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Analysis of Sectoral Environmental Product Declarations as a Data Source for Life Cycle Assessment

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Abstract: The life cycle assessment (LCA) methodology is becoming increasingly prevalent in the quantification of the environmental status in the building sector following new legislative frameworks. Countries need to quantify and assess their environmental impacts as a previous step to regulation and decision-making. In this context, based on a consensus with manufacturers, standardized national data sets are being developed, referred to as sectoral environmental product declarations (EPDs). This study assesses these EPDs with the aim of providing relevant information for global decision-making, focusing on their consistency and shortcomings. An assessment was carried out at both the national level, considering all sectoral EPDs and declared products, and at the international level, with three common building materials (brick, steel, and concrete). The results highlight the lack of traceability in the development and assessment of uncertainty, resulting in substantial discrepancies in reported impacts, especially in the later stages of the life cycle (up to 90% difference). Meanwhile, impacts such as global warming potential or total renewable and non-renewable primary energy use show homogeneous values in the cradle-to-gate stages, with differences generally being under 10%. The analysis of sectoral EPDs should act as a guideline for designing buildings with environmental sustainability criteria, as the last section of this study attempts to highlight.

Keywords: environmental product declaration; life cycle assessment; generic databases; environmental impacts; uncertainty; product category rules (PCRs)

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1. Introduction

The construction sector is responsible for almost 40% of the energy-related carbon emissions into the atmosphere and 50% of all the materials extracted from nature. The global building stock is forecast to double by 2060, when almost 70% of the world's population will live in urban areas [1]. Therefore, the environmental impact of the construction sector will increase drastically unless more sustainable materials, products, and technologies are developed.

The life cycle assessment (LCA) methodology is a tool for quantifying the environmental impacts of a material, product, or process and, therefore, its sustainability. The standard EN ISO 14040:2006/A1 "Environmental management. Life cycle assessment. Principles and framework" [2] defines LCA as "the collection and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle", as shown in Figure 1. LCA calculation is a complex task that requires technical knowledge and experience in both the application of its methodology and the interpretation of data and results. It can be applied to the environmental assessment of building materials and products, as well as to the constructed building, although it is seldom used to optimize the design or help to make decisions in the early stages of the project. Its use has the potential to improve environmental, social, and economic sustainability [3].

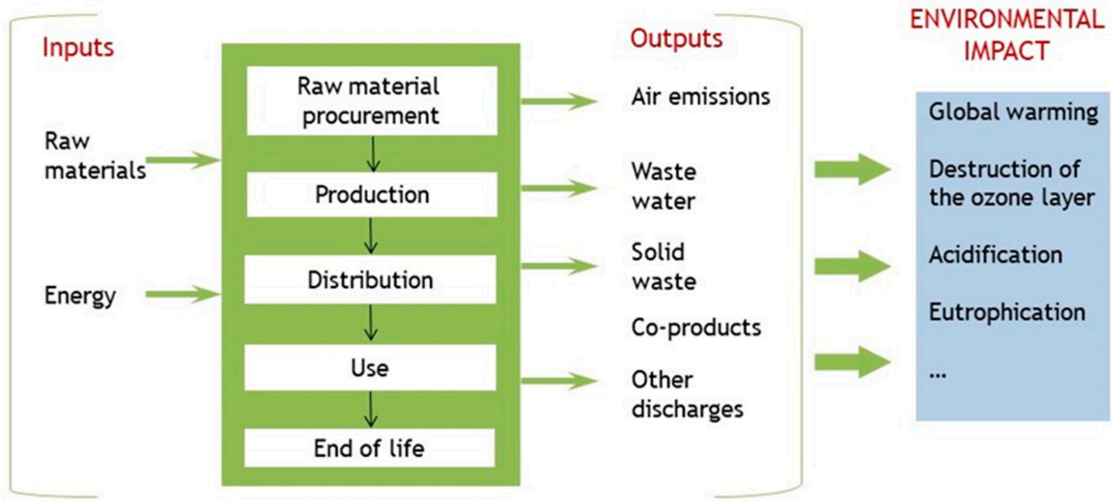


Figure 1. Structure of the life cycle analysis (source: authors' own elaboration).

In Europe, the standard EN 15978:2011 "Sustainability of Construction Works. Assessment of Environmental Performance of Buildings. Calculation Method" [4] defines the basic guidelines for calculating the environmental performance of buildings. The calculation depends on many factors that are open to interpretation, which can lead to deviations and divergences in the final results. Numerous studies have reported such divergences, reaching between 50 and 70% in the case of certain environmental impacts for a specific product [5]. A review by Anand et al. [6] of articles published in the last five years regarding the LCA of buildings confirms that a multitude of parameters affect the current disparity in the results. These include the sensitivity of the initial data, system boundaries, and the useful life considered.

According to Häfliger et al. [7], the design of a sustainable construction project requires numerous aspects related to its constituent elements to be considered, such as the structure, envelope, finishes, and other elements. Generally speaking, using more specific data provides significant improvements in the reduction of environmental impacts such as global warming potential (GWP). This results from more specific products being defined for use in the project, in contrast with the use of generic data or data from commercial databases. Because the environmental analysis is not based on assessing a finished building, the project designer should select materials based on sustainability criteria. This design phase should be agile and user-friendly, use well-known software, produce interpretable results, and even have predetermined data and impact values for products, solutions, and spaces [3].

Obtaining the data for the application of the LCA poses a significant challenge, this being one of the most delicate phases. The CEN/TR 15941:2011 IN standard "Sustainability in construction. Environmental product declarations. Methodology for the selection and use of generic data" [8] establishes the sources of data and their quality criteria, as well as the hierarchy of their use according to their quality. This standard establishes the preferential use (as it is considered of higher quality) of data from either specific or sectoral environmental product declarations (EPD). It also establishes the use of data from life cycle inventory (LCI) databases in second place and, lastly, bibliographic information with referenced traceability. Depending on the type of data they store, databases (DBs) are classified into the following types: DBs based on EPDs (ÖKOBAUDAT or INIES), life cycle inventory databases (LCI DBs, e.g., GaBi or Ecoinvent), and others with a strong national character and which try to transmit the industry's technologies and geographical conditioning factors (climate database from Boverket in Sweden or Klimagassregnskap in Norway). There are others that produce hybrid embodied carbon coefficients (very disaggregated data), such as EPiC in Australia [9].

In the case of EPDs for construction products, these are defined on the basis of the requirements of EN 15804:2012+A2:2020 "Sustainability in construction. Environmental product declarations. Basic product category rules for construction products" [10], which allows the non-consideration of all life cycle (LC) stages. Studies such as the one by Kellenberger et al. [11] estimate that a simplification whereby the energy required for transport, construction, and end of useful life are not included leads to a decrease of between 27 and 42% in the results compared to when all the stages are taken into consideration.

The appropriate choice of input data stands out as one of the critical initial points in the LCA of a building [12]. Collecting and understanding these data represents a highly sensitive step. Comparing the data included in inventory databases such as Ecoinvent and EPD databases such as INIES has revealed remarkable disparities in their starting values [13]. Using data from multiple databases in the LCA calculation of the same product, material, or process is considered inappropriate. This is due to the fact that these databases may incorporate highly specific processes used by manufacturers, which complicates their adaptation to the geographical and technological context and, consequently, their integration into LCA calculations [14]. The same author states that the additional impact categories in the new standard [10] require a substantial volume of input data that is hard to control and has the potential to skew the results away from reality.

In Europe, government initiatives have tackled these issues from various perspectives. The initiatives of the global entities Eco Platform [15] and InData [16] should be highlighted. ECO Platform is the European Association of EPD Verification Programme Managers and other stakeholders involved in sustainable development. Meanwhile, InData is an informal working group whose main objective is to generate a European LCA data structure for construction products (called ILCD + EPD format) that can be used in the early stages of the project, in line with current standards.

Among the InData member countries, the policies and actions in the field of environmental assessment of the construction sector in France, Germany, Denmark, Norway, Sweden, the Netherlands, Italy, and Spain are of note. The main characteristics are detailed in Table 1. Moreover, the Nordic action plan for the sustainability and competitiveness of the construction sector (Finland, Sweden, Norway, Iceland, and Denmark) should be highlighted.

Table 1. Locations of environmental impacts for construction materials analyzed.

Country	Environmental DB	LCI DB	LCA Software	Administrator/Operator
Spain	OpenDAP	-	-	Global EPD and DAPcons
France	INIES	INIES	-	INIES
Germany	ÖKOBAUDAT and IBU	ÖKOBAUDAT	-	IBU
Denmark	Nationale Milieudatabase (NMD)	Nationale Milieudatabase (NMD) and ÖKOBAUDAT	LCAbyg 2023	EPD Denmark
Norway	Klimagassregnskap	-	Excel based tool (2022a)	EPD Norge
Sweden	Boverkets	-	-	The International EPD
Netherlands	-	-	-	Stichting MRPI
Italy	-	-	-	EPD Italy

In addition to LCA, other tools for quantifying the sustainability of buildings are the so-called sustainable building certification systems. These systems generate voluntary accreditations based on the criteria of the certification system. These are used to evaluate and confirm the sustainability of buildings by referring to environmental parameters and establishing a hierarchy and score to show the building's level of sustainability. Among the best-known internationally are LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method), while the most widely used in Spain is VERDE. There are significant differences between the requirements of the different systems, which results in a high level of subjectivity in the validation of results and significant differences depending on the system used. For example, BREEAM requires at least five regional or local materials and/or products from a verified EPD data source [17], while VERDE demands the use of EPDs for 70–100% of the total mass of concrete, ceramics, gravel or sand. For other materials, the use of EPDs is required for 20–40% of the total mass. These requirements cover materials in the structure, insulation, and finishes. Furthermore, 50% of the EPDs should include a cradle-to-grave assessment in accordance with the EN 15804 standard. In the LEED v4 system, using EPDs in products from different manufacturers permanently installed in the building can score a total of 20 points [18]. According to these and many other requirements, a final rating is obtained that grades the building within the system. A subjective, visual rating is obtained that adds value to the building in the eyes of consumers and allows comparisons to be made.

The aim of this study is to carry out a detailed analysis of the EPDs available for use as input data for the calculation of building LCAs. In the hierarchy established in the standard [8], it is the input data that is of the highest quality for calculating the LCA of buildings. The data are established within a program manager that manages and generates a compliance framework. Accordingly, they are checked by established third parties according to the current regulations and declared by the manufacturers or their associations who contribute their own data. Sectoral EPDs are chosen from among the different kinds of EPD. These are produced by several manufacturers or manufacturer associations and contain a consensus of the members. These associates often represent a large share of the market production, making the data they provide wide-ranging. In turn, the heterogeneous data from a range of sources make them perfect for analysis and verification.

2. Materials and Methods

This study focuses on a detailed two-level analysis of sectoral EPDs. On the level of Spain, all the sectoral EPDs for construction products of Spanish associations published to date were analyzed to determine the degree of homogeneity and representativeness of the information they contain. On an international scale, the analysis was limited to the study of sectoral EPDs for three specific construction products. These were ceramic bricks for cladding, corrugated steel bars, and mass concrete from a number of European countries where advanced environmental approaches have been developed within their respective policy commitments (Figure 2). In particular, the cases of France, Germany, Denmark, Norway, Sweden, the Netherlands, Italy, and Spain have been studied.

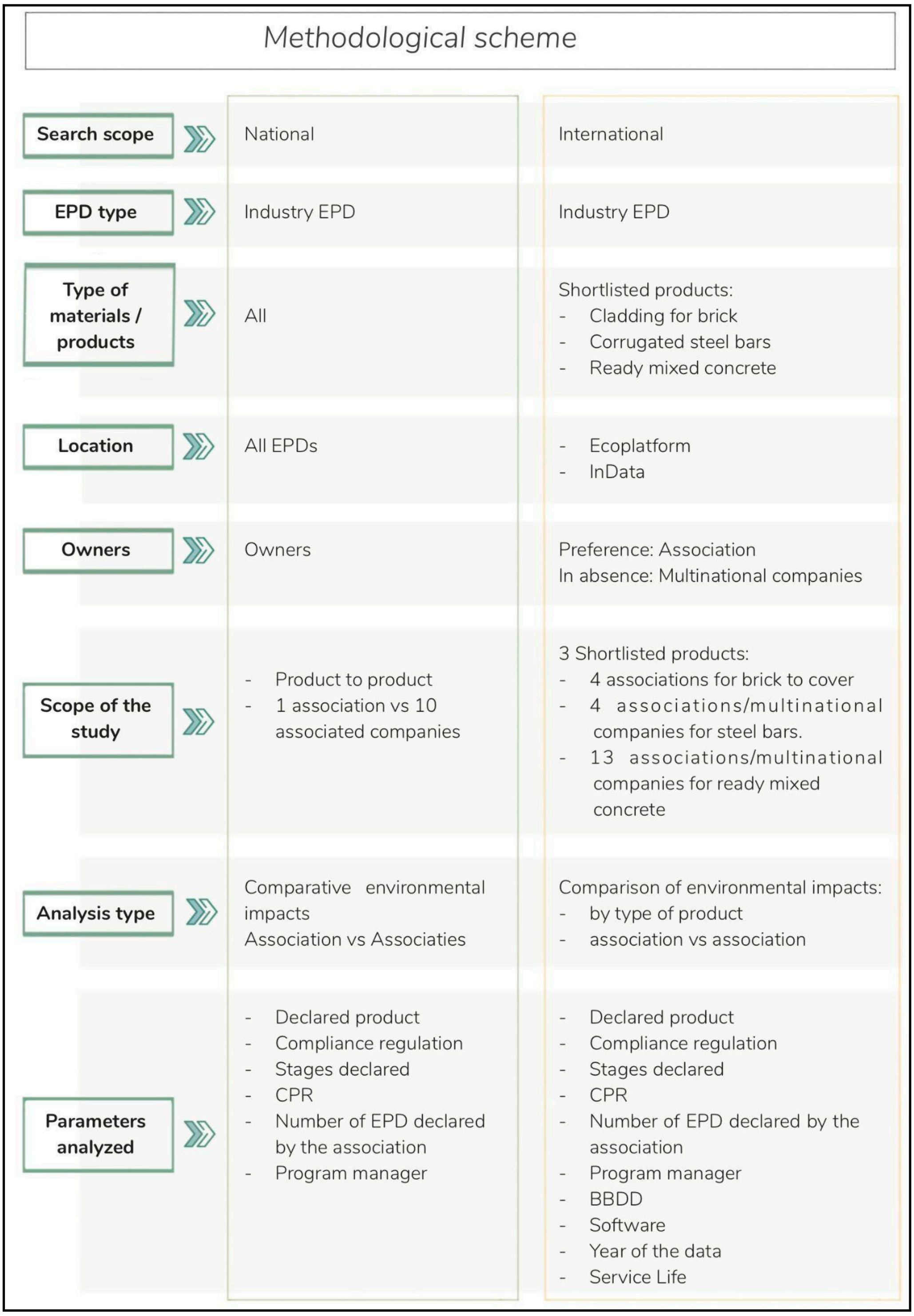


Figure 2. Analytical scheme of the methodology (source: authors' own elaboration).

To this end, first, it is necessary to categorise EPDs according to their owner and the information they include and according to the conceptualization included in the standards [4,8,10]. As shown in Table 2, EPDs from a manufacturer (manufacturer-specific EPDs) can be based on data provided from a single product (product-specific), the average of several products (average product) or data from a representative product (representative product). EPDs owned by more than one manufacturer (collective EPDs) are also classified into the same three categories above and into the so-called "worst case" category. According to this classification, sectoral EPDs represent a large share of the market production, which gives them a wider-ranging and more and consensual nature among the subscribing partners. At the same time, their heterogeneous component of the multiplicity of data sources makes them a perfect element the analysis and verification conducted in this study.

Table 2. Classification of EPD types (Source: own elaboration).

CEN/TR 15941:2011 Types of EPD (Art. 5.4)	Manufacturer-Specific EPDs (1 Manufacturer)	Collective EPDs (from >1 Manufacturer, Associations, Sectors)
Specific product	1 product, 1 plant 1 product, >1 plant	1 product, >1 plant, >1 manufacturer
Average product	Average product, 1 plant Average product, >1 plant	Average product, >1 plant, >1 manufacturer
Representative product	Representative product, 1 plant Representative product, >1 plant	Representative product, >1 product group
Worst-case product		1 product, survey > 1 manufacturer, >1 product group

2.1. Sectoral EPD Analysis in the Context of Construction Products in Spain

The analysis at the level of Spain focuses, as stated above, on the sectoral EPDs for construction products published to date with a Spanish geographical location, analyzing the type of product or groups of products declared and the number of EPDs declared for each one. This comparative analysis was conducted paying special attention to the following aspects related to the definition of the product:

- Established objective and scope, and the association and declaration of the different products that each association represents; current regulation applicable to the development of the EPD, including the recently updated EN 15804:2020+A2 standard, the old and new standard having co-existed until the end of October 2022;
- Declared life cycle stages, which, although already established in the current mandatory standard, were affected by the recent update;
- Compliance PCRs: these being the specific regulations established for each category or product family that aim to provide detailed guidelines for the specific preparation of their EPDs.

Some studies have already shown these parameters to be critical points susceptible to variety, such as the one by Portuguese researchers using the NativeLCA method [19]. They tried to generate national data for cases in which the EPD of a product was lacking, the so-called reference value, or REVA.

To this end, all the 30 sectoral EPDs existing in Spain to date were reviewed. The traceability of the four elements of interest described above has been studied (declared product, standard, declared stage, and PCRs), and the decisions taken by each manufacturers' association to check whether there are regulatory aspects susceptible to subjective interpretation were also taken into account. This may therefore lead to different calculation procedures being applied and different results being obtained, even if the regulations are complied with in all cases. The review of the Spanish sectoral EPDs has identified cases of products with values that differ greatly from those provided by the individual manufacturers.

The sectoral EPDs under study are published in the Global EPD Programme Managers [20] and The International EPD System [21]. Among the holders of these EPDs, there are associations that declare, in the same document, several types of products that are generally distinguished by their technical characteristics. Other associations produce declarations for each of the different products they represent. Although the Institut Bauen und Umwelt e. V. (IBU) [22] and DAPcons [23] have also developed several EPDs for national products, these are not sectoral and have therefore not been considered in this study. The Spanish sectoral EPDs analyzed are listed in Table A1, while Table A2 shows a summary of the information analyzed.

The case of the product called "Ceramic tiles, porcelain stoneware (Bla classification according to UNE-EN 14411:2016 [24])" should be highlighted, as its sectoral EPD offers a value that has been called a "matrix value". However, ten of the manufacturers participating in this sectoral EPD were also found to provide their own specific EPD. Six manufacturers declared identical EPD values (which we will refer to as the "standard value"), except for the impact of the abiotic depletion values for elements (ADPE). The four remaining EPD values differ greatly from each other and are shown in shaded text in Table A2. This table presents the different parameters that the ten EPDs define and how they are calculated, including data sources, definition of system boundaries, software, and databases.

2.2. Sectoral EPD Analysis in the International Context of Ceramic Bricks for Cladding, Corrugated Steel Bars, and Mass Concrete Production

The identification of sectoral EPDs containing data significantly different to those found in the EPDs of the individual manufacturers was the starting point to try to find out about similar cases occurring in other countries and how they are resolved. Obviously, it is not possible to analyze all construction products across eight countries in a single study due to the diversity of products and industries and the difficulty of data handling and processing. Therefore, the scope of the study was limited to the three most-used building materials according to [25,26]: ceramic bricks for cladding, corrugated steel bars, and mass concrete (defined as shown in Table 3) in eight European countries (France, Germany, Denmark, Norway, Sweden, the Netherlands, Italy, and Spain), resulting in a total of 20 sectoral EPDs being analyzed. The selection of these products covers a large share of the materials used in traditional construction [27] and embraces the increase in global warming potential and energy demands incorporated in these materials and their associated construction typology, prioritizing the current building reality over new technologies. In the case of concrete, specific EPDs from large multinational production companies were also included in the study, due to the large number of such declarations identified and the market share they represent.

Table 3. Definition of the three shortlisted materials.

Product	Functional Unit	Features of Interest
Ceramic brick for cladding	1000 kg of ceramic brick for cladding	
Corrugated steel bars	1000 kg of corrugated steel bars	
Mass concrete	1 m^3 of mass concrete	Mechanical strength: 30–37 MPa Density: 2380 kg/m^3 Without added additives [1]

[1] Use of any additives or other additives may cause the results to vary, as demonstrated in the studies by Anderson and Moncaster for 306 EPD [28].

Tables A3–A5 in Appendix A show the international sectoral EPDs studied for each of the three selected products and detail the parameters that condition their comparability and influence on the final results.

Table A3 shows the sectoral EPDs identified for bricks from Spain, Germany, and Great Britain. Although the German EPD has two published versions, one in line with the 15804+A1 [29] standard and another more current version conforming to 15804+A2, only the first one has been analyzed, as it coincides with the standard used by the Spanish and British EPDs. The differences in the useful life of each sectoral EPD must be taken into account in the analysis, since, although the reasons are not specified, the British EPD establishes a useful life of 60 years, while in the other two, the useful life is set at 150 years.

The selection process for corrugated steel bars used in reinforced concrete was more complex. In Spain, the Steelwork Sustainability Association, which represents 100% of the national market, has declared its sectoral EPD. However, these were not located in any other European country. Therefore, the EPDs of large companies with an international presence and large market shares were analyzed, as shown in Table A4. One of these is ArcelorMittal

Europe; another is Outokumpu Oyj, based in Helsinki, whose data represent the UK, US, and Swedish plants; and finally, CCL Scandinavia A/S in Denmark, the Scandinavian sector leaders.

In the case of mass concrete (Table A5), 13 EPDs were selected, extending the study to sectoral and company-specific EPDs due to the large number of localized declarations. Five EPDs were sector-specific and conformed to 15804+A2, while eight others were manufacturer-specific and conformed to 15804+A1. Due to the recent update of the standard, it was considered essential to take this aspect into account.

For the comparative analysis, the declared unit, compliance standard, and matching stages were maintained in all cases. However, the PCRs, inventory databases, calculation software used, year of data collection, and useful life are different, which does not allow for a fully equitable comparison.

The international sectoral EPDs were located using the search engine of EcoPlatform, which is the umbrella organization for the various national EPD managers and other sectoral actors involved in sustainable development of inData member countries.

The analysis criteria used were the same as for the Spanish sectoral EPDs (declared product, standards, PCRs, and declared stages), to which information was added about the databases used, calculation software, year of the data provided, and useful life considered. The analysis of these three groups of materials and their corresponding EPDs was carried out using tables showing the countries selected in the coinciding stages, as well as the average value per stage and environmental indicator. This was done by calculating the percentage of deviation of each environmental indicator with regard to the mean value (m) for every country using Equation (1).

$$\text{Indicator Xi} = [(\text{EPDi} / \text{EPDm})] - 1] \times 100 \tag{1}$$

where EPDm is the average of indicator X for all countries and for the stage under consideration, and EPDi is the value of the impact on the stage(s) declared for country i.

The results obtained were classified into five categories defined by the values shown in Table 4. The representation of the results is reinforced by different coloured shading for each cell, depending on the category to which the impact value it represents belongs. The intervals of the categories reflect a grouping of the results obtained in the comparison of the three materials, but they are not heterogeneous. Greater sensitivity was applied, and more subgroups were created for the area below 50% and less for the higher percentages.

Table 4. Description of the analysis intervals in the environmental impact comparison.

Category	Deviation from the Mean (%)	Color
I	[0, ±10)	Black text on pale yellow background
II	[±10, ±20)	Black text on salmon background
III	[±20, ±50)	Black text on coral background
IV	[±50, ±90)	Black text on red background
V	>±90	White text on maroon background
VI	Not available	Empty cell

Finally, in order to assess the environmental impact of each material and its influence on the percentage of material used on-site, the three materials studied were compared for the following indicators: global warming potential (GWP), total renewable primary energy use (PERT) and total non-renewable primary energy use (PENRT), considering the A1–3 stages of the EPDs carried out according to the 15804+A1 standard.

3. Results

3.1. Results of Sectoral EPD Analysis in the Context of Construction Products in Spain

Within the context stated above regarding the sectoral EPD in Spain for “ceramic tiles, porcelain stoneware”, the declared values were named the “matrix value”. The value provided in the EPDs by the group of six manufacturers that was identical was called the "standard value". The final group comprised the four manufacturers whose EPDs differed greatly, and all were members of the association declaring the sectoral EPD. Table 5 shows the results of comparing the values for one company (Equipe Cerámica) from the group of four manufacturers with the "standard value". This company was chosen because several parameters were the same as in the group declaring the "standard value". Table 6 compares the impact results for the group of four EDPs with the greatest discrepancies, the "standard value", and the mean of the ten specific EPDs in terms of the ratio to the matrix value. Both tables take into consideration coincide with life cycle stages A1–3. The values much higher or lower than one are shaded in grey.

Table 5. Ratios between a manufacturer-specific EPD and the type-specific EPD. Stages A1, A2, A3, A1–3.

LCA Stages	A1	A2	A3	A1–3	D
EIC [1]	**EC Value [2]/SV [3]**	**EC Value/SV**	**EC Value/SV**	**EC Value/SV**	**EC Value/SV**
GWP—total	1.57	0.37	1.23	1.26	2.03
ODP	1.79	2.68	1.18	1.79	14.33
AP	1.65	0.92	0.78	1.15	1.79
EP	1.29	0.85	1.30	1.23	4.00
POCP	1.43	0.83	1.05	1.17	1.83
ADPE	3.88	0.21	2.17	3.67	2.12
ADPF	1.46	0.36	1.24	1.25	1.64

[1] Environmental impact categories. [2] Equipe Cerámica. [3] Standard value.

Table 6. Ratios between the ten specific EPDs and the sectoral EPD. Stages A1–3.

	LCA Stages A1–3					
EIC [1]	**Equipe Cerámica / MV [2]**	**Mainzu / MV**	**Peronda Group / MV**	**Grespania / MV**	**SV [3] / MV**	**Average 10 EPD / MV**
GWP-total	1.14	0.62	1.08	1.31	0.90	0.77
ODP	1.69	0.83	1.05	1.20	0.95	0.86
AP	1.43	5.71	1.35	1.29	1.24	1.47
EP	1.26	1.96	1.25	0.96	1.03	0.95
POCP	1.36	3.13	1.33	1.27	1.16	1.17
ADPE	0.28	1.12	0.31	0.16	0.08	0.22
ADPF	1.29	0.74	1.23	1.51	1.03	0.89

[1] Environmental impact categories. [2] Matrix value. [3] Standard value.

3.2. Results of Sectoral EPD Analysis in the International Context of Ceramic Bricks for Cladding, Corrugated Steel Bars, and Mass Concrete Production

The results obtained for each of the three products analyzed are shown in Tables 7–13. For brick, two tables are presented (Tables 7 and 8). In the first one, the coinciding stages are A1–A5, while the second one presents stages C2–C4 and module D. The steel bars are also presented in two tables (Tables 9 and 10), the coinciding stages being A1-2, C3, and D. The first shows the impact assessments and resource use, while the second presents wastes and outflows. Finally, in the case of mass concrete, three tables are presented (Tables 11–13). The first is in accordance with standard EN 15804:A1, and the other two are in accordance with standard EN 15804:A2. The stages analyzed are modules A1–3, as they are the stages that coincide in all the EPDs studied and are those that confer greater reliability and certainty to the analysis, as they come from the data of the EPD holders themselves. This eliminates the influence of data from inventory databases. Furthermore, it was necessary to limit this analysis to the number of EPDs analyzed, which in the end amounted to 20.

These tables (Tables 7–13) show the average value for the set of countries studied (shaded grey column) and, as a percentage, the difference of each country with respect to the average. A chromatic gradient has been added, detailed in the legend of the tables, with five chromatic intervals that provide an initial visual understanding. In this way, the highest percentages are represented by the colour maroon and reflect the most substantial differences between the average of all countries and the country in question. On the other hand, countries reporting a value more similar to the average have the lowest percentages and are represented in pale yellow.

Table 14 presents a comparison of the values of the impact indicators GWP, PERT, and PENRT for the three materials studied. Focusing on these indicators, the relationship between them is shown in the bar graphs below for stages A1–3. Figure 3 shows the 13 GWP indicators for each EPD for mass concrete, with a mean value of 270.90 kg CO_2-eq. The primary energy use indicators, PERT and PENRT, are shown in Figure 4a,b, with respective means of 163.42 MJ and 1371.085 MJ.

Table 7. Chromatic gradient of 3 sectoral EPDs of ceramic bricks for cladding according to EN 15804+A1 according to the declared stages. Part 1 of 2: stages A1–3, A4, and A5.

EN 15804+A1			Stages A1–3 % of the Country Compared to Average				Stage A4 % of the Country Compared to Average				Stage A5 % of the Country Compared to Average			
	Unit	Indicator	AVG. [1] A1–3	Spain (%)	UK (%)	Germany (%)	AVG. [1] A4	Spain (%)	UK (%)	Germany (%)	AVG. [1] A5	Spain (%)	UK (%)	Germany (%)
Impact assessment	(kg CO2-eq.)	GWP	2.15×10^{2}	9.7	−1.0	−8.7	6.53×10^{0}	−28.2	22.8	5.4	5.10×10^{0}	−88.9	124.8	−35.9
	(kg CFC 11-eq.)	ODP	6.17×10^{-6}	−99.7	199.7	−100.0	4.93×10^{-7}	−100.0	200.0	−100.0	3.60×10^{-7}	−99.9	199.9	−100.0
	(kg SO2-eq.)	AP	1.51×10^{0}	−41.3	130.5	−89.2	1.45×10^{-2}	−19.8	86.7	−66.9	5.97×10^{-2}	−97.2	196.7	−99.5
	(kg Phosphat-eq.)	EP	6.83×10^{2}	−4.7	56.6	−51.9	3.65×10^{-3}	−21.9	94.0	−72.1	2.14×10^{-3}	−87.0	183.9	−96.9
	(kg NMVOC eq.)	POCP	9.20×10^{-2}	−15.1	92.4	−77.3	3.15×10^{-4}	−1230.9	1386.7	−155.8	3.17×10^{-3}	−94.8	194.1	−99.3
	(kg Sb-eq.)	ADPE	5.05×10^{-5}	−79.6	145.5	−65.9	7.37×10^{-6}	−95.0	186.4	−91.4	2.81×10^{-6}	−100.6	199.8	−99.2
	(MJ)	ADPF	2.26×10^{3}	6.4	5.0	−11.4	9.25×10^{1}	−30.9	31.0	0.0	4.50×10^{1}	−91.6	190.6	−98.9
Resource use	(MJ)	PERE	2.99×10^{2}	34.8	−59.9	25.1	3.80×10^{0}	15.9	−57.7	41.7	2.21×10^{0}	−81.1	178.5	−97.5
	(MJ)	PERM	1.85×10^{-4}				5.99×10^{-6}				9.90×10^{-6}		0%	
	(MJ)	PERT	2.99×10^{2}	34.8	−59.9	25.1	3.80×10^{0}	15.9	−57.7	41.7	2.21×10^{0}	−81.1	178.5	−97.5
	(MJ)	PENRE	2.33×10^{3}	8.0	4.1	−12.1	9.23×10^{1}	−30.4	30.0	0.4	4.60×10^{1}	−91.5	191.3	−99.8
	(MJ)	PENRM												
	(MJ)	PENRT	2.33×10^{3}	8.0	4.1	−12.1	9.23×10^{1}	−30.4	30.0	0.4	4.60×10^{1}	−91.5	191.3	−99.8
	(Kg)	SM	2.47×10^{2}			0%								
	(MJ)	RSF	3.92×10^{-3}	0%										
	(MJ)	NRSF	4.12×10^{-2}	0%										
	(m^3 world eq.)	FW	3.89×10^{0}	170.2	−77.8	−92.3	1.20×10^{-1}	174.1	−78.3	−95.8	8.70×10^{-2}	139.0	−47.1	−91.9
Wast × 10	(Kg)	HWD	4.63×10^{-1}	−99.9	199.9	−100.0	2.55×10^{-2}	−100.0	100.0	−100.0	3.75×10^{-2}	−100.0	100.0	−100.0
	(Kg)	NHWD	1.82×10^{0}	−97.3	197.3	−100.0	2.83×10^{0}	−100.0	100.0	−100.0	4.37×10^{-1}	3681.3	97.0	−97.0
	(Kg)	RWD	3.42×10^{-2}	35.7	−79.6	43.9	3.48×10^{-4}	−68.1	140.1	−72.0	1.50×10^{-4}	−100.0	190.6	−90.6
Outflows	(Kg)	CRU	3.36×10^{1}		0%						5.17×10^{1}		0%	
	(Kg)	MFR	1.74×10^{-1}	0%							1.41×10^{1}	0%		
	(Kg)	MER	9.40×10^{-3}	0%							1.10×10^{-1}	0%		
	(MJ)	EEE	4.47×10^{-2}	0%							3.33×10^{0}	−78.7		78.7
	(MJ)	EET									1.37×10^{1}			

[1] Average of all countries reporting values at that stage.

Table 8. Chromatic gradient of 3 sectoral EPDs of ceramic bricks for cladding according to EN 15804+A1 according to the declared stages. Part 2 of 2: stages C2, C3, C4, and D.

				Stage C2 % of the Country Compared to the Average				Stage C3 % of the Country Compared to the Average				Stage C4 % of the Country Compared to the Average				Stage D % of Country Compared to Average	
	EN 15804+A1 Unit	Indicator	AVG. [1] C2	Spain (%)	UK (%)	Germany (%)	AVG. [1] C3	Spain (%)	UK (%)	Germany (%)	AVG. [1] C4	Spain (%)	UK (%)	Germany (%)	AVG. [1] D	UK (%)	Germany (%)
Impact assessment	(kg CO2-eq.)	GWP	1.90×10^{0}	102.2	−86.8	−15.4	-4.38×10^{0}	−127.6	−173.0	300.6	3.52×10^{0}	146.1	−70.8	−75.3	-9.27×10^{0}	72.6	−72.6
	(kg CFC 11-eq.)	ODP	1.54×10^{-8}	−99.9	199.9	−100.0	1.96×10^{-7}	−100.0	200.0	−100.0	9.10×10^{-8}	−99.9	199.9	−100.0	-9.15×10^{-7}	100.0	−100.0
	(kg SO2-eq.)	AP	3.70×10^{-3}	147.3	−77.3	−70.0	1.64×10^{-2}	−48.9	49.7	−0.8	2.16×10^{-2}	141.2	−66.4	−74.8	-5.20×10^{-2}	88.2	−88.2
	(kg Phosphat-eq.)	EP	9.05×10^{-4}	148.7	−75.6	−73.1	4.03×10^{-3}	−49.9	51.4	−1.6	3.36×10^{-3}	110.7	−28.8	−81.9	-1.47×10^{-2}	92.1	−92.1
	(kg NMVOC eq.)	POCP	-8.78×10^{-4}	212.0	−116.6	−95.3	2.40×10^{-3}	−49.2	75.3	−26.1	2.20×10^{-3}	127.3	−45.5	−81.8	-6.32×10^{-3}	91.4	−91.4
	(kg Sb-eq.)	ADPE	3.70×10^{-7}	−19.1	78.9	−59.8	2.01×10^{-6}	7.2	−45.1	37.9	1.60×10^{-6}	87.4	−7.9	−79.5	-3.88×10^{-5}	98.3	−98.3
	(MJ)	ADPF	2.60×10^{1}	102.3	−85.4	−16.9	3.84×10^{1}	−40.4	20.3	20.0	5.01×10^{1}	125.4	−49.3	−76.1	-1.30×10^{2}	76.8	−76.8
R × 10source use	(MJ)	PERE	1.64×10^{0}	120.2	−96.9	−23.3	2.34×10^{0}	−24.2	−45.5	69.7	5.68×10^{0}	134.3	−86.3	−47.9	-1.10×10^{1}	14.1	−14.1
	(MJ)	PERM	1.87×10^{-7}	−100.0		−100.0	6.37×10^{-7}	−100.0		−100.0	2.12×10^{-6}	−100.0		−100.0	-3.68×10^{-5}		−100.0
	(MJ)	PERT	1.64×10^{0}	120.2	−96.9	−23.3	2.34×10^{0}	−24.2	−45.5	69.7	5.68×10^{0}	134.3	−86.3	−47.9	-1.10×10^{1}	14.1	−14.1
	(MJ)	PENRE	2.61×10^{1}	102.2	−85.6	−16.6	3.87×10^{1}	−39.3	17.5	21.7	5.50×10^{1}	112.7	−53.5	−59.2	-1.37×10^{2}	75.8	−75.8
	(MJ)	PENRM															
	(MJ)	PENRT	2.61×10^{1}	102.2	−85.6	−16.6	3.87×10^{1}	−39.3	17.5	21.7	5.50×10^{1}	112.7	−53.5	−59.2	-1.37×10^{2}	75.8	−75.8
	(Kg)	SM					9.37×10^{2}										
	(MJ)	RSF															
	(MJ)	NRSF															
	(m3 world eq.)	FW	9.03×10^{-2}	197.8	−99.1	−98.7	1.89×10^{-1}	189.3	−95.8	−93.5	2.19×10^{0}	198.4	−98.7	−99.7	-1.90×10^{-1}	96.8	−96.8
Waste	(Kg)	HWD	7.95×10^{-4}	−100.0	99.9	−99.9	1.46×10^{-2}	−100.0	100.0	−100.0	9.55×10^{-3}	−100.0	100.0	−100.0	-1.09×10^{-1}	100.0	−100.0
	(Kg)	NHWD	9.04×10^{-2}	−100.0	95.8	−95.8	1.88×10^{-2}	−100.0	24.8	−24.8	2.13×10^{2}	153.1	−53.1	−100.0	-1.32×10^{1}	−59.4	59.4
	(Kg)	RWD	4.67×10^{-5}	95.3	−44.1	−51.2	3.17×10^{-4}	−28.1	4.7	23.4	6.80×10^{-4}	139.8	−76.9	−62.9	-1.38×10^{-3}	−17.4	17.4
Outflows	(Kg)	CRU									9.00×10^{2}		0%				
	(Kg)	MFR					4.60×10^{2}	0%									
	(Kg)	MER															
	(MJ)	EEE															
	(MJ)	EET															

[1] Average of all countries reporting values at that stage.

Table 9. Chromatic gradient of 4 sectorial EPDs of corrugated steel bars according to EN 15804+A1 according to the declared stages. Part 1 of 2: stages A1–3, A4, and A5.

			Stages A1–3 Percentage of the Country Compared to the Average					Stages C3 Percentage of the Country Compared to the Average			Stages D Percentage of the Country Compared to the Average			
	EN 15804+A1 Unit	Indicator	AVG. [1] A1–3	Spain (%)	CCL Scand-UK (%)	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)	AVG. [1] C3	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)	AVG. [1] D	Spain (%)	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)
Impact assessment	(kg CO2-eq.)	GWP	1.65×10^{3}	−75.1	50.3	−50.4	75.2	2.04×10^{0}	−21.6	21.6	-1.97×10^{2}	−74.7	−308.3	383.0
	(kg CFC 11-eq.)	ODP	1.43×10^{-5}	216.2	−16.2	−100.0	−100.0	3.52×10^{-12}	−98.7	98.7	-1.69×10^{-6}	200.0	−100.0	−100.0
	(kg SO2-eq.)	AP	7.45×10^{0}	−61.7	−40.9	−77.9	180.5	6.30×10^{-3}	−52.5	52.5	-1.89×10^{0}	−84.6	−133.9	218.5
	(kg Phosphat-eq.)	EP	5.68×10^{-1}	−23.0	3.4	−72.5	92.1	8.19×10^{-4}	−45.3	45.3	$-1.49 \times 10^{-}{}_{1}$	8.6	−131.0	122.5
	(kg NMVOC eq.)	POCP	7.73×10^{-1}	90.2	−30.4	−82.8	22.9	4.80×10^{-4}	−45.8	45.8	-6.26×10^{-2}	−68.5	−405.3	473.8
	(kg Sb-eq.)	ADPE	5.12×10^{-2}	−86.8	−98.3	−99.8	284.9	8.05×10^{-7}	−41.6	41.6	-2.08×10^{-2}	−46.3	−105.1	151.4
	(MJ)	ADPF	1.13×10^{4}	−55.7	−100.0	−25.1	180.8	2.35×10^{1}	−22.4	22.4	-2.58×10^{3}	−77.6	−265.0	342.6
Resource use	(MJ)	PERE	2.97×10^{3}	−42.8	−21.2	−82.8	146.8	1.21×10^{1}	0.8	−0.8	-7.16×10^{2}	−92.5	−63.0	155.5
	(MJ)	PERM	4.21×10^{-4}		0.0									
	(MJ)	PERT	2.97×10^{3}	−42.8	−21.2	−82.8	146.8	1.21×10^{1}	0.8	−0.8	-7.16×10^{2}	−92.5	−63.0	155.5
	(MJ)	PENRE	2.05×10^{4}	−64.9	38.8	−55.7	81.8	3.45×10^{1}	−18.1	18.1	-2.69×10^{3}	−73.9	−256.6	330.5
	(MJ)	PENRM												
	(MJ)	PENRT	2.05×10^{4}	−64.9	38.8	−55.7	81.8	3.45×10^{1}	−18.1	18.1	-2.69×10^{3}	−73.9	−256.6	330.5
	(Kg)	SM	7.64×10^{2}	46.6	−96.5	50.5	−0.6							
	(MJ)	RSF												
	(MJ)	NRSF												
	(m3 world eq.)	FW	1.45×10^{1}	−83.1	50.3	−89.8	122.6	1.42×10^{-2}	−16.6	16.6	4.33×10^{0}	−123.1	532.3	−409.2

[1] Average of all countries reporting values at that stage.

Table 10. Chromatic gradient of 4 sectorial EPD of corrugated steel bars according to EN 15804+A1 according to the declared stages. Stages A1–3, A4, and A5. Part 1 of 2: waste and outflows.

			Stages A1–3 Percentage of the Country Compared to the Average					Stages C3 Percentage of the Country Compared to the Average			Stages D Percentage of the Country Compared to the Average			
	EN 15804+A1 Unit	Indicator	AVG. [1] A1–3	Spain (%)	CCL Scand-UK (%)	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)	AVG. [1] C3	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)	AVG. [1] D	Spain (%)	Arcelor Mittal Europe (%)	Outokumpu Oyj UK, USA and Sweden (%)
Waste	(Kg)	HWD	3.02×10^{0}	−99.2	264.0	−65.9	−98.9	1.67×10^{-7}	−95.8	95.8	-4.12×10^{-2}	−91.5	−100.0	191.4
	(Kg)	NHWD	7.69×10^{1}	−100.0	15.1	−96.2	181.0	2.51×10^{1}	−99.9	99.9	-1.37×10^{1}	−99.9	292.6	−192.7
	(Kg)	RWD	5.83×10^{1}	−99.9	−99.2	−99.6	298.7	4.35×10^{-3}	−10.5	10.5	-3.35×10^{-2}	−94.6	−98.6	193.2
Outflows	(Kg)	CRU												
	(Kg)	MFR	3.62×10^{1}		0.00%			9.50×10^{2}		0.00%				
	(Kg)	MER												
	(MJ)	EEE												
	(MJ)	EET												

[1] Average of all countries reporting values at that stage.

Table 11. Chromatic gradient of 8 sectorial EPDs of mass concrete according to EN 15804+A1 according to the declared stages. Stages A1–3.

	EN 15804+A1 Unit	Indicator	AVG. [1] A1–3	Stages A1–3 Percentage of the Country Compared to the Average (%) Spain (Association)	UK (Association)	Germany (Association)	Thinkstep Germany	Denmark (Association)	DK Beton	Valla Iceland	Cemex Poland
Impact assessment	(kg CO2-eq.)	GWP	2.69×10^{2}	0.7	−18.3	−18.6	5.2	4.8	11.1	10.7	4.4
	(kg CFC 11-eq.)	ODP	3.51×10^{1}	−99.8	−100.0	−100.0	−100.0	−100.0	−100.0	−100.0	699.8
	(kg SO2-eq.)	AP	4.11×10^{-1}	69.4	−11.4	−22.9	−27.8	6.1	13.9	−63.5	36.3
	(kg Phosphat-eq.)	EP	1.30×10^{-1}	25.5	−73.3	−54.5	−55.8	7.8	18.5	2.4	129.4
	(kg NMVOC eq.)	POCP	5.13×10^{-2}	33.5	126.2	−49.7	−104.8	−69.0	−63.9	−35.5	163.2
	(kg Sb-eq.)	ADPE	1.18×10^{-1}	−99.8	−99.6	−99.4	−100.0	−99.9	−99.9	−99.9	698.6
	(MJ)	ADPF	1.09×10^{3}	87.2	−89.7	−8.5	−20.7	24.8	33.1	−10.8	−15.3
Resource use	(MJ)	PERE	1.79×10^{2}	−35.3	−67.0	13.8	44.3	6.0	−5.7	43.9	−100.0
	(MJ)	PERM	7.51×10^{-2}	596.5	−100.0	−100.0	−100.0	−100.0	−96.5	−100.0	−100.0
	(MJ)	PERT	2.46×10^{2}	−52.4	−75.9	−16.9	5.3	−22.6	−31.2	5.0	188.7
	(MJ)	PENRE	1.33×10^{3}	65.6	−8.6	−17.6	−29.6	3.4	11.7	−25.0	−100.0
	(MJ)	PENRM	1.41×10^{1}	79.6	118.5	−100.0	−100.0	16.7	35.8	−50.6	−100.0
	(MJ)	PENRT	1.15×10^{3}	87.2	−96.4	−4.2	−18.3	21.9	31.4	−12.1	−9.5
	(Kg)	SM	3.71×10^{1}	−73.4	−16.6	−38.0	−100.0	81.0	137.7	35.2	−25.8
	(MJ)	RSF	2.82×10^{2}	−82.7	−85.3	−27.5	−98.9	−45.6	−28.2	124.2	244.2
	(MJ)	NRSF	2.74×10^{2}	−69.3	−5.3	41.8	−88.3	2.3	−17.8	67.7	68.8
	(m3 world eq.)	FW	2.03×10^{1}	208.9	−98.5	−95.4	−97.8	338.7	−94.9	−97.5	−63.6
Waste	(Kg)	HWD	1.07×10^{-2}	50.1	254.3	−96.5	−99.9	−54.1	12.8	−95.4	28.7
	(Kg)	NHWD	4.32×10^{1}	−97.7	100.5	−9.7	95.9	−7.9	−57.6	14.8	−38.2
	(Kg)	RWD	2.02×10^{-2}	−75.8	107.7	108.2	47.6	−83.7	−17.7	−100.0	−86.4
Outflows	(Kg)	CRU									
	(Kg)	MFR	4.96×10^{-1}	−90.2	−100.0	−100.0	−100.0	−99.4	−15.4	−100.0	605.0
	(Kg)	MER	1.06×10^{-1}	384.0	−100.0	−100.0	−100.0	35.8	80.2	−100.0	−100.0
	(MJ)	EEE									
	(MJ)	EET									

[1] average of all countries reporting values at that stage.

Table 12. Chromatic gradient of 5 sectoral EPDs of mass concrete according to EN 15804+A2 according to the declared stages. Stages A1–3. Part 1 of 2: impact assessment and resource use.

				Stages A1–3 Percentage of the Country Compared to the Average				
	EN 15804+A2 Unit	**Indicator**	**AVG. [1] A1–3**	**HOLCIM Germany (%)**	**Iston Istanbul Turkey (%)**	**Aggelos Greece (%)**	**Interbeton Greece (%)**	**Votorantim Brazil (%)**
Impact assessment	**(kg CO2-eq.)**	**GWP-total**	2.74×10^{2}	−36.8	27.2	15.5	−13.0	7.1
	(kg CO2-eq.)	*GWP-fossil*	2.72×10^{2}	−36.4	26.6	14.4	−12.4	7.8
	(kg CO2-eq.)	*GWP-biogenic*	1.77×10^{0}	−89.3	94.4	184.1	−96.6	−92.6
	(kg CO2-eq.)	*GWP-luluc*	1.01×10^{-1}	−0.9	44.7	−29.2	−64.3	49.7
	(kg CFC 11-eq.)	**ODP**	1.09×10^{-5}	−100.0	75.4	18.5	−33.4	39.6
	(mol H+ eq.)	*AP*	8.13×10^{-1}	−58.2	22.2	1.6	−33.1	67.4
	(kg P eq.)	*EP-freshwater*	8.49×10^{-2}	−99.9	−52.8	283.8	−52.0	−79.2
	(kg N eq.)	*EP-marine*	1.20×10^{-1}	−8.4	124.0	82.4	−99.2	−98.8
	(mol N eq.)	*EP-terrestrial*	2.64×10^{0}	−51.1	15.3	−5.9	−32.1	73.7
	(kg NMVOC eq.)	**POCP**	6.62×10^{-1}	−54.7	20.5	−5.5	−32.6	72.3
	(kg Sb-eq.)	**ADPE**	6.06×10^{-4}	−98.9	117.8	102.9	−76.4	−45.4
	(MJ)	**ADPF**	1.16×10^{3}	−14.9	74.8	−37.5	−36.0	13.7
	(m3)	*WDP*	7.67×10^{1}	−95.0	8.7	23.7	25.7	36.9
Resource use	**(MJ)**	**PERE**	1.37×10^{2}	−50.1	54.3	−49.5	−59.6	104.8
	(MJ)	**PERM**	4.32×10^{0}	−95.8	−100.0	395.8	−100.0	−100.0
	(MJ)	**PERT**	1.41×10^{2}	−51.5	49.6	−35.8	−60.8	98.5
	(MJ)	**PENRE**	1.32×10^{3}	−25.5	79.4	−29.9	−35.8	11.8
	(MJ)	**PENRM**	1.76×10^{2}	−94.3	−99.9	394.3	−100.0	−100.0
	(MJ)	**PENRT**	1.49×10^{3}	−33.6	58.3	20.1	−43.3	−1.4
	(Kg)	**SM**	1.54×10^{1}	−33.9	−100.0	−41.0	−23.5	198.3
	(MJ)	**RSF**	4.66×10^{1}	288.5	−100.0	−93.7	5.2	−100.0
	(MJ)	**NRSF**	7.73×10^{1}	307.5	−100.0	−93.5	−14.0	−100.0
	(m3 world eq.)	**FW**	1.95×10^{0}	−71.8	2.1	15.4	18.5	35.9

[1] Average of all countries reporting values at that stage.

Table 13. Chromatic gradient of 5 sectoral EPDs of mass concrete according to EN 15804+A2 according to the declared stages. Stages A1–3. Part 2 of 2: waste and outflows.

				Stages A1–3 Percentage of the Country Compared to the Average				
	EN 15804+A2 Unit	Indicator	AVG. [1] A1–3	HOLCIM Germany (%)	Iston Istanbul Turkey (%)	Aggelos Greece (%)	Interbeton Greece (%)	Votorantim Brazil (%)
Waste	(Kg)	HWD	4.98×10^{1}	−100.0	−100.0	300.0	−100.0	−100.0
	(Kg)	NHWD	3.54×10^{1}	5.5	−0.7	−58.1	−100.0	53.3
	(Kg)	RWD	6.14×10^{-2}	−18.5	−85.1	103.7	−100.0	−100.0
Outflows	(Kg)	CRU						
	(Kg)	MFR	2.47×10^{1}	−100.0	−100.0	−78.9	−100.0	278.9
	(Kg)	MER	4.33×10^{-3}	−100.0	−100.0	−100.0	−100.0	300.0
	(MJ)	EEE						
	(MJ)	EET						

[1] Average of all countries reporting values at that stage.

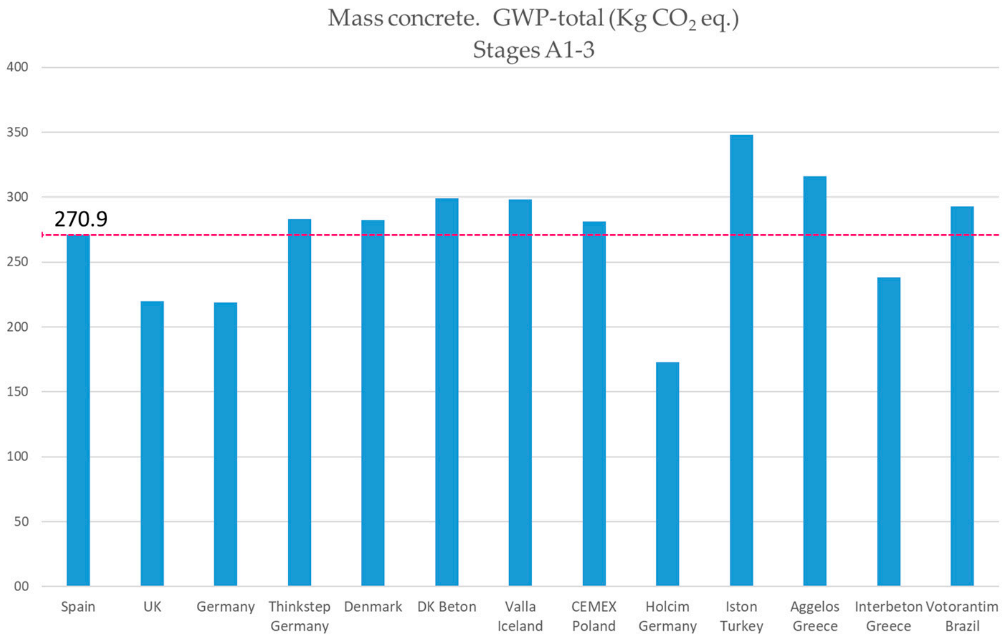
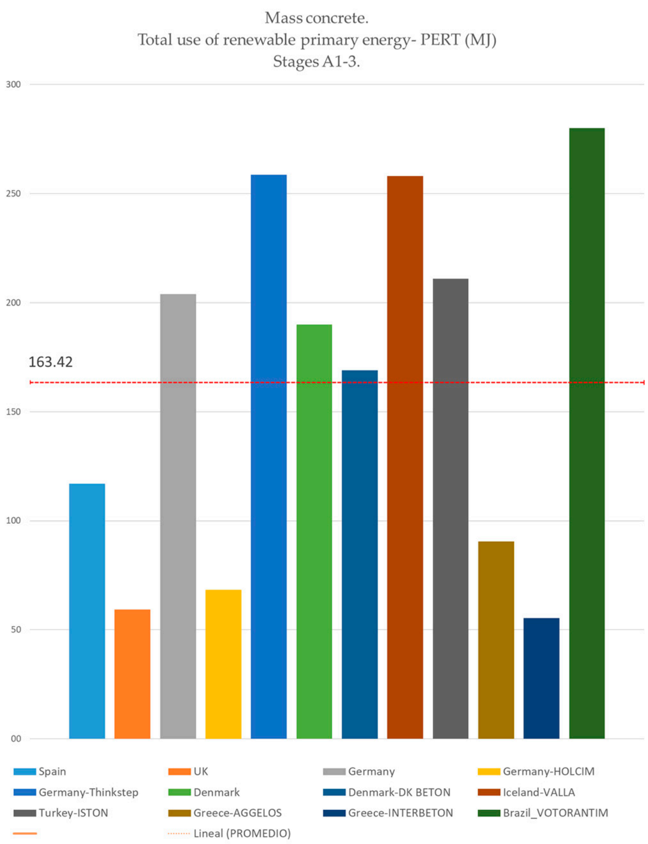
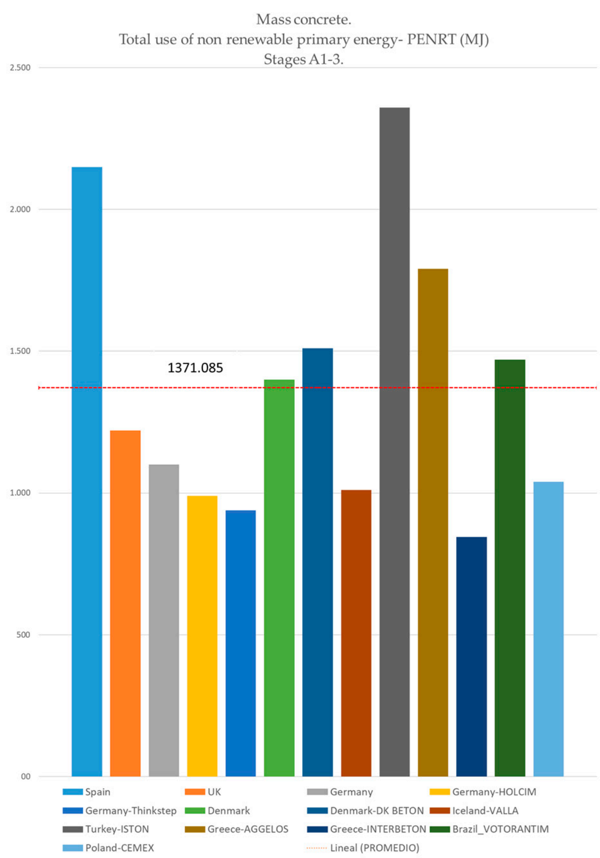


Figure 3. GWP—total impacts in stages A1–3 for 13 EPDs of mass concrete. The average value is represented by the red line.





(**a**) (**b**)

Figure 4. Total primary energy use in stages A1–3 for 13 EPDs for mass concrete. (**a**) Total renewable primary energy use (PERT) and (**b**) total non-renewable primary energy use (PENRT). The average value is represented by the red line.

Table 14. Comparison of GWP—total, PERT, and PENRT indicators at stages A1–3 for the three studied materials: corrugated steel, ceramic bricks for cladding, and mass concrete.

	EN 15804+A1 Stages A1–3	GWP—Total (Kg CO_2-eq.)	PERT (MJ)	PENRT (MJ)
Reinforcing bar	Spain [2]	410.0	1700.0	7190.0
	CCL scand-UK [1]	2480.0	2340.0	28,400.0
	ArcelorMittal Europa [4]	818.0	512.0	9070.0
	Outokumpu UK, USA and Sweden [4]	2890.0	7330.0	37,200.0
Ceramic bricks for cladding	Spain [2]	236.0	403.0	2520.0
	UK [2]	213.0	120.0	2430.0
	Germany [2]	196.5	373.9	2052.0
Mass concrete	Spain [2]	271.0	117.0	2150.0
	United Kingdom [2]	220.0	59.2	41.3
	Germany [2]	219.0	204.0	1100.0
	Thinkstep Germany [3]	283.1	258.6	939.1
	Denmark [2]	282.0	190.0	1400.0
	DK Beton [4]	299.0	169.0	1510.0
	Valla Iceland [4]	298.0	258.0	1010.0
	CEMEX Poland [4]	281.0	709.0	1040.0

[1] Company-specific data. [2] Association EPD. [3] Developed generic data. [4] Multinatinal EPD.

4. Discussion

When interpreting the results obtained, it is necessary to bear in mind that environmental product declarations are a document used to provide environmental information to potential customers and for business-to-business (B2B) and/or business-to-consumer (B2C) communication. Their comparability is defined by the environmental performance in the building and for the whole life cycle, as they are not tools to compare building products or services outside this framework. In any case, the diversity of criteria in their development, despite complying with current regulations, even affects the results at the building level [30].

An initial assessment of the results obtained shows that, despite strict compliance with the regulations in force, the sectoral EPDs have shortcomings in terms of the traceability of the information they include and the context in which they are developed. This, consequently, affects the homogeneity and comparability of the impact values they declare.

Sectoral EPDs, given their prevalence as a source of environmental information and their application in life cycle assessments (LCAs) of buildings, should exhibit consistent consensus within each sector and be truly representative of the national market. Research such as the study conducted in Portugal by ref. [31], which develops the native method to generate generic data at the national level, emphasizes the importance of prioritiing the use of sectoral EPDs when a manufacturer EPD is not available for a particular product. However, a more detailed review and analysis of sectoral EPDs in Spain shows that the homogeneity of the data presented and their traceability is conditioned by important aspects such as the definition of both the system boundaries and calculation scenarios, as well as various aspects related with the use of the data and calculation of impacts, which can greatly affect the results obtained (Table A1).

The analysis of the Spanish sectoral EPDs shows a lack of uniformity in the definition of the products declared and in the formulas and criteria used for grouping, as shown in Table A1. The standard does not require information regarding the uncertainty criteria adopted in the EPDs; therefore, they are often produced subjectively, with consequent repercussions in the results. Table A1 also shows that there are sectoral EPDs in which each manufacturer declares its EPD in an identical way to the EPD of the association to which it belongs, with the only difference being the name of the association (such as the

Spanish Iron and Steel Association). On the other hand, others group several of their products in a single EPD that includes the impact values of each one (such as AISBL-EWA). It can also be seen that some sectoral EPDs have a large share of the market for the product(s) they represent (OFICEMEN + IECA), while others do not (ASCER), without any connotation being reflected in their results. In fact, even sectoral EPDs of associations with large numbers of members and high representativeness only incorporate data from a small number of them (FdA), thus conditioning their representativeness of the sector. The weighting of EPDs according to the sample representativeness (market share, represented manufacturers, etc.) could be a solution, combined with individual EPDs which provide an aggregate mean [32]. Table A2 shows the specific case of ceramic tile products, in which the sectoral EPD (called the matrix value) calculates values based on the data provided by some of its partners. These values are subsequently adopted by some of them (called standard values) to make their own manufacturer EPD (modifying the ownership). Meanwhile, other partners produce their own EPDs with impact values (called different values) higher than those of the sectoral EPDs, identified in the table by cells with grey shading. Table 6 expresses these ratios in numerical values. The accuracy of the specific EPD data at the cradle-to-gate stages (A1–3) should provide lower impacts, as they are direct from the manufacturer compared to the EPD of the association [33].

Extending the analysis to the international context and taking into account the three criteria identified as key to the development of an EPD, namely the version of the standard, the PCRs, and the declared stages and PCRs, it can be concluded that there is a lack of uniformity in the results, as shown in Tables 7–13. As explained above, two versions of the EN 15804 standard have coexisted until the end of October 2022. When the results are analyzed, taking into account the version of the standard applied, it can be seen that there have been marked variations that further increase the inequalities described so far. Currently, EPDs can no longer be developed in accordance with version 15804+A1, but EPDs developed until now under this standard are valid until their expiry date (normally five years after their issue).

Regarding the results for bricks, Table 7 shows closer values for stages A1–3 (product stages) than for stage C3 (waste treatment), shown in Table 8. This is because these stages correspond to those for which more information is available from the factories themselves, and to those with more predictable future scenarios, respectively. However, stage A5, commissioning, shown in Table 7, presents greater differences. With regard to the impact indicators, it is worth noting the similar GWP values between the countries and similar results relating to the total use of renewable and non-renewable primary energy (PERM and PENRM). This can be seen in the values presented in Table 7 for Spain, the UK, and Germany in stages A1–3, declaring GWP values of 236 kg CO_2-eq, 213 kg CO_2-eq, and 196.51 kg CO_2-eq, respectively.

In the case of corrugated steel bars, Tables 9 and 10 show a high number of values with differences of more than 50%, with maroon and red tones predominating. The lowest percentages are concentrated in the uses of renewable and non-renewable primary energy for the C3 waste treatment stage, while module D contains the highest discrepancies together with the set of waste indicators. As an example, we can highlight that in the GWP-total indicator, the Steelwork Sustainability Association in Spain declares −49.91 Kg CO_2-eq, ArcelorMittal Europa declares +411 Kg CO_2-eq, and the multinational Outokumpu Oyj declares −953 Kg CO_2-eq.

Table 11 shows the selected EPDs of mass concrete in accordance with EN 15804+A1, with the GWP being the most homogeneous indicator in all the EPDs, with differences not exceeding 20%. Strazza et al. in their study of Italian cements [34] already confirmed the uniform global warming profile (GWP). In Tables 12 and 13, where the statements according to EN 15804+A2 are presented, the GWP is divided into four indicators (GWP-total, GWP-fossil, GWP-biogenic, and GWP-luluc), with all of them presenting similar values except for GWP-biogenic, where the difference in values exceeds 90%.

Additionally, it must be taken into account that product category rules are another source of variability in the results. PCRs that have not been standardized by the standards committee are normally developed independently by the corresponding program manager, leaving the definition of aspects as important as the type of functional unit, useful life, and declared scenarios that are established in the PCRs to their discretion. Thus, it is possible that sectoral EPDs with different criteria coexist. One clear example is bricks, whereby Great Britain establishes a useful life of 60 years, while in Spain and Germany, it is considered 150 years. Another example is the definition of the functional unit, which is defined as 1 m^3 of brick in the sectoral EPD of Germany, while in the other countries, the functional unit is 1000 Kg of brick. Moreover, although they are not evidently stated in the EPDs, decisions as fundamental as the system boundaries, cut-off criteria, etc., are made by the PCR and vary according to their compliance.

No less important in the development of an EPD is the human factor and its capacity for interference in the different sources of uncertainty due to the parameters, the scenarios, and the calculation model. First of all, in relation to the uncertainty of the parameters, the quality and variability of the data must be taken into account. Studies such as that of Martínez-Rocamora et al. [35] report marked differences between Ecoinvent and GaBi, such as values for the GWP impact of aluminum of 8.54 CO_2-eq/kg and 0.726–0.891 CO_2-eq/kg, respectively. Another is that by Loli et al. [36], where according to EPD Norge, the carbon footprint for producing 1 kg of reinforcement steel in Norway is 0.3 kgCO_2-eq., while in Ecoinvent, the production of steel in the European market (RER) has an environmental cost of 2.1–0.3 CO_2-eq. These are determining factors that vary the scale of the results. In general, the preselected EPDs of the three materials maintain few parameters in common, despite their interference and the importance to the results being known [33]. Regarding the methodological uncertainty for the definition of LCA scenarios, it is necessary to take into account the selection of the FU (functional unit), the geographical area, and the date, among others, as well as the choice of impact evaluation method [37].

The effects of the human factor on the uncertainty of the results are not unique to building products. Scrucca et al. [37] analyzed the LCA of a bottle of wine performed by six different developers and showed the divergences even when many of those uncertainties were determined. Similarly, Pomponi et al. [38], in their analysis of five building projects in the United Kingdom by three independent environmental consultants, showed the inequalities due to the subjective choices of the evaluators throughout the project. These uncertainties could be represented in the EPD with approaches as simple as the one reflected in the work of Waldman [39], although, as has been proven, it has not been implemented.

Table 14 shows a comparison of the three impact indicators studied for the three materials analyzed. Regarding the GWP—total, 1 m^3 mass concrete has a value of 200–300 Kg CO_2-eq, 1000 kg of brick has approximately 200 Kg CO_2-eq, and 1000 Kg of corrugated steel has 400–800–2800 Kg CO_2-eq, showing clear trends.

Consequently, in the execution of a reinforced concrete structure, which will require a large amount of concrete and steel, the carbon footprint of steel will be very high compared to that of concrete. If the envelope is designed in brick, although its impact is low, the amount of material is very high [35]. In terms of energy consumption, corrugated steel remains the material with the highest impacts. In general, concrete is the material that requires the least energy, although, in all three cases, the consumption of non-renewable primary energy is considerably higher than that of renewable energy. This trend indicates the need for a change in government policies in countries to promote more sustainable energy sources.

The three final figures show an analysis focused on the indicators with the most things in common. Figure 3 shows the environmental impact of GWP—total in stages A1–3 for the 13 EPDs analyzed for concrete. A horizontal line shows the mean value of them all (270.90 Kg CO_2-eq). Holcim in Germany has a lower value of 173 kg de CO_2-eq; 36.13% of the mean value. The British and German associations present respective values of 220 kg and 219 kg de CO_2-eq, 18.78% and 19.14% lower than the mean. By contrast, the Turkish company Iston presents a higher value of 348 kg of CO_2-eq, an increase of 28.49%. Generally speaking, the values do not present differences above 20%, showing homogeneous behavior. This tendency towards convergence is due to the reliability of the information, especially from the extraction of raw materials to the factory door. Moreover, the use, application, and mastery of this indicator is widespread [14], and databases are hardly used for these stages since data and processes specific to each manufacturer are used. This factor unifies the results and makes it easier to compare these initial stages, in this indicator in particular [7].

The impacts of the use of energy are analyzed in Figure 4a for the case of the total use of renewable primary energy (PERT) and in Figure 4b for the total use of non-renewable primary energy (PENRT). These figures show stages A1–3 for the 13 EPDs of concrete, except in Figure 4a, where CEMEX Poland has been removed. Its value of 709 MJ is so different from the mean that comparison is impossible. This EPD is thought to contain certain criteria and uncertainties that make its values very different from the others.

The analysis of Figure 4a reveals two result scales. Some declarations clearly exceed the mean value (163.42 MJ), while other present much lower values. The EPDs with lower values are those in accordance with EN 15804:A2 and belong to private companies, together with the sectoral EPDs of Spain and Great Britain. The values that are higher than the mean correspond to the EPDs in accordance with EN 15804:A1 and the Turkish EPD of the company in accordance with EN 15804:A2. It is confirmed that data provided by the manufacturers, which are more specific than in collective EPDs, are more reliable and lead to better results.

In Figure 4b, the sectoral EPDs from Spain and the Turkish company Iston stand out, with values 56% and 72% above the mean, respectively. In contrast, the Greek company Interbeton presents values more than 38% below the mean. It is worth noting that there is a sub-group of values that are below the mean but are comparable with each other. This group includes the sectoral EPDs of Great Britain, Germany, Holcim in Germany, Thinkstep in Germany, Valla en Iceland, Interbeton in Greece, and Cemex in Poland. All these EPDs present differences of 2–20% between each other, with a mean value close to 1000 MJ. Regarding the numeric value, the amount of non-renewable primary energy used is nearly ten times greater than the renewable energy in the production of concrete. This is evidence of the deficient use of renewable energies worldwide.

Of note is the stability of certain indicators such as the GWP, PERT, and PENRT, which, as Figures 3 and 4 show, undergo smaller changes due to their relations to government policies [14]. According to Lasvaux et al. [14], indicators involving fossil fuel consumption are less variable (more comparable, with variations of approx. 25%) in building materials. Meanwhile, developing policies continue to focus their actions on certain indicators, towards decarbonization and energy efficiency. This will imminently tip the balance towards other impacts. For example, launches of new technologically advanced materials that reduce operational energies are already shifting their impacts to their manufacturing processes. This action, studied globally in the building, will decrease certain environmental burdens at the use stages, burdens that will be increased at the manufacturing stages of the materials. A recent global review of environmental sustainability certifications and regulations identified 156 schemes in 26 countries, of which 105 included direct measures for embodied carbon [40], identifying the trend of action towards decarbonization.

These three indicators, therefore, allow for greater comparability, and they can be used to assess, in a general way, the contributions of the use of different materials to the total computation of the environmental impacts of buildings. In view of the results obtained, and taking everything considered in the previous paragraphs into account, it can be stated that the analysis of the sectoral EPDs of the three products selected on an international scale shows the lack of parity of criteria in their calculation. In 2017, Gelowitz et al. [33], in a study of more than 50 EPDs, confirmed that more than 38% lack the information required by the standard, and 8% contained contradictory information. Even within the EPDs developed under the same PCRs, 61% were not comparable. Along the same lines, the study of 436 EPDs by Moré et al. in 2022 [41] stated that, of all potential comparisons, 8.06% of the documents could not be compared in any aspect, 89.15% were considered incomparable, 2.75% could be compared with caution, and only 0.04% were comparable. Based on the results presented in Table 14, which show fifteen values from indicators for three materials, values could be provided for more materials for use as a guide for their preselection during the design phase of buildings with environmental sustainability criteria.

5. Conclusions

Measuring the environmental impact of buildings should involve an LCA. To this end, one of the first steps is the suitable selection of materials and input data. The results reported in the selected EPDs have shown the lack of uniformity in the criteria for calculating their LCA, with only a few similarities having been found in the first stages of the life cycle. A better control of the technological processes in the factory and the manufacturer providing their own data would result in values that can be analyzed in a common context: the building.

The new version of the 15804+A2 standard has increased the number of environmental indicators. This will require more input data and, above all, a greater standardization of the calculation criteria, allowing for the homogenization of results.

It is necessary to generate user-friendly and reliable databases that are accessible to the consultant and that reduce the level of uncertainty that currently exists in the results of the EPDs based on sectoral EPDs. These must be correctly contextualized geographically, technologically, and temporally.

Following the results obtained in this study, a line of research is opened to minimize the differences between EPDs, allowing progress to be made in their homogenization through consensus and adaptation of the regulations. Many countries are developing national databases, many of which are based on data from the EPDs of building products from their country. Sectoral EPDs should be an example of consensus, establishing standard values or ranges that enable calculations to be made in cases where specific data are not available. The value of these EPDs, weighted by the market share and with more details about factors of uncertainty, would result in more accurate values in the geographical context.

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Appendix A

Table A1. Summary of the sectoral EPDs analyzed in the context of construction products in Spain.

Owner	Participation		Number of EPDs	Product Definition [1]	PCR	EN15804	Lifecycle Stages
	Nº	(Units)					
ANEFHOP	300	Companies	1	Several (2)	EN 16757:2018 [42]	A1	Partial
HISPALYT	+150	Associates	6	Single	Global EPD-RCP-008	A1	Partial
FdA	700	Companies	3	Single	Not stated	A2	Partial
AEA	89 64	Associates % Market share	2	Several (6)	PCR 2019:14 v1.0 EPD System	A2	Partial
AISBL-EWA	43 95	Factories % Market share	1	Several (8)	PCR 2019:14. EPD System	A2	Partial
ASE	80–100	% Market share	3	Several (3)	PCR 2019:14 v1.0 EPD System	A1	Partial

Table A1. *Cont.*

Owner	Participation		Number of EPDs	Product Definition [1]	PCR	EN15804	Lifecycle Stages
	Nº	(Units)					
ANFAPA	10	Companies	4	Single	Global EPD-RCP-006 and 007	A1	Full
OFICEMEN + IECA	100	% Market share	7	Several (7)	Global EPD-RCP-003	A1/A2	Partial/Full
ATEDY	9	Factories	2	Single	Global EPD-RCP-004	A1	Partial
ASCER	40	% Market share	1	Single	Global EPD-RCP-002	A1	Full

[1] Number of different products included in the EPD indicated in brackets.

Table A2. ASCER sectoral EPDs and 10 specific EPDs of associated manufacturers.

Owner	Standard	Declared Stages	Value Type	Database	Software	Date of Data
ASCER	15804+A1	All	Matrix value	Company PD [1,2] GaBi SD [3], compilation 8.7.0.18.	GaBi 8.7.0.18.	2017
PAMESA CERÁMICA, S.L.	15804+A1	All except A4–A5, B2, C2–C4	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
GEOLÓFICA TILE, S.L.U.	15804+A1	All except A4–A5, B2, C2–C4	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
CERAMIC TILE INTERNATIONAL, S.L.U.	15804+A1	All except A4, A5, B2, C2, C3, C4.	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
AZULEJOS FOSET, S.L.U.	15804+A1	All except A4, A5, B2, C2, C3, C4.	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
NAVARTI CERÁMICA, S.L.U.	15804+A1	All except A4, A5, B2, C2, C3, C4.	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
TAU CERÁMICA SOLUTIONS, S.L.U.	15804+A1	All except A4, A5, B2, C2, C3, C4.	Standard	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
PERONDA GROUP, S.A.	15804+A1	All	Different values	Company PD GaBi SD, compilation 8007	GaBi 8.0.7.18	2017
GRESPANIA, S.A.	15804+A1	All	Different values	Company PD GaBi SD, compilation 8007	GaBi 8.0.7.18	2017
EQUIPE CERÁMICA, S.L.	15804+A1	All except A4, A5, B2, C2, C3, C4.	Different values	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	2018
MANUFACTURA INDUSTRIAL AZULEJERA S.L.	15804+A1	All	Different values	Company PD GaBi SD, compilation 8007	GaBi 9.1.053.	May 2019–May 2020

[1] Primary data. [2] Representing 40% of Spanish production. [3] Secondary data.

Table A3. Parameters of selected facing brick EPDs.

Owner Association	Declared Product	Standard	PCR	Declared Stage	Database	Software	Year Data	Service Life (Years)
Federal Association of the German Brick and Roof Tile Industry	1 m^3 of unfilled brick (density: 575 Kg/m^3)	15804+A1	RCP bricks 1.2017 (IBU)	All except B1, B2, B6 and B7 (module not relevant B3, B4 and B5)	BBDD GaBi SP39 2019	GaBi 9	2019	150
Brick Development Association	1 Tm of average UK brick BDA	15804+A1	BRE Environmental Profiles	All (module not relevant B1-B7 and C1)	Ecoinvent 3.2	SimaPro v8	2017	60
Spanish Association of Manufacturers of Baked Clay Bricks and Tiles (HISPALYT)	1000 kg of ceramic facing bricks and their special parts	15804+A1	GlobalEPD-RCP-008	All except module D (module not relevant B1–7, C1 and D)	No specified	No specified	2015	150

Table A4. Parameters of the selected corrugated steel EPDs.

Owner	Declared Product	Standard	PCR	Declared Stages	Database	Software	Year Data	Service Life (Years)
CCL Scandinavia A/S	1 kg of corrugated conduit used in precast and post-tensioned concrete	15804+A1	BRE PCR PN514	A1, A2, A3, A1–3	ecoinvent v3.2 (2015)	Pat Hermon BRE LINA v2	2020	No specified
Arcelor Mittal Europe	1 Tm of reinforcing steel	15804+A1	Reinforcing Steel, 11.2017 (IBU)	A1–3, C3, C4, D	GaBi (2021)	GaBi v. 2021.2	2022	No specified
Outokumpu	1 Tm of long stainless steel	15804+A1	Structural steels, 07.2014 (IBU)	A1–3, C3, D	GaBi DataBase SP36	GaBi v. 2018	2017–2018	No specified
Association for Steel Sustainability	1000 kg of rebar production	15804+A1	UNE 36904-1:2018	A1, A2, A3, A4, D	Ecoinvent 3.5 (2018)	SimaPro 9.0.0.30	2016–2017	No specified

Table A5. Parameters of the selected mass concrete EPDs.

Owner	Declared Product	EN 15804	PCR	Declared Stages	Database	Software	Year Data	Service Life (Years)
ANEFHOP	1 m^3 of ready-mixed concrete	+A1	UNE-EN 16757:2018	Partial	Ecoinvent 3.6 database 2020	Sectoral calculator based on Simapro 9.1.1 (2020)	2017	50–100
British Ready-Mixed Concrete Association	1 m^3 generic ready-mixed concrete	+A1	IBU	Partial	GaBi and data of associates	Precast Envision EPD Tool v. 2017	2014	100
Concrete GmbH	1 m^3 unreinforced structural concrete (C30/37)	+A1	IBU	Partial	GaBi v 8.7.0.18, SP 34	GaBi v. 8.7.0.18, SP 34	2016	<50
Thinkstep	1 m^3 unreinforced structural concrete (C30/37)	+A1	No specified	Partial	GaBi v. 2020, SP40	GaBi	2018	Not specified
Danish Concrete Manufacturers Association	1 m^3 of factory concrete (exposure class XC2, XC3, XC4, XF1 y XA1)	+A1	DS/EN 16757:2017	Partial	BBDD GaBi 2019	Not specified	2018	100
DK Beton	1 m^3 of factory concrete (exposure class XC2, XC3, XC4, XF1 y XA1)	+A1	DS/EN 16757:2017	Partial	GaBi 8.7	GaBi	2020	100
BM Valla	1 m^3 exterior ready-mixed concrete C30/37	+A1	EPD norge	Partial	Ecoinvent	Not specified	2020	60
CEMEX Poland	1 m^3 ready-mixed concrete	+A1	ETB-EPD	Partial	Ecoinvent v.3.9.	Not specified	2020	Not specified
Holcim GmbH	1 m^3 of unreinforced concrete C30/37 XC4 XF1 XA1 F3 16 M ECOPact	+A2	IBU	Partial	GaBi SP40, 2020	GaBi v. 10.6.1.35	2020	50
ISTON	1 m^3 of ready-mixed concrete C 30/37 Ready-mixed concrete	+A2	EPD System	Partial	Ecoinvent 3.8	SimaPro 9.3	2021	Not specified
Aggelos B. Peppass S.A	1 m^3 of ready-mixed concrete	+A2	EPD System and UNE-EN 16757	Partial	Ecoinvent database (3.8)	OpenLCA 1.11.0	2021	Not specified
Interbeton Building Materials S.A	1 m^3 of ready-mixed concrete	+A2	EPD System and UNE-EN 16758	Full	Ecoinvent v.3.5	GCCA industry EPD tool v3.1	2020–2021	50
Votorantim Cimentos	1 m^3 of ready-mixed concrete	+A2	EPD System and UNE-EN 16759	Partial	Ecoinvent v.3.5	BetonTec v.2021	2021	50

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