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The Use of Environmental Product Declarations of Construction Products as a Data Source to Conduct a Building Life-Cycle Assessment in Spain

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Abstract: The Life-cycle Assessment (LCA) method and the Environmental Product Declaration (EPD) each play a crucial role in reducing buildings' embodied environmental impacts. EPDs provide the validated and geographically representative data necessary to conduct an LCA. However, the development of EPDs in the European context is still irregular. Countries such as Germany and France have many EPDs for construction products, while other countries, such as Spain, have a limited number of EPDs and more than one operator programme, which is pointed out in the literature as a possible limiting factor for comparing results. This study aimed to examine the use of construction product EPDs manufactured in Spain, to then use as a data source to conduct a building LCA. We analysed the comparability of the results among the different EPD programmes and investigated to what extent the use of Spain's geographically representative construction product EPDs can contribute to conducting a building LCA, including all the materials and products that compose a building, and covering all the building life-cycle stages (product, construction, use, and end-of-life). The results showed that plasterboard and thermal insulation products have the highest numbers of EPDs in different EPD programmes. The case study analysis showed that 20% of the construction products that compose a building can potentially use these EPDs as a data source to conduct a building LCA, and 89% of those product categories include at least the product, use, or end-of-life stage modules. Finally, recommendations and challenges to improve LCA development in the architecture, engineering, construction, and operation industries were included.

Keywords: environmental product declarations; life-cycle assessment; building; design process

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1. Introduction

During the last decade, most measures, and regulations to reduce the impacts of built environments have been focused on improving the operational impacts in use stages, e.g., the Energy Performance of Building Directive (EPBD) [1]. However, it is increasingly being recognized that operational impact reduction needs to be accompanied by reducing embodied impacts [2]. Embodied impacts are related to the materials that compose the building, including raw materials, products manufacturing, transport, construction, use, and end-of-life stages [3]. The embodied energy impacts are crucial [4] as they will remain after a reduction in energy consumption in the operational phase has been achieved [5]. Thus, a building LCA allows for the addition of the embodied and operational impacts of a building (see Figure 1).

	Building Life Cycle																Additional information
	Product stage			Construction process stage		Use stage											Potential benefit and loads
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
	Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy use	Operational water use	Deconstruction	Transport	Waste processing	Disposal	Recovery-reuse-recycling potential
Embodied																	
Operational																	

Figure 1. Building life-cycle stages according to EN 15978:2011. The life cycle related to embodied impacts are indicated separately from the ones related to operation impacts. (Source: based on IEA EBC Annex 57 [3]).

The life-cycle assessment method is a scientifically valid method used to estimate the embodied impacts produced throughout the life cycle of a building [3]. Environmental data regarding the building elements, components, materials, products, and processes play a crucial role. The existing European standards EN 15978 [6] for building LCA propose Environmental Product Declarations (EPDs) as a verified certification to indicate the impact of building products [7]. EPDs are also endorsed by the International Reference Life-Cycle Data (ILCD) system as a means of developing a consistent and robust LCA [8]. Indeed, EPDs or Type III environmental declarations according to the EN ISO 14025 [9], and for buildings according to EN 15804 [10], are recognised tools for providing quantified environmental data of a product as the basis of an LCA study [11].

Consequently, EPDs are data sources that help to obtain verified and third-party validated data to calculate buildings' embodied impacts. These impacts, from manufacturing the construction materials and constructing, maintaining, refurbishing, and deconstructing the buildings, are organised according to the modularity principle [6] (see Figure 1). To adapt this data source into a building LCA, we must multiply the environmental performance factors provided by the EPD by the material quantities of the product used in construction, using the same functional unit. This procedure of conducting a building LCA is proposed in the EN 15978 [6] standard regarding building LCA. The standard proposes that the building LCA results include the impacts generated by the construction products and processes that compose the building (included in the life-cycle inventory).

Currently, the demand for the implementation of building LCA in the design process is growing considerably, especially in the Green Building Rating Systems (GBRS) [12–14]. Under these systems, the use of construction products with EPDs to conduct a building LCA is compulsory to achieve different requirements and credits. For example, LEED v4.1 (Leadership in Energy and Environmental Design) [15] gives one point (credit) if at least 20 different permanently installed products sourced from at least five different manufacturers meet the criteria of having a publicly available LCA report (conforming to ISO 14044 [16] standard or specific construction products LCA standards). BREEAM international [17] gives at least one credit in LCA application if at least 20 points are achieved by using construction products with an EPD from the recognised EPD types which are grouped according to the material classification, as outlined in the methodology section of the manual at the design stage and installed by the post-construction stage. The Verde (España, 2020) [18] certification also assigns 23.5% of its credits to the Natural Resources

(RN) category, in which one of the indicators is the "Materials Impact Assessment" (RN11). This certification awards the use of EPD for 70 to 100% (of the total mass) of concrete, ceramics, gravel, and sand; for 20 to 40% (of the total mass) of other materials, excluding concrete, ceramics, gravel, and sand; and for materials used for the structure, insulation, and finishing. Furthermore, 50% of the EPDs should include a cradle-to-grave assessment following EN 15804 [10] and use locally manufactured products. It is also possible to achieve the RN7 indicator "Use of locally manufactured materials".

The European Framework for assessing building sustainability Level(s) also recommends using EPDs that include life-cycle modules in the LCA application as much as possible. Hence, there is currently a clear tendency towards increasing the use of construction product EPDs in building LCA, covering all the building systems and comprising a cradle-to-grave assessment. Božiček et al., (2021) [19] argue that although important gaps need to be filled, the EPD scheme is the most suitable means of providing building designers with relevant environmental data.

Therefore, the greater the number and variety of materials and building products with geographically representative EPDs, the more feasible and the easier it is to complete the LCA of a building in the design phase, to identify which construction products can help to reduce the building impacts and to achieve the LCA credits for sustainability certifications. Thus, one of the main advantages of having a greater number of EPD products is the possibility of using validated and representative data in a building LCA, as well as being able to compare and analyse EPD results and use the construction product that produces the lowest impacts. Moreover, reductions in transport distances due to the use of products from regional and local manufacturers can also reduce the embodied impacts of building products and materials [20]. These facts provide evidence of reliable, verifiable, and geographically representative information on the environmental performance of building products and materials. Hence, relevant aspects include the level of development of the EPD programmes and the number of regionally manufactured products with EPDs. Spain has a limited number of EPD products [21]; however, it does promote several strategies for building sector decarbonisation [22], highlighting the use of EPDs to conduct relevant LCA. Other countries that have in practice higher levels of development in buildings' carbon assessment (such as France [23] or Sweden [24]) have higher levels of development regarding the EPDs of construction products. For example, France has more than 3400 EPDs [21], and Germany more than 1200 [21]. Previous studies [21] provide evidence that the number of national EPD programmes is generally one per country (such as in Germany, Italy, etc.) The highest possible number of programmes per country s three: for example, two national programmes and an EPD International System.

Existing studies in the field have detected two limitations related to the market and the environmental data. The first one concerns the EPD market and derives from the costs and times of the certification process [25], which can limit access for all types/scales of manufacturing enterprises. The other relates to using environmental data (verified and validated) in a building LCA. Here, despite the growth of EPDs, several problems regarding the consistency and comparability of EPDs, as well as a lack of harmonization among the Product Category Rules (PCRs), have been underlined in the literature [26,27]. The product category rules establish requirements for developing an EPD for any construction product or service [28]. Even though several types of products have specific sector PCRs, such as window and doors [29], concrete [30], and thermal insulation [31], each specific EPD programme develops its own PCRs for EPD development [10], so inconsistency problems can be found [32]. Božiček et al., [19] underline that although the amount of research on the topic of EPDs for building products has grown, a lack of discussion regarding topics such as the harmonisation and quality of environmental data [25,33], LCA integration of design tools [34,35], the use of EPDs in building LCA [36,37], and gaps in the interpretation of results remain.

Additionally, there are still few types/categories of construction products with EPDs [7], which in several cases include incomplete information about the LCA modules [38].

Rangelov et al. [26] underline that one of the current limitations is that most EPDs are focused on the product stage. This can also be explained by the ISO 21930 [28] EPD definitions of upstream process, core process, and downstream process. It focuses on the "core process", i.e., those processes over which the manufacturer has greater control. Therefore, there are limitations on integrating other impacts such as transport (A4, C2) and waste treatment (C3), which are estimated or calculated using generic data. However, the newest versions of the standards EN 15804 [10] and ISO 21930 [28] encourage the integration of the end-of-life stage and benefits beyond the system information modules.

Existing studies [39] neither examinate the comparability of the different EPD programmes in Spain, nor analyse the factors that can limit them. To overcome this barrier, analyse the current status, and detect challenges to address in the EPD development in Spain, this study investigated the existing EPD programmes and compared the results from similar categories of construction products using Global Warming Potential (GWP) as an exemplary indicator, due to its relevance in achieving decarbonisation objectives [40].

Previous studies in this field have highlighted the opportunities to explore the comparability of and limitations involved in the use of EPDs to conduct complete and whole life-cycle building LCA with Spanish programme EPDs [39]. To overcome these knowledge gaps, the present study aimed to determine to what extend the use of Spanish programme construction product EPDs as a source of environmental data might be feasible in conducting a complete (comprising the building parts, elements, and materials) and whole life-cycle (comprising all the life-cycle stages) building LCA in Spain. Moreover, this paper proposes possible solutions to the problems and challenges detected.

The study sought to answer the following Research Questions (RQs):

- RQ1: Are the EPD results of similar construction products and different operator programmes comparable?
- RQ2: Can a complete building and a whole life-cycle LCA be conducted using Spanish construction product EPDs?

Firstly, the study aimed to detect the factors limiting the comparability of the EPDs developed by different EPD programmes. Thus, the analysis started by classifying the EPDs according to their certification programme and PCRs. Then, the construction product EPDs certified by more than one programme were detected. Based on those findings, the functional units and LCA modules included in the assessment and total results indicators were identified. The study also compared similar types of products, their functional units, system boundaries and LCA results. Secondly, the authors have focused on a case study analysis to detect to what extent it is possible to conduct a complete and whole life-cycle building assessment using Spanish construction product EPDs.

2. Materials and Methods

To fill the detected gaps in knowledge, the present study aimed to: (i) analyse the scope and characteristics of the existing, web-published construction product EPDs in Spanish programmes; (ii) identify the limitations in the comparability of the results; (iii) identify the limitations on conducting a complete and whole life-cycle LCA using the construction product EPDs in Spanish programmes as a data source based on a case study application; and (iv) detect the challenges, recommendations and remarks to be addressed in future developments.

The method followed four steps (Figure 2). The existing EPDs certified by the geographically representative EPD programmes in Spain were collected. The search included web-published EPDs valid at least until the end of 2021 from the three existing EPD programmes in Spain: the international EPD®system, the GlobalEPD from the Asociación Española de Normalización y Certificación (AENOR) and the DAPconstrucción, including products manufactured in Spain.

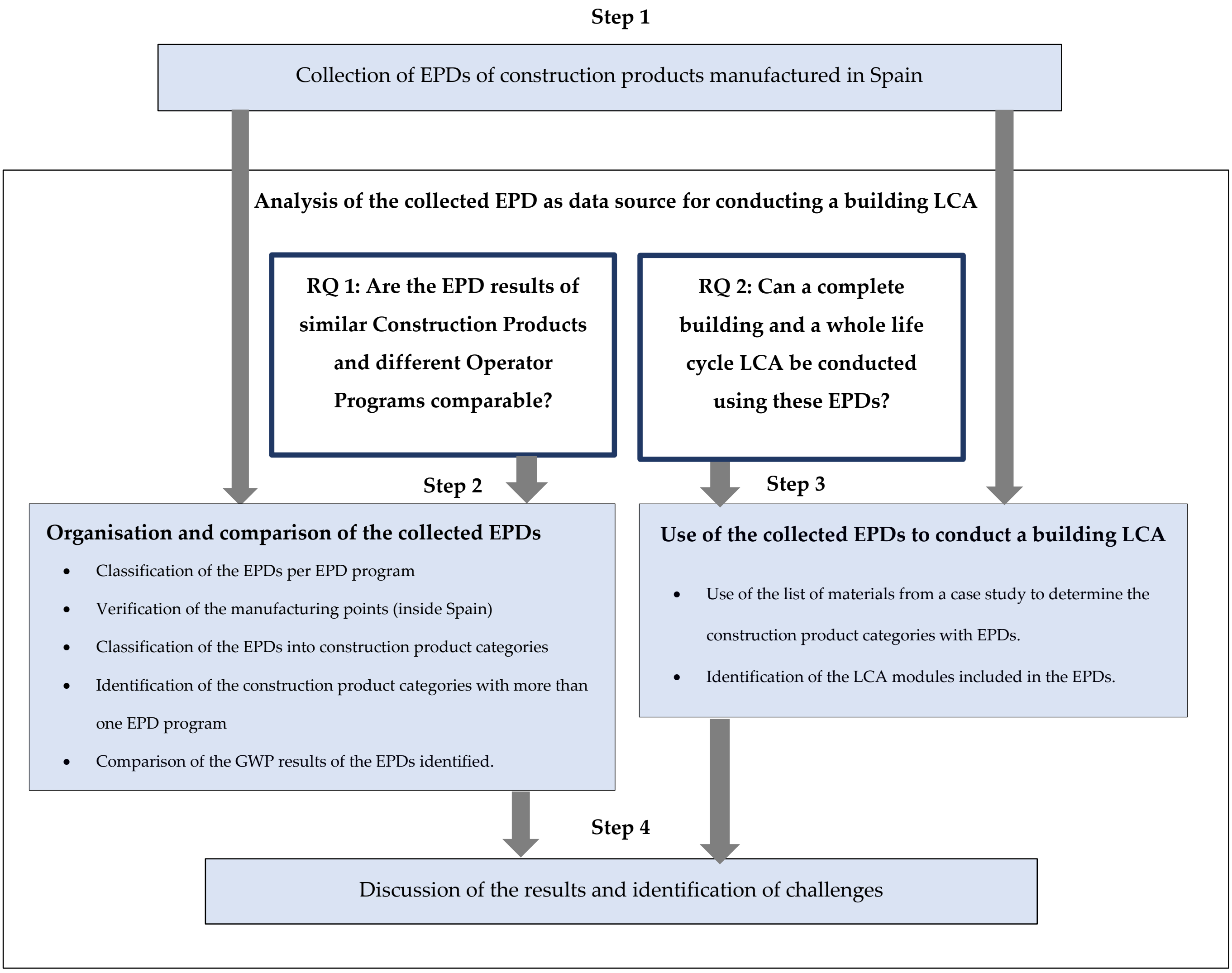

Figure 2. Scheme of the methodology developed in this study.

The following steps (Step 2 to 4) focused on analysing the collected EPDs as a data source to conduct a building LCA. Step 2 aimed to answer RQ1 and included sub-steps to prepare and organise the collected EPDs, and to verify the comparability of the EPD results of similar product categories and different EPD programmes. To complete the first objective, the steps followed included: (i) the classification of the EPDs per EPD programme, (ii) the verification of the manufacturing points declared in the EPD (if the construction product has been effectively manufactured in Spain), and (iii) the classification of the EPDs into construction product categories. To complete the second objective, the steps followed included: (iv) the identification of the construction product categories that have EPDs certified with more than one EPD programme, (v) the comparison of the GWP results of the selected EPDs using the same functional unit and system boundaries (life cycle information modules). The comparability study included the main aspects [26] that can be affected, such as the functional unit definition, the PCRs, the EPD programme, the LCA modules included and the data sources.

Step 3 aimed to answer RQ2 and consisted of using the list of materials from a case study to determinate the construction products manufactured in Spain with EPDs and the LCA modules that are included in those EPDs. This step identified how many products could be assessed using the collected EPDs and identified which LCA modules could be assessed using those EPDs, in order to analyse the potential use of geographically representative data to conduct a complete building and whole life-cycle LCA in Spain.

Step 4 discussed the results obtained and the existing challenges to be addressed.

Case Study Description

The case study was La María (Figure 3), a multi-family house located in Seville, Spain. The building was built by EMVISESA [41], a public enterprise dedicated to constructing public housing. The building´s total area is 2119 square meters, distributed across five levels (including the ground floor) and 16 apartments. The structure is mainly reinforced concrete, and the foundation is made of a concrete slab. The total number of construction products included in the analysis was 429, including the full list of materials used to obtain the cost estimations at the detail design stages. The complete list of materials is included in the Supplementary Materials.

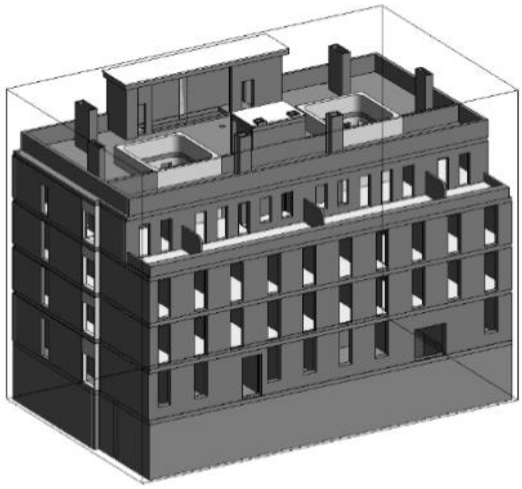

Figure 3. A 3D model of the building captured using Revit.

3. Results

The overview of the existing EPDs (Figure 4) shows that the most used EPD programme across a total number of 289 EPDs is EPD international (40%), followed by the national programmes GlobalEPD AENOR (33%) and DAPconstrucción (27%).

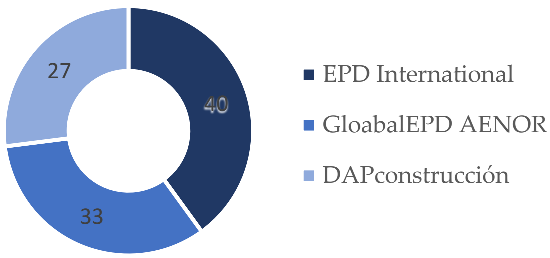

Figure 4. Existing EPD programmes.

The first step of the classification aimed to characterise the construction products and organise the existing EPDs into similar product categories or materials (e.g., wooden boards, metal profiles), with a focus on grouping those construction products that have a similar function in the building, e.g., thermal insulation or plasterboard. Appendix A Table A1 includes the complete list of collected EPDs and the construction product category defined for each. Appendix A Figure A1 includes a figure to illustrate the manufacturing locations of the construction products with EPDs, to provide evidence that products have effectively been manufactured in Spain. Appendix A Figure A1 also shows the dispersal of the manufacturing of construction products with EPDs across Spanish provinces. The region in which the highest number of construction products with EPDs have been fully or partially manufactured is Andalusia (23%), followed by Valencia (18%), Catalunya (12%), and Madrid (10%). Other regions, such as the Algarve (Portugal), can use the EPDs available from the Andalusia region. The figure provides evidence that the manufacturing process of the construction product is generally not focused in one province, and that there are sectorial EPDs that cover more than one province and region in Spain (17 EPDs).

The second step in the classification aimed to detect the most frequent construction product categories and the influence of the different EPD programmes on the comparability of the results. In Table 1, the grey-coloured rows show the product category, with different EPDs certified in more than one EPD programme. This group includes aluminium windows, cement, curtain wall system, metal profiles (structure and joinery), plasterboard, thermal insulation, tiles and waterproofing sheets and barriers. Table 1 shows that the product with the highest number of EPDs is plasterboard (22.49%), followed by cladding (14.53%), thermal insulation (12.8%) and tiles (6.23%).

Table 1. Product category classification, EPD programme and FU detection. Darker shades of blue indicate higher numbers of EPD, lighter shades lower numbers, grey coloured product categories indicate the ones with more than one EPD programme.

	Number	%	EPD®	AENOR	DAPConst	Functional Unit
Acoustic (sheet and membrane)	3	1.04	2		1	m^2
Acrylic adhesive	1	0.35			1	100 mL
Aluminium doors	2	0.69			2	m^2
Aluminium window	4	1.38	2		2	m^2
Asphalt	2	0.69	2			m^2
Cement	10	3.46		7	3	t
Cladding	42	14.53		42		m^2, t
Clay products	13	4.50		13		t
Copper rod	2	0.69	2			kg
Curtain wall system	3	1.04	1		2	m^2
Electronic lock	1	0.35	1			unit
Floor (access and finishing)	5	1.73	5			m^2, kg
Galvanised steel and glass joinery	1	0.35	1			m^2
Panel (wall and ceiling)	16	5.54	11		5	m^2, m^3, t
Gypsum-based product	2	0.69	2			kg
Long steel bars and construction products	13	4.50	2	11		t
Metal profiles (structure and joinery)	11	3.81	8	1	2	kg, t, mL, unit
Mortar	4	1.38	2		2	m^2
Pipes	2	0.69	2			t, kg
Plaster	1	0.35	1			kg
Plasterboard	65	22.49	37		28	m^2
Powder coating	2	0.69		2		m^2
PVC joinery	2	0.69		2		m^2
Quartz parts	1	0.35	1			t
Solar panels	1	0.35		1		m^2

Table 1. *Cont.*

	Number	%	EPD®	AENOR	DAPConst	Functional Unit	
Synthetic fabric blinds and rollers	1	0.35	1			m^2	
Synthetic polyester and PVC fabric	1	0.35	1			m^2	
Thermal insulation	37	12.80	30	4	3	m^2	
Tiles	18	6.23	4		14	m^2	m^3
Varnish	1	0.35	1			m^2	
Wall paint	4	1.38	4			m^2	
Waterproofing sheets and barriers	9	3.11	3	4	2	m^2	
Wood (laminated or boards)	7	2.42	7			m^3	m^2
Zinc sheets	2	0.69		2		kg	
Total Number of EPDs	289	100	133	89	67		

The results also show that different functional units have been considered in similar products, such as metal profiles or tiles. Generally (as in 22 of the 34 construction product categories), the functional unit used to conduct the construction product EPD is m^2. However, several cases, such as the metal profiles, use more than one functional unit (e.g., kg, t, ml, piece).

The results show that 55.71% of the construction product categories have EPDs in different EPD programmes, and the correlation between the EPD, PCR programme and the functional unit definition is not direct. This means similar product categories certified in different EPD programmes generally have the same functional unit (see Table 1).

To analyse the comparability of products with the same functional unit within the different EPD programmes, Table 2 compares impact results declared in the EPDs of aluminium windows, cement, curtain wall systems, reinforcing steel bars, metal profiles (structure and joinery), plasterboard, thermal insulation, tiles, waterproofing sheets, and barriers. The GWP results were compared, including the system boundaries of the LCA. The outcomes show that seven of the nine construction product categories include different module combinations in the LCA.

Table 2 shows that two of the seven product categories' EPDs in the LCA can be compared. This means that the LCA scope was equivalent to comparing total LCA results and the functional unit was the same for the compared products. This also demonstrates that the LCA module comparison is the most comprehensive strategy for comparing the LCA results of EPDs. Full details regarding the LCA results are included in the Appendix A (see Table A1). The "LCA module included" column refers to the LCA modules from which at least two EPDs have been compared and included in the report. The results show that production stage (A1–A3) is the most included (100%) in the LCA. However, the end-of-life stage is included in 89% of cases. The column "Complete comparability" indicates the feasibility of comparing the LCA results. It shows that only two product categories (cement and waterproofing) have the same FU and the same LCA modules: A1–A3 for cement and A1–A3, C2, and C4 for waterproofing sheets and barriers.

In contrast, Table 2 shows that three product categories have been excluded (one or two EPDs each) from the comparison due to differences in the functional unit. Reinforcing steel bars was the only product category to be excluded due to differences in the FU of the certification programmes. The DAPconst. EPDs used "mL" as the FU, while the other EPD programmes used "tonnes" as a unit of product. The median values for long steel bars (2181 kg CO_2 eq. 1 tonne FU) were the highest, while and the lowest were for plasterboard (3.81 kg CO_2 eq. per 1 m^2 FU).

Table 2. Overview of the product categories with EPDs in more than one EPD programme. Grey coloured rows indicate product categories with more than one EPD programme.

Product Category	Number of Existing EPD	Number of Compared EPD	EPD Programme	Complete Comparability (Yes/No)	Reason	FU Compared	Max. Value GWP ($kgCO_2eq.$)	Min Value GWP ($kgCO_2eq.$)	Media GWP ($kgCO_2eq.$)	Standard Deviation GWP ($kgCO_2eq.$)	Life-Cycle Modules Included
Aluminium window	4	3	EPD DAPconst.	Partial (excluding products)	Deference in the FU	m^2	1.11×10^2	1.06×10^2	1.27×10^2	1.73×10^1	A1–A3, C2, C3, C4; D
Cement	10	10	GlpobalEPD, DAPconst	Yes	-	tonne	1.15×10^3	4.17×10^2	7.34×10^2	2.54×10^2	A1–A3
Curtain wall	3	3	EPD Dapconst	Partial (by module)	LCA scope	m^2	1.38×10^2	6.70×10^1	1.52×10^2	6.28×10^1	A1–A3, C2, C3, C4, D
Reinforcing steel bars and construction products	18	16	AENOR EPD int. DAPconst.	Partial (excluding products and by module)	Deference in the FU LCA scope	tonne	6.00×10^3	5.33×10^2	2.18×10^3	1.75×10^3	A1–A3, A4, A5, C2, C4, D
Metal profiles	6	6	GlpobalEPD, EPD programme	Partial (by module)	LCA scope	kg	1.01×10^1	2.83×10^0	6.54×10^0	2.97×10^0	A1–A3
Plasterboard	64	64	EPD DAPconst	Partial (by module)	LCA scope	m^2	3.50×10^1	1.17×10^0	3.81×10^0	5.89×10^0	A1–A3, C2, C3, C4, D
Thermal Insulation	35	35	AENOR EPD int. DAPconst. Indep.	Partial (by module)	LCA scope	m^2	2.31×10^2	5.60×10^{-1}	1.42×10^1	4.46×10^1	A1–A3, C2, C3, C4, D
Tiles	17	16	EPD Inter. DAPconst	Partial (excluding products and by module)	Deference in the FU LCA scope	m^2	7.690×10^1	1.103×10^1	2.59×10^1	2.51×10^1	A1–A3, B2, C2, C3, C4, D
Waterproofing	9	9	GlobalEPD, EPD programme DAPconst	Yes	-	m^2	1.91×10^1	6.54×10^{-1}	5.16×10^0	5.10×10^0	A1–A3, C2, C4

In order to provide a more in-depth analysis of the result comparability and fair comparison of EPDs for similar product categories, Figures 5–8 show the results for the A1–A3 modules, which were included in all the EPDs and generally provided the highest information module values. The results show that the variation is not directly related to the EPD programme differences. For example, the results for cement are similar regardless of the EPD programme. On the other hand, the results for the thermal insulation product category show atypic values for EPD within the same EPD programme.

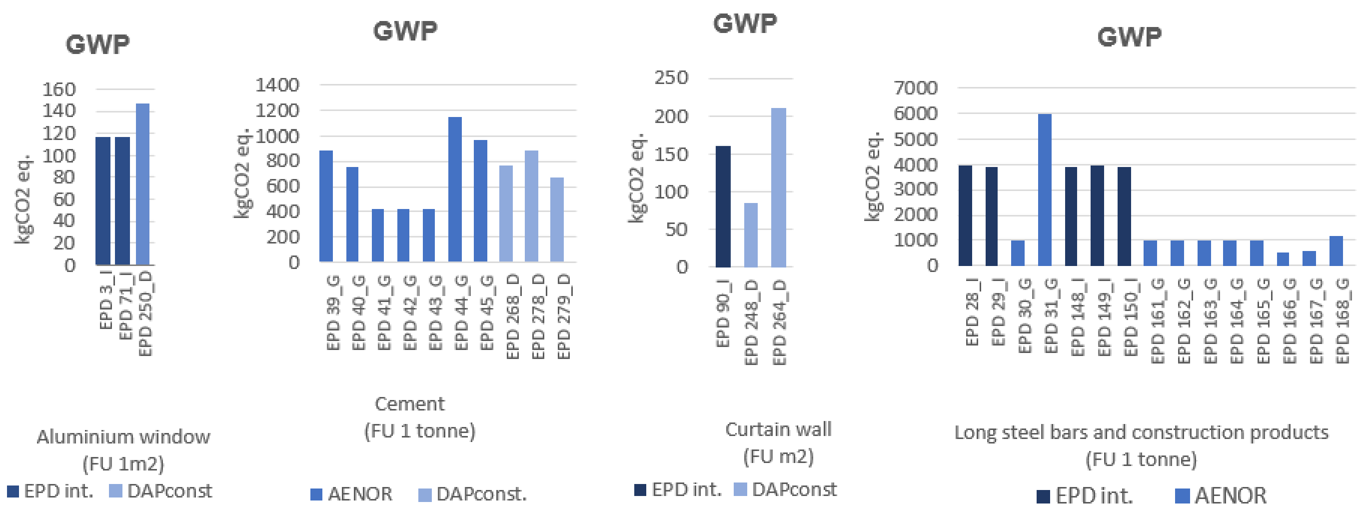

Figure 5. Comparison of GWP results for A1–A3 stages for the following product categories: aluminium window, cement, curtain wall system, and long steel bars and construction products.

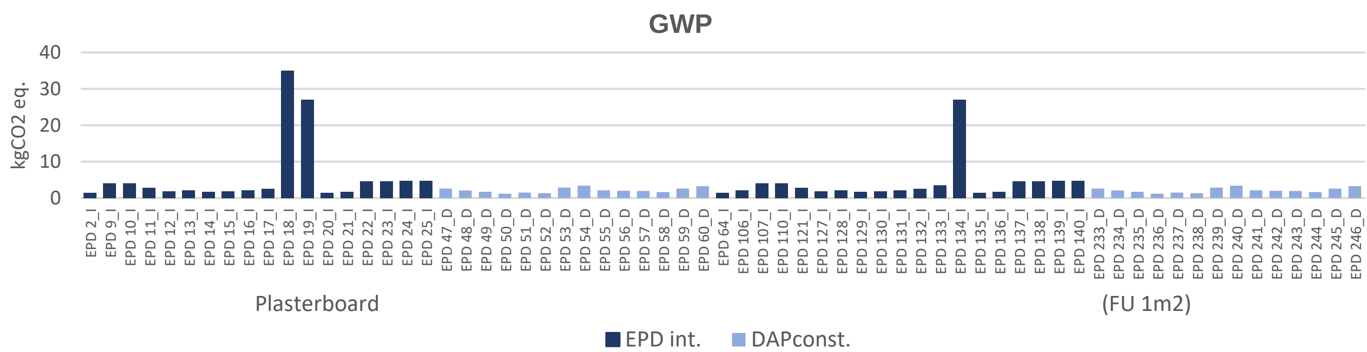

Figure 6. Comparison of GWP results for A1–A3 stages for the product category of plasterboard.

The unexpected variations in thermal insulation, tiles, and waterproofing sheets and vapour barriers are probably related to the product's specific characteristics (Figures 7 and 8). Even though they can perform the same function (e.g., finishing, thermal insulation), they may have other specific characteristics that make them suitable for certain cases, e.g., thermal insulation for cold rooms. For tiles, the variation could be related to energy and fossil fuel consumption. In this case, the product specifications are relevant in product selection. Thus, to compare similar product categories in the design process, other technical specifications should be included (e.g., thermal conductivity, thickness).

Case Study's Use of EPDs

The present study focused on a case study analysis, using geographically representative EPDs of construction product EPDs available in Spain to conduct complete and whole life-cycle building LCA. The results show that only 20% of the construction products (including 19 construction product categories) could potentially be assessed using an EPD (see Figure 9). Table S1 (Supplementary Materials) shows the complete list of the construction materials included in the study and the list of construction product categories with EPDs that can be used in the building LCA.

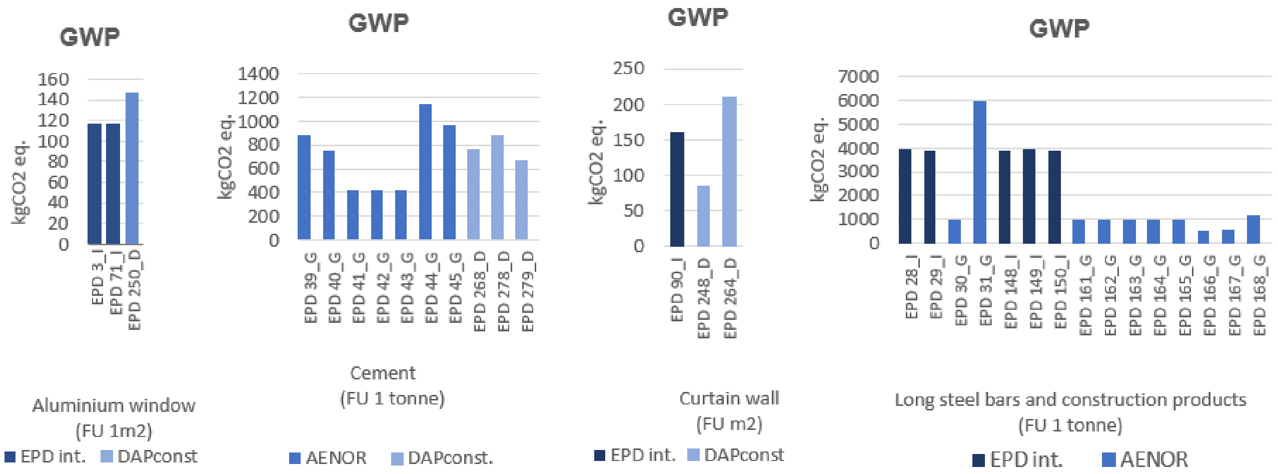

Figure 7. Comparison of GWP for A1–A3 stages for the following product categories: metal profiles, tiles, and waterproofing sheets and vapour barriers.

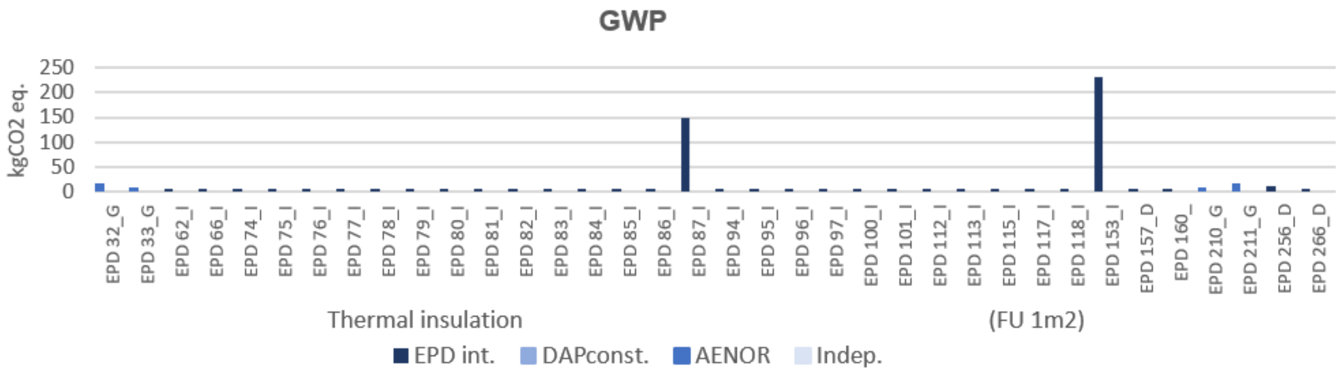

Figure 8. Comparison of GWP for A1–A3 stages for the product category of thermal insulations.

Figure 9 shows the number of products in the case study with EPDs and summarises the type of product categories with and without locally representative EPDs. These products mostly consisted of those used in the envelope and finishing systems, such as plasterboard, thermal insulation, cladding and tiles, among others. The construction product categories that had the lowest number of locally representative EPDs were the building products, such as sewerage pipes, cups, and electrical systems. These results provide evidence of the limited variety of products available for conducting an LCA with locally representative EPDs in Spain.

Considering a system boundary analysis of the locally representative EPDs, Table 3 shows that the life cycle modules included in the EPDs are heterogeneous and generally depend on the type of product included in the assessment. For example, the use stage is included in products related to the finishing system, such as tiles or cladding. The light grey-coloured areas in the table denote the product categories with differences in the LCA modules included in their EPDs, while the dark grey areas included the same LCA modules. It is also evident that around 80% of the product categories included some of the end-of-life modules, while 70% included A4, A5 and D, which, apart from A1–A3, were the most frequently included in the compared EPDs.

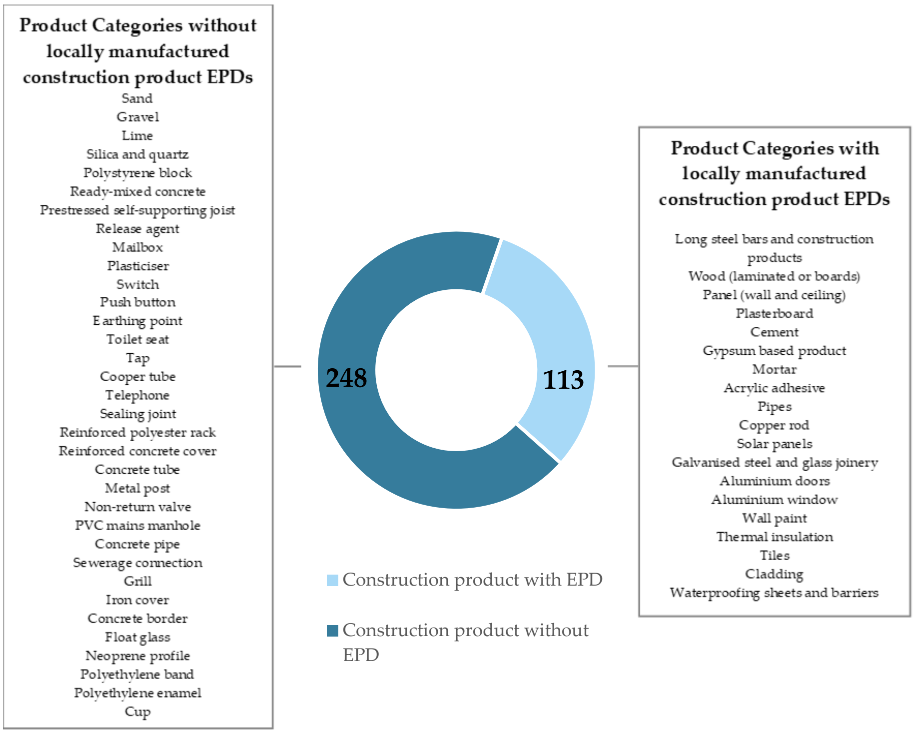

Figure 9. Type and number of products that can be assessed with EPDs in Spanish programmes.

Table 3. Construction product categories included in the case study and the LCA modules integration analysis. Dark grey coloured rows indicate product categories with the same LCA modules included, light grey coloured rows indicate product categories with the different LCA modules included.

Product Categories	Number of EPDs	Life-Cycle Modules According to EN 15804												
		A1–A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Long steel bars and construction products	18	■	■	■						■	■	■	■	■
Wood (laminated or boards)	7	■								■	■	■	■	■
Panel (wall and ceiling)	17	■	■	■		■				■	■	■	■	■
Plasterboard	66	■	■	■						■	■	■	■	■
Cement	10	■												
Gypsum-based product	2	■	■	■	■	■	■	■	■	■	■	■	■	
Mortar	4	■	■	■	■			■		■		■	■	■
Acrylic adhesive	1	■												
Pipes	2	■	■	■						■		■	■	■
Copper rod	2	■												
Solar panels	1	■												
Galvanised steel and glass joinery	1	■	■	■						■	■	■	■	■
Aluminium doors	2	■	■	■		■	■			■	■	■	■	■
Aluminium window	2	■	■	■		■	■			■	■	■	■	■
Wall paint	4	■	■	■						■		■	■	■
Thermal insulation	39	■	■	■			■			■	■	■	■	■
Tile	18	■	■	■		■				■	■	■	■	■
Cladding	44	■	■	■		■				■	■	■	■	■
Waterproofing sheet and barrier	9	■									■	■	■	

4. Discussion

4.1. RQ1: Are the EPD Results of Similar Construction Products and Different Operator Programmes Comparable?

Currently, in Spain, there are three EPD programmes focused on construction product certification, which can be beneficial to increasing the use of EPDs to conduct building LCA. However, differences in the methodological approach (e.g., differences in the functional unit definition, lack of homogeneity of the PCRs) can limit the product comparability and, consequently, the impact results [7,26,27]. The product comparability study for the construction products categories focused on the different PCR programmes and showed that the most frequent factor limiting the comparability was the differences in the LCA modules included in the assessment, which can make the results unsuitable for comparison. The results obtained in Table 2 show that the LCA modules included in the EPDs were not the same for similar construction product categories. Other studies have also detected this tendency [7,32]. Thus, a reliable and consistent EPD comparison should consider the LCA results by information modules and not only the total results. Results show that seven of the thirty-four construction product categories used different functional units. Certain cases included similar products (e.g., wood (laminated or boards), pipes, floor, or cladding) certified by the same EPD programme, which was another detected limitation on the product comparability.

In Table 2 and Figures 5–8, the study provided evidence that the atypical variation of the result is not directly related to differences in the EPD programmes. Conversely, the existence of different EPD programmes for Spanish locally manufactured construction products is not a general limitation.

Apart from this, the results confirm that the EPD comparability for similar product categories could also be influenced by the specific product characteristics related to the technical specifications, as shown in Figures 5–8. Moreover, other aspects such as differences in production technology, energy mix, transport modelling and end-of-life scenario definitions could affect EPD results, as also seen in similar studies [7].

4.2. RQ2: Can a Complete Building and Whole Life-Cycle LCA Be Conducted Using the EPDs of Construction Products Manufactured in Spain?

Regarding the possibility of using specific data from locally manufactured construction products to cover the building elements that compose the building, the results in Figure 9 and Table 3 provide evidence of the expected (limited) scenario. The product classification shows that the range of products is mostly limited to the envelope and the finishing systems, and the feasibility of conducting a building LCA based on EPDs is still limited, as previously demonstrated by Rosario et al. [7]. Depending on the size, typology and building programme, the number of construction products that are needed to conduct a whole-building LCA could be around 400 [42]. However, the number of EPDs not only reflects the number of construction products with EPDs but also the possibility of comparing different construction products to optimise the building LCA results.

The results in Tables 2 and 3 highlight differences in the scope of the LCA stages considered in the construction products. This could be due to differences in the assumptions used to define the LCA scenarios, depending on the product categories and the product manufacturers' uncertainties. For example, cement is a product that can be used in a wide variety of construction products and building elements (e.g., cement mortar, concrete beam) that may form different use and end-of-life scenarios. Nevertheless, other products such as tiles, generally used in building for a specific function (finishing), have been included use (B2) and end-of-life (C2, C3, C4) modules, in certain EPDs. This could be a beneficial consequence of the newest version of the standard EN 15804 [10] which encourages the integration of these stages.

Thus, it is necessary to distinguish between materials and construction (specific) products, as this can influence the possibility of conducting a whole life-cycle assessment using EPDs as a data source. These two types of EPDs also influence how the EPD results are used in the building LCA. The results show that the EPDs of product categories such as the cement, metal profile, wood, and panels cannot be directly used to assess a building element, considering, for example, the data structure usually used to organise a building life-cycle inventory, better described by Soust-Verdaguer et al. [43,44]. Hence, in order to use these EPD results, a rigorous quantification of the construction material following the product specifications and adapting it to the functional unit of the building element, should be conducted.

4.3. Barriers and Challenges to Be Addressed

Considering the aspects mentioned above, the most important challenges that need to be addressed are related to the expansion of the range of construction products with EPDs, which is also a problem related to the market characteristics and the limited voluntary requirement of conducting a complete building LCA in Spain.

Another detected challenge is related to the data granularity, and the use and the communication format of the information included in the EPDs for digitalization in the AECO (Architecture, Engineering, Construction and Operation) industry, an issue that is starting to be considered in the recently published ISO 22057 [45] standard. In practice, there are still difficulties in using information automatically. The existing web pages are focused on the EPD as a certification (document) and not as an environmental data source. Indeed, the documents analysed in this study were in PDF format, and only the EPD international programme has limited machine-readable formats on its web page. National initiatives such as OpenDAP [46] are working towards the digitalization of the EPDs of construction products manufactured in Spain. The national programmes DAPconstrucción and GlobalEPD (AENOR), which are mostly focused on the national context, do not include a machine-readable format in their webpages, and the results are published in Spanish. These EPD programmes seem to focus on frequently used construction materials in this given context.

Regarding the diversity in the product categories detected in the results, it was found that in several cases the information included in the EPDs can be associated with an object or building element (e.g., tile, aluminium window). However, in other cases (e.g., aluminium profile, cement), the information needs to be edited (e.g., calculating the aluminium needed for a window in kilograms of material). Hence, considering the existing challenge of digitalization [47], EPD comparability and the growing integration of LCA in the design process and in digital tools (such as BIM [48,49]), functional unit harmonization becomes crucial. This means that special attention should be paid to using the same units and data aggregation to assess similar types of products. To avoid extra effort and unexpected errors in the material quantity take-offs required to conduct the LCI, the material quantity take-off unit in the BIM model should be the same as in the EPDs. In this respect, a possible solution could be to develop shortcuts to assist the use of EPDs of materials such as aluminium profiles or cement, which should be edited and adapted to be used in a building element (e.g., window) or material (e.g., concrete slab) assessment. If this is not feasible, a possible equivalence or conversion should be included to enable practical use of the information in the BIM models.

Another detected challenge was the treatment of the information related to transport impacts and the manufacturing points of construction products. It should be noted that this information (included in Appendix A Figure A1) was not easily detected in the EPDs, and none of the reports included used geographic coordinates or other systems to provide this data. The digitalization of the manufacturing points of construction products, which necessitates the use of geolocation systems (such as GIS), can facilitate the digitalization process of the localization of the manufacturing point and the logistic chain to model the transport impact. It enables comparability of the transport distances in the EPDs as a material selection criterion. This has been addressed in other studies [50]. Thus, further effort should be made to integrate information on geographical coordinates, an issue that is still not addressed in the ISO 22057 [45] data template for integrating EPDs in BIM objects.

4.4. Limitations of the Present Study

The limitations of the present study are related to the time scope of the analysis, which was limited to a given period that can vary. The detected tendencies, challenges, and recommendations are proposed to improve the future development of these construction product certifications.

Another detected limitation is the system boundaries analysis of the EPDs based on a case study. Further development can be focused on verifying these aspects using a larger number of case studies and conducting studies in other countries to evaluate the feasibility of exploiting locally representative EPDs in building LCA.

5. Conclusions

The growing requirement of building LCA in current practice demands an increase in the development of construction product EPDs in different regions and countries. The benefits of using regionally manufactured construction products with EPDs include the availability of geographically representative environmental data used to conduct a building LCA and the potential reduction in transport impacts. This can contribute to obtaining environmental impact results that better match real scenarios (e.g., national energy mix) and optimizing the construction product logistic chain. Thus, the study of the existing EPDs of construction products manufactured in Spain, focused on analysing the comparability and feasibility of using this data source to conduct a complete building and whole life-cycle LCA, revealed that existing limitations derive from diversity in the function of materials and products, and differences in the definition of the life-cycle scenarios (e.g. a product, such as the cement, that can be used in different building elements with different reference service life).

Therefore, future work should focus on improving EPD comparability and facilitate EPD integration in the LCA application as well as the building design process, in order to harmonise the PCRs of similar product categories, especially the functional units and the life-cycle scenarios, and to promote the development of EPD products ready to use in the building LCI. This means defining the product FU considering the units used to conduct the building life-cycle inventory and the automatic material quantity take-off from the design tools (e.g., in BIM), and promoting the development of EPDs that cover products from the installations and building services, such as machinery, which present a high level of complexity in LCA and are generally removed from LCA if no representative data is available.

Finally, the next steps recommended include focusing on consolidating the use of EPDs as a source of data for LCA. Thus, it should be highlighted that in Spain, future action to increase the development of comparable, verified, and validated data sources to conduct a complete and whole life-cycle building LCA should be supported by all the stakeholders involved, including user-clients, architects, constructors, and policymakers, and not only those relegated to voluntary application in GBRS.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15021284/s1, Table S1. List of the construction materials and construction material categories included in the study.

Author Contributions: Conceptualization, B.S.-V., E.P., C.L., E.H. and A.P.; Methodology, B.S.-V., E.P., C.L., E.H. and A.P.; Software, B.S.-V.; Validation, E.P., C.L., Á.V.A., M.D.F.G. and E.H.; Formal analysis, B.S.-V., E.P., Á.V.A., M.D.F.G. and E.H.; Investigation, B.S.-V., Á.V.A., M.D.F.G., E.H. and A.P.; Resources, Á.V.A. and M.D.F.G.; Data curation, E.P., C.L., Á.V.A., M.D.F.G., E.H. and A.P.; Writing—original draft, B.S.-V.; Writing—review & editing, B.S.-V., C.L., E.H. and A.P.; Visualization, B.S.-V. and E.P.; Supervision, C.L.; Project administration, C.L.; Funding acquisition, C.L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

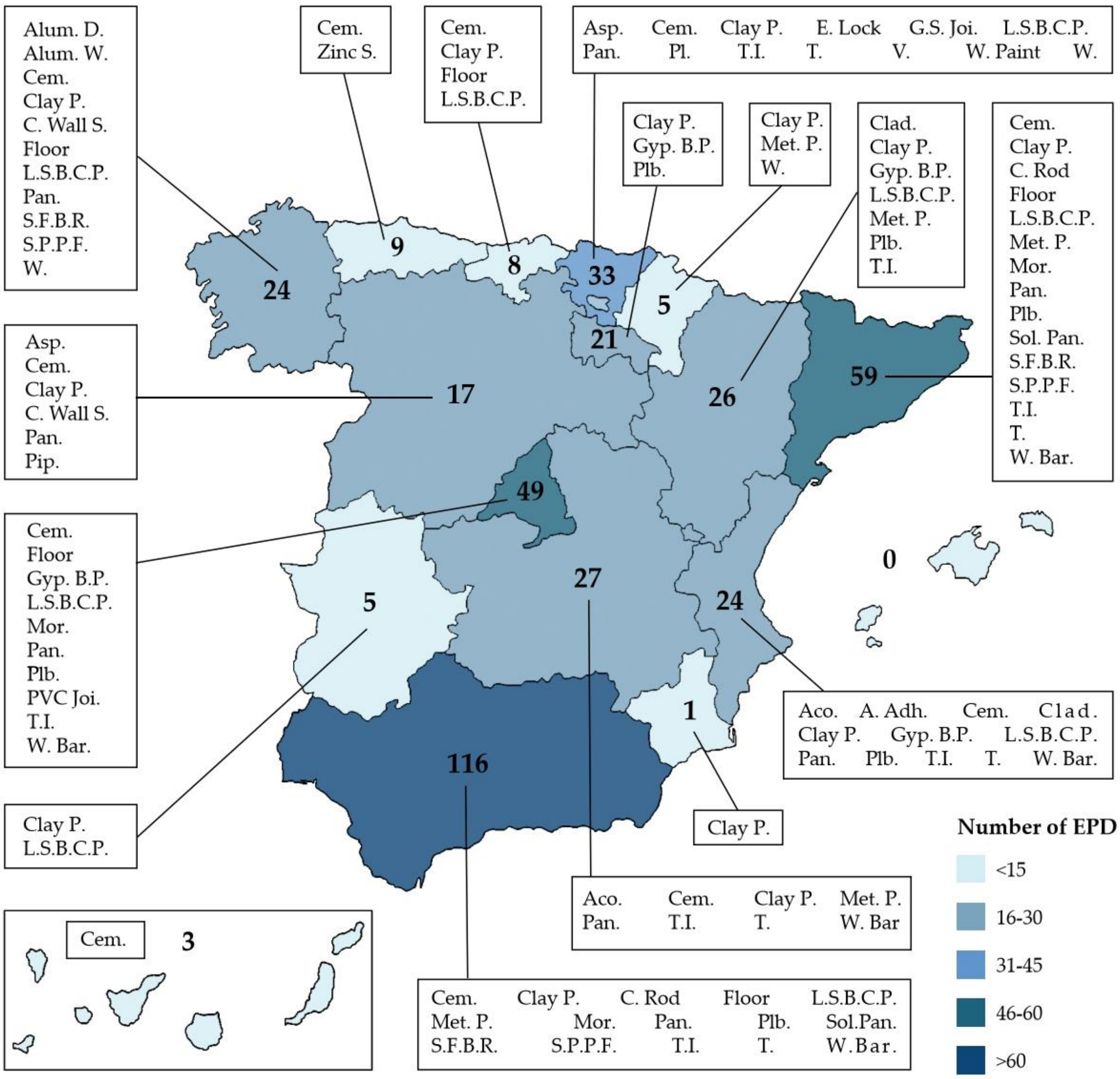
Appendix A

Table A1. List of EPDs included in the study. Blue coloured rows indicate product categories with more than one EPD programme. Darker shades of green indicate higher numbers of EPD, yellow shades moderate numbers and red shades lower number.

	Number	%	EPD®	AENOR	DAPConst	PCR	Functional Unit
Acoustic (sheet and membrane)	3	1.04	2		1	PCR 2012:01-SUB-PCR-C Acoustical System Solutions V2.2. RCP 100 v 2 PCR 2012:01 v 2.3.3	m^2
Acrylic adhesive	1	0.35			1	RCP 100. v.2	100 mL
Aluminium doors	2	0.69			2	RCP 100 v. 2 RCP 100 NCPR 014 Windows and doors	m^2
Aluminium window	4	1.38	2		2	PCR 2019:14 v 1.0 RCP 100 NCPR 014 Windows and doors. PCR-007 EN 17213:2020 [29]	m^2
Asphalt	2	0.69	2			PCR 2018:04 Asphalt mixture, v 1.02	m^2
Cement	10	3.46		7	3	RCP-003 AENOR GlobalEPD. EN 15804:2012 [10] RCP 100. v 2	t
Cladding	42	14.53		42		RCP 002 GlobalEPD EN15804-001 EN 15804:2012+A1:2013 [10]	m^2 t
Clay products	13	4.50		13		RCP 008	t
Copper rod	2	0.69	2			PCR 2012:01 v2.3.1	kg
Curtain wall system	3	1.04	1		2	PCR 2012:01, v 2.2 RCP 100 v 2	m^2
Electronic lock	1	0.35	1			EN 15804[10] ISO 14025 [9]	piece
Floor (access and finishing)	5	1.73	5			PCR 2019:14 v 1.0 PCR 2012:01, v 2.2 PCR 2012:01, v 2.3 Sub-PCR-F Resilient, textile and laminate floor coverings	m^2 kg
Galvanised steel and glass joinery	1	0.35	1			PCR 2019:14, v 1.1	m^2
Panel (wall and ceiling)	16	5.54	11		5	PCR 2019:14 v 1.0 PCR 2012:01 v 2.3 PCR 2012:01 v 2.1 RCP 100. v 2 Sub-PCR. Wood and wood-based products for use in construction PCR 2012:01 v 2.2 EN 16757 [30]	m^2 m^3 t

Table A1. *Cont.*

	Number	%	EPD®	AENOR	DAPConst	PCR	Functional Unit
Gypsum-based product	2	0.69	2			PCR 2012:01, v 2.3	kg
Long steel bars and construction products	13	4.50	2	11		UNE-EN 15804:2012+A1:2014 [10] UNE 36904-1:2018 [51] PCR 2019:14, v 1.0	t
Metal Profiles (structure and joinery)	11	3.81	8	1	2	EN 15804:2012+A1:2014 [10] PCR 2012:01 v. 2.3 PCR 2019:14, v 1.0. RCP 100. v. 2 PCR 2019:14, v 1.0.	kg t mL piece
Mortar	4	1.38	2		2	PCR 2012:01 v. 2.3 Sub-PCR-A Mortars applied to a surface	m^2
Pipes	2	0.69	2			PCR 2019:14, v 1.0 PCR 2012:01, v 2.3	t kg
Plaster	1	0.35	1			PCR 2012:01, v 2.2	kg
Plasterboard	65	22.49	37		28	PCR 2012:01, v 2.32 UNE-EN 15804:2012+A1:2014 [10] RCP 100. v. 2	m^2
Powder coating	2	0.69		2		RCP 002	m^2
PVC joinery	2	0.69		2		GlobalEPD EN15804-004 EN 15804:2012+A1:2013 GlobalEPD EN15804-005 UNE-EN 17213:2020 [29]	m^2
Quartz parts	1	0.35	1			PCR 2012:01, v 2.3	t
Solar panels	1	0.35		1		EN 15804:2012+A1:2014 [10]	m^2
Synthetic fabric blinds and rollers	1	0.35	1			PCR 2012:01, v 2.1	m^2
Synthetic polyester and PVC fabric	1	0.35	1			PCR 2012:01, V 2.3	m^2
Thermal insulation	37	12.80	30	4	3	PCR 2019:14 v 1.1 PCR 2012:01, v 2.3. Sub-PCR-I Thermal insulation products EN 16783 [31] GlobalEPD-RCP-007 PCR 001, v.2	m^2
Tile	18	6.23	4		14	RCP 002 v.2 PCR 2012:01 v 2.2. SUB-PCR-D Bricks, blocks, tiles... PCR 2012:01, v 2.1 PCR 100 v.2 UNE-EN 17160 [52]	m^2 m^3
Varnish	1	0.35	1			PCR 2019:14, v 1.1	m^2
Wall paint	4	1.38	4			PCR 2019:14, v 1.1 PCR 2019: 14 v 1.1.	m^2
Waterproofing sheet and barrier	9	3.11	3	4	2	RCP 100.v 2 Flexible sheets for waterproofing bitumen . . . , v 1.0 PCR 2012:01, v 2.2 PCR 2012:01 v 2.3 PCR 2019:14 v 1.11. GlobalEPD EN15804-011 EN 15804:2012+A1:2013 [10] RCP 100. V 2	m^2
Wood (laminated or boards)	7	2,.42	7			PCR 2012:01 v. 2.3 EN 16485 [53] PCR 2019:14, v 1.11 PCR 2012:01	m^3 m^2
Zinc sheets	2	0.69		2		GlobalEPD EN 15804-009 EN 15804:2012+A1:2013 [10]	kg
		289	133	89	67		
Total Number of EPDs			289				



References
Construction Product EPD

Aco.	Acoustic (sheet and memembrane)	Mor.	Mortar
A. Adh.	Acrylic adhesive	Pan.	Panel (wall and ceiling)
Alum. D.	Aluminium doors	Pip.	Pipes
Alum. W.	Aluminium window	Pl.	Plaster
Asp.	Asphalt	Plb.	Plasterboard
Cem.	Cement	PVC Joi.	PVC joinery
Clad.	Clading	Sol. Pan.	Solar panels
Clay P.	Clay products	S.F.B.R.	Synthetic fabric blinds and rollers
C. Rod	Copper rod	S.P.P.F.	Synthetic polyester and PVC fabric
C. Wall S.	Curtain wall system	T.I.	Thermal insulation
E. Lock	Electronic lock	T.	Tile
Floor	Floor (access and finishing)	V.	Varnish
G.S. Joi.	Galvanised steel and glass joinery	W. Paint	Wall Paint
Gyp. B.P.	Gypsum based product	W. Bar.	Waterproofing sheet and barrier
L.S.B.C.P.	Long steel bars and construction products	W.	Wood (laminated or boards)
Met. P.	Metal Profiles (structure and joinery)	Zinc S.	Zinc sheets

Figure A1. Location of the manufacturers and the occurrence of construction product EPDs in Spain.

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