from 2020 originates from Iceland, while the 2021 EPDs are from Greece and Spain. Additionally, the 2022 dataset corresponds to Denmark. The predominance of recent EPD highlights the increasing availability of up-to-date environmental data, which enhances the reliability of LCAs by reflecting current production technologies and material compositions.

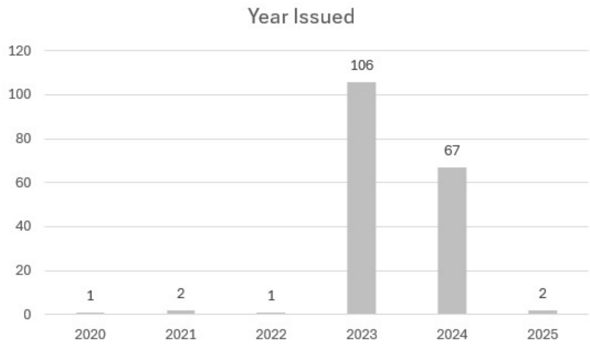

Fig. 12. Years Issued of the analysed EPDs.

4 Discussion

The analysis of EPDs for C25/30 concrete across different life cycle phases reveals significant variability in reported environmental impact values. This variability arises primarily from differences in scenario assumptions, methodological choices, and allocation procedures, particularly in the end-of-life phase and beyond (phase D).

EN 16757 was introduced to provide a standardized framework for EPDs of concrete and concrete elements, aligning them with EN 15804. However, the majority of EPDs analysed in this study do not explicitly refer to this standard over their complete life cycle modelling, contributing to the observed discrepancies.

The end-of-life phase of concrete presents particular complexity due to regional variations in demolition, recycling, and disposal practices. Different modelling approaches for concrete waste treatment, whether it is crushed for reuse as aggregate, incorporation in road construction, or landfill disposal, result in substantial discrepancies in reported environmental impacts. An enhanced EN 16757 harmonised framework for end-of-life modelling, including standardized impact factors for common recycling and disposal pathways, would enhance consistency. Furthermore, establishing clear guidelines on material recovery rates and defining uniform methodologies for calculating avoided burdens in phase D would reduce inconsistencies and improve comparability across EPDs.

A key challenge in EPD comparability is the lack of transparency in the underlying assumptions and datasets. Many EPDs provide only limited documentation regarding methodological choices, making it difficult to interpret and compare results accurately. Establishing standardized reporting guidelines that mandate comprehensive disclosure of system boundaries, data sources, allocation rules, and modelling assumptions would mitigate these challenges. Additionally, an alternative approach could involve providing results for different scenarios within the same life cycle phase of an EPD, allowing users to adapt the data to their specific applications. This flexibility would enhance the relevance and applicability of the EPDs for wider range of contexts, ensuring that the environmental impact assessments can be tailored to reflect regional differences, material variations, and project-specific requirements. While EN 16757 offers a harmonized approach for concrete EPDs, its limited application in existing declarations suggests a gap between theoretical standardization and practical implementation.

5 Conclusion

Standardization, transparency, and harmonization of end-of-life modelling and beyond and allocation methodologies are crucial for improving the reliability of EPDs. By addressing these challenges, stakeholders can make more informed decisions, reduce uncertainty in sustainability assessments, and enhance the overall credibility of life cycle impact assessments for construction materials. Future efforts should focus on applying the existing standards more consistently, ensuring their implementation across all relevant stages while accommodating regional and technological differences.

The standardisation, transparency, and harmonization of life cycle modelling, particularly in the end-of-life phase and beyond, are essential for improving the reliability and comparability of EPDs for concrete. The analysis highlights that while EN 16757 provides a standardized framework for concrete EPDs, its limited adoption contributes to inconsistencies in reported environmental impact values. Addressing these challenges through greater alignment with established standards, improved methodological transparency, and harmonized allocation approaches would significantly enhance the robustness of EPDs as decision-making tools in sustainable construction.

A key priority for future efforts should be the development and enforcement of comprehensive guidelines that mandate clear documentation of scenario assumptions, system boundaries, and allocation methods.

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