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Development of a new environmental scoring methodology for building products, a French case study

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Abstract. The building sector consumes about one-third of total final energy and contributes to 38% of greenhouse gas (GHG) emissions around the world. Thus, the EU has established a set of directives that includes the EPBD and the EED to achieve carbon neutrality by 2050. Hence, France adopted more challenging legislation by introducing the new environmental regulation RE2020. Among other measures, the RE2020 allocates a carbon budget to new housings starting from 2022. As a consequence, it promotes the use of materials and products that have a lower environmental impact. In this low carbon material competition, one of the challenges is related to the comparability of environmental product declarations (EPDs) and the lack of harmonization in terms of functional units and lifespan. Also, EPDs have multiple impact categories that make the decision-making process complex. In this context, the objective of this research is to develop a new environmental scoring methodology for building products based on their life cycle assessment. The methodology has been applied to two product families: windows and insulation as case studies thanks to the French EPD database called INIES.

Keywords: construction product, LCA, sustainability assessment

1. Introduction

Global climate change is one of the biggest environmental challenges of our time. Numerous signs confirm global warming such as rising sea levels and temperatures and more extreme weather events. Climate change is caused primarily by the excess release of Greenhouse Gases (GHG) that absorb infrared radiation and trap heat in the atmosphere. Multiple gases contribute to the greenhouse effect. The most impactful are among others carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4). Thus, 192 countries committed in Paris in December 2015, to mitigate their GHG and limit global warming below +2°C by the end of the century, and ideally below +1.5°C.

The building sector is a major contributor to climate change. Buildings are responsible for 38% of CO2 emissions in the world. Within this proportion, 10% are related to buildings construction industry (manufacturing building construction materials), 17% to residential buildings and 11% to non-residential buildings[1]. In this context, France adopted more challenging regulation by introducing the new environmental RE2020 that allocates a carbon budget to new housings starting from 2022 considering the overall environmental impact of buildings throughout their four life cycle stages. Among other measures, this promotes the use of materials and products that have a lower environmental impact.

The Life Cycle Assessment (LCA) methodology is widely used to quantify the environmental impacts of products, services or processes according to international standards ISO 14040 (principles and framework) and ISO 14044 (requirements and guidelines). This methodology is used to produce Environmental Product Declarations (EPD), standardized documents that communicate the environmental impacts of a product or system during its entire life cycle. At the European level, EPDs for construction materials are produced in compliance with the EN 15804 standard. All results communicated on an EPD document are obtained per functional unit. Thus, to be comparable, two EPDs must be based on the same functional unit and the same Product Category Rules (PCR). PCRs determine for a product family, the LCA calculation rules, such as allocation rules, data collection, system boundaries, environmental indicators, and the format in which the data should be presented.

It should be noted that two EPDs can have different functional units because some products categories rules provide guidance on how to define a functional unit but do not imply the use of a unique lifespan or main performance. In addition, to this complexity of comparing, EPDs have multiple impact categories that make the decision-making process complex. Designers and specifiers are increasingly highlighting the need for methodological guidance to compare EPDs and interpret their results.

Within this context, this paper presents a new methodology that allows comparative analysis of different EPDs. The proposed approach was applied to the INIES EPD database (France) as a comprehensive case study. The following chapters present first the state of the art about building and product performance rating methods. Second, the methodology developed within the scope of this research later applied to a case study. Finally, we present the principal findings, limitations and future research possibilities.

2. **Literature review**

This section provides an overview of previous research focusing on different rating methodologies at national and international levels. Thus, a review of different scoring methods at building and products scales is presented.

2.1. Building products and green certification schemes

Due to the impact of the construction industry on the environment, several green building rating methods have been developed over the last 30 years to promote sustainability within the built environment and facilitate design choices. Among others, BREEAM (UK), LEED (US) and NF HQE (France) are sustainable building certifications that are based on different assessment attributes, processes and scoring methods. The Building Research Establishment (BRE) developed a first version of BREEAM certification [2] in 1990. The building quality is evaluated based on nine categories and an additional one (innovation) e.g.: management, materials, energy, pollution health & well-being and waste. Each category is divided into several criteria with a maximum credit achievable. Thus, a percentage of achieved credits is calculated for each category. The overall score of the building is given by aggregating all the degrees of fulfilment achieved [3] [4].

Like BREEAM, the LEED rating system is based on different categories with corresponding weights according to their importance. This rating system was developed in the United States in 1998 by the Green Building Council. Points are given for the fulfilment of individual criteria within each category. The overall points score is obtained using a weighting method [5].

All the above-mentioned certifications consider the category ‘materials’ to evaluate the environmental performance of a building. Each rating method assigns a different weight for the environmental performance of materials. The weights defined by BREEAM and LEED are respectively 12.5% and 13%, coming after energy and site [6]. Previous studies (Berardi, 2012) show that assessed building in the scope of LEED reached only 40% of the available points in average in the category of materials which is not very significant. Hence, having scoring methods addressed to materials scale might allow to better optimize the environmental impact related to materials and products within the built environment.

2.2. Rating methods for environmental performance comparison of products and materials

The development of environmental rating methods addressed to materials scale might allow to better highlight and optimize the environmental impact related to materials and products within the built environment. Having rating tools at building and materials scales simultaneously will encourage a more inclusive approach in sustainability analysis. Otherwise, during environmental building design, designers are forced to perform a complex comparison between different construction solutions [7]. The lack of a simple tool makes the design or optimization work more complex [8] [9] [10] [11] [12].

Several scoring initiatives have been developed for products and materials in recent years with different purposes and methodologies. Among them, one can cite the Eco-score which has been developed in France to compare the environmental impact of agricultural and food products [13]. Based on the results of the LCA available from the database of French agriculture products developed by ADEME and INRAE in 2009. The score of a product is obtained by normalizing and weighting 16 environmental impacts eg. climate change, ozone depletion, eutrophication and acidification. This gives a score expressed in points per 100g of finished products. A letter of performance is then attributed to products after converting values on a scale from 0 to 100. It classifies products into 5 categories (A, B, C, D, E) where A represents the lowest impact.

In the field of construction, the BRE the Building Research Establishment (BRE) proposes a comparison indicator for building materials and components [14]. This indicator is calculated based on the environmental profiles established by BRE. The comparison of construction products using the environmental profiles has only been done for a building-wide use, using a functional unit of an installed element in a specific scenario. Thus, the Environmental Profiles (UK) were established corresponding to the functional unit "Per element installed over a 60-year study period in the building (cradle to grave)". The environmental class of a product is obtained by weighting 13 impact categories from an LCA. The most important weight is given to climate change with 21.6% followed by water extraction with 11.7%. Finally, the overall score is expressed in the form of bands ranging from A+ (best choice) to E (to be avoided) by using an equidistance discretization. In this case, the distance between the performance classes is constant. The bandwidth is calculated by dividing the range of normalized impacts values by the desired number of classes as follow:

$$(Ecopoint_{maximum} - Ecopoint_{minimum})/_{6} \quad (1)$$

Equal width discretization depends on the uniformity of the distribution. This can result in empty or unbalanced intervals in case of skewed distribution [15].

Other rating methods are proposed based on monetization of environmental impacts such as the classification [16] developed by the Nederlands Instituut voor BouwBiologie en Ecologie (NIBE). Based on LCA results, the tool compares the environmental performance of construction materials with the same functional unit using 17 impact indicators. Products are classified based on their shadow costs ranging from 1a (lowest impact) to 7c (highest impact). The determination of the classes is always based on the best product that represents class 1a. The other products are classified thanks to environmental costs of the reference one that is representing class 1a. Detailed information has not been found about the methodology used to set the width of environmental performance classes.

2.3. EPD databases

All of these scores are based on product LCA to determine the environmental performance of one product compared to another. There are different databases of environmental data. A distinction can be made between generic and specific data like EPD. The largest database containing generic data is Ecoinvent. Concerning specific data, there are various EPD databases developed in several countries within the framework of different programs having as a common basis the 15804+A1 standard [17]. Although they all using the 15804+A1 as a basis, EPD databases have their specificities in terms of Product Category Rules for example allocation rules, requirements and system boundaries. The INIES (France) and MRPI (Netherlands) databases have homogeneous PCR for construction products like steel, concrete, insulation and paint [18]. In this context, EPDs collected from different databases could be generally not comparable because of the different PCRs used. These differences can then cause problems of concordance of results obtained on two LCA tools.

Table 1 provides a non-exhaustive summary of different databases. The French and German programmes present the largest database with hundreds of EPD [19].

Table 1.EPD databases

Database	Number of EPD
INIES (France)	3969
IBU (Germany)	1289
UL Environnement (USA)	1284
EPD Norge (Norway)	1605
International EPD System (SE/ANZ/TU/LA)	1881
BRE EN 15804 EPD (UK)	279
MRPI (Nederlands)	247
Global EPD (Spain)	127

2.4. Limitations of the state of the art and Research Objectives
Several research have highlighted the complexity of comparing EPDs. To begin with, despite the existing rules for product categories, according to EN 15804, EPDs can have different life spans or different main performances related to the functional unit. Thus, the comparison of the environmental impacts of two products requires a preliminary analysis and standardization work. This complexity of comparing building products is often emphasized by specifiers, architects, and engineers during the life cycle assessment phase, given the heterogeneity of functional units and the amount of information contained in EPDs [7]. Different methods were developed at the international level to compare the environmental performance of buildings and products. Some methods propose a weighted score based on different environmental indicators after normalizing them with a reference value like the impact of an average European citizen. For environmental performance classes, rating methods used different approaches. The definition of rating bands is based on an equal width discretization that performs well in the case of uniform distribution. Otherwise, one method developed in France is The Eco-score which was established for agricultural and food products. To our knowledge, no prior scoring methods have been applied to construction materials in France.

Thus, this paper aims at developing a new multicriteria environmental scoring methodology for building materials that can be applied to the French specific context based on the INIES database and RE2020 regulation.

3. **Methods**
The methodology adopted follows three steps as described below. The first step consisted of collecting data from the available EPD database and the analysis of data quality and completeness. Then, we conducted a data processing phase to harmonize EPDs to enable suitable comparison. Following this, we obtained an indicator for comparing the environmental performance of materials based on a discretization approach.

3.1. (EPDs) Collection
The first step consisted of collecting available data on construction materials and their environmental profiles. We focused on specific data available in EPD database. The main data to be collected were:

- The type of EPD and product category,
- The functional unit (life span and performance of the functional unit),

- The life cycle stages and associated environmental impacts.

To enable a multi-criteria analysis, the environmental indicator is established for the following impact categories in compliance with the future French standard NF EN 15804+A2 and its national addition NF EN 15804/CN for EPDs:

- Global warming potential (GWP, kg CO_{2eq}),
- Soil and water acidification (kg SO_{2eq}),
- Ozone depletion (kg CFC-11_{eq}),
- Eutrophication (kg (PO4)3-$_{eq}$),
- Photochemical ozone formation (kg $C2H4_{eq}$),
- Abiotic resource depletion - elements (kg Sb_{eq}),
- Abiotic resource depletion - fossil fuels (MJ).

For the sake of clarity and simplification, this paper focused on GWP (kg CO_2 eq), but the proposed methodology could be applied similarly to other impact categories. For each EPD, environmental data were analysed to detect missing values and outliers for the different environmental impact categories. EPDs with missing data were excluded from the analysis.

3.2. Data processing: standardization of the functional unit

Products and materials are compared considering a building-scale approach. Within a family, construction materials and products may have different life spans. To perform a suitable comparison, it is necessary to normalize their environmental impacts to a common service life. The RE2020 methodology is based on a dynamic method for the GWP calculation and sets a 50 year lifetime for the building. Thus, we considered 50 years as a lifetime to calculate GWP values.

For the dynamic approach defined by the RE2020, the value of GWP caused by a product used in the building is calculated by weighting the emissions at a yearly time step to associate the right weighting coefficient. For example, Table 2 shows the temporality of emissions related to a construction product. The line Y=product lifespan represents the lifetime of the product which corresponds to the year in which the product is renewed

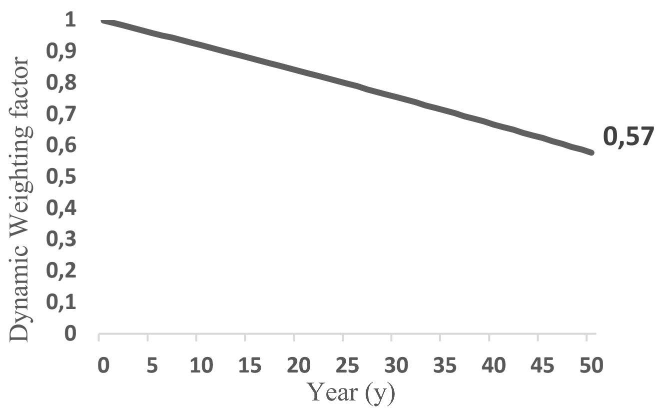

Figure 1. Weighting factors to be applied to GHGs according to the year of emissions based on the RE2020 regulation.

Table 2. Temporality of environmental impacts of products involved in the building life cycle according to RE2020.

Occurrence year	Activity/process	LCA module
y=0	Product manufacturing and installation	A1-A5
y=[1 – 50]	Building use	B1-B7
y = product lifespan	Product manufacturing and installation End of life stages Benefits and loads beyond the system boundary (D)	A1-A5 C1 – C4 D
y = 50	End of life stages and Benefits and loads beyond the system boundary (D)	C1 – C4 D

Once the environmental impacts were normalized over 50 years, the second step consisted of uniformizing the functional units of EPDs collected using weighting factors. This work was performed by product families. This step is fundamental as the functional unit is the unit of measurement used to describe and compare the service provided by products. It mentions the function of the product, its life span and the main performance.

3.3. *Discretization and score determination*

To improve the readability of environmental data and ease the performance comparison of materials and products, data were decomposed into different classes from *A* to *G*. The distance between each two classes increases according to an arithmetic progression at a rate of *d* which is calculated according to an extent of the series divided by the addition of the number of classes [20].

$$d = (\max - \min)/(n(n+1)/2) \qquad (2)$$

In our case n =7 where n is the number of classes.
The bandwidth of classes is class A: min to min+d, class B: min+d to min+ 2d, etc.
As shown in Figure 2, the minimum and maximum values considered to determine d are calculated according to the interquartile distance I = Q3 - Q1 to exclude outliers from the definition of rating classes. Outliers of the distribution are the values that are not in the interval [Q1 - I ∗ 1.5, Q3 + I ∗ 1.5].

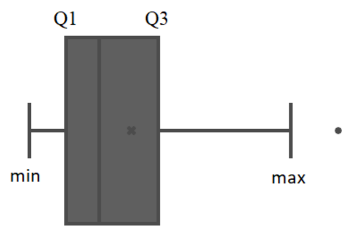

Figure 2. Data distribution through their quartiles

4. **Application of the methodology to the French case study**

For this study, we focused on the largest European EPD databases INIES which include 4616 Environmental and Sanitary Declaration Forms (FDES) related to construction materials. These FDES are produced in compliance with the NF EN 15804+A1 standard and its national supplement NF EN 15804/CN. The database contains also Product Environnemental Profile (PEP) related to electrical, electronic and climatic equipment established in compliance with NF XP C 08-100-1. INIES is governed by a multiparty protocol that defines the rules of governance. Since 2011, the Alliance HQE-GBC is in charge of managing the database. It contains different types of FDES. There are individual environmental declarations, produced by the manufacturer for a specific product and collective environmental declarations, drafted for some similar products produced by several manufacturers. The database also contains conventional values obtained by averaging different existing FDES related to similar products or based on assumptions defined by the French Ministry of the environment and the French Ministry of sustainable housing for products that have not been subjected to any environmental declaration yet.

5. Results

5.1. (EPDs) Collection and data cleaning

EPDs from INIES database are classified by product family. Table 3 presents the number of EPDs included in each product family. After analysing the database, the number of excluded EPDs represents only 6% of the total of the database. This 6% refer to EPDs with missing or aberrated values.

Table 3. Number of EPDs and percentage of EPDs collected after data cleaning

Product Family	Number of EPDs	Individual	Collective	Conventional
Road construction materials	200	36	21	143
Structure/Masonry	484	121	151	212
Facades	200	51	118	31
Roofing/Waterproofing	106	39	15	52
Exterior and Interior Carpentry	259	111	67	81
Insulation	1192	1040	10	142
Partitioning/suspended ceilings	499	419	21	59
Floor covering/painting/decorating products	385	196	70	119
Others	208	125	16	67
Total	3533	2138	489	906

5.2. Data processing: standardization of the functional unit

After carrying out the work on the standardization of the functional units and by investigating the perimeter of studies defined in the different FDES, we observed that 80% of available declarations can be compared within each product family as presented in Table 4.

Table 4. Percentage of comparable EPDs within each product family

Product Family	% of comparable EPDs
Road construction materials	81%
Structure/Masonry	80%
Facades	72%
Roofing/Waterproofing	82%
Exterior and Interior Carpentry	82%
Insulation	81%

In the following sections, the environmental scores are detailed for two product families: windows and insulation materials.

5.3. Windows. The INIES database contains 67 EPDs of windows classified according to the window frame material. Figure 3 shows the distribution of GWP values over 50 years according to the dynamic approach defined by the RE2020 and including replacements of construction products to match 50 years. GWP values are determined by considering the whole of life cycle phases (production, construction process, use and end of life) as well as the module D (cf Table 2). The functional units described in the different environmental product declarations have in common the reference flow rate of 1 m^2 of window.

However, the lifetimes are different from one EPD to another, generally 25 or 30 years. EPDs also have different thermal performances expressed in terms of thermal transmittance U_w.

By normalizing all impacts to a common lifetime (50 years), we were able to compare all EPDs related to windows. Windows with wood frames present the best environmental performance and are classified A in the case of individual environmental declarations. Wood windows classified as E or F are related to conventional data.

We can see from the figure 3 that class A contains different types of windows frame materials. Windows with steel frame represent the largest distribution.

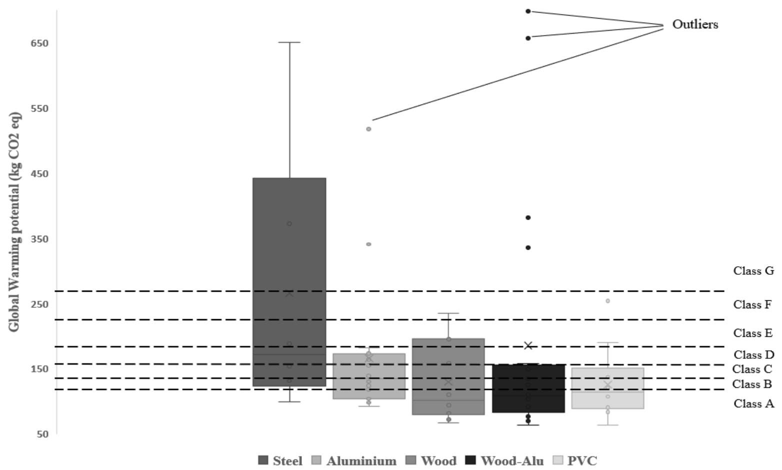

Figure 3. Distribution of dynamic GWP per m^2 values obtained for windows

5.4. Interior insulation materials

There are 249 EPDs associated with insulating materials in INIES database. Figure 4 shows the distribution of GWP values over 50 years obtained according to the dynamic approach defined by the RE2020. The functional units described in the different EPDs have in common the reference flow rate of 1 m^2. However, the available EPDs may have different main performances. We normalized the environmental impacts using a correction factor that depends on the thermal resistance of the product and the median R-value of the family. Using this, we were able to compare 79% of the available EPDs associated to interior insulation materials.

Unlike the windows family, we noticed higher data heterogeneity for insulation materials, which present disparate functional units in terms of performance requirements that products must fulfil. We have considered thermal resistance as the main performance. Thus, we normalized the environmental impacts using a correction factor that depends on the thermal resistance of the product and the median R-value of the family. Using this approach, we were able to compare 79% of the insulation materials.

Unlike windows, only one insulation category (Grass silage) belongs to performance classes A, B and C. This can be explained by the biogenic carbon storage and dynamic weighting coefficients considered in the RE2020.

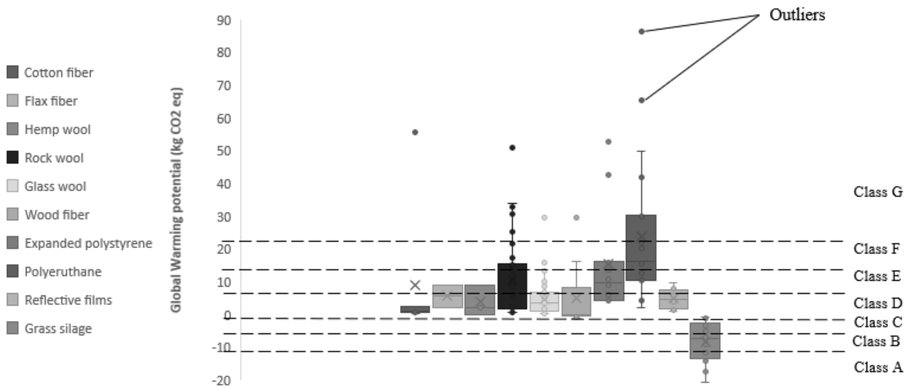

Figure 4. Distribution of GWP per m^2 values obtained for interior insulation materials

5.5. *Discretization and score determination*

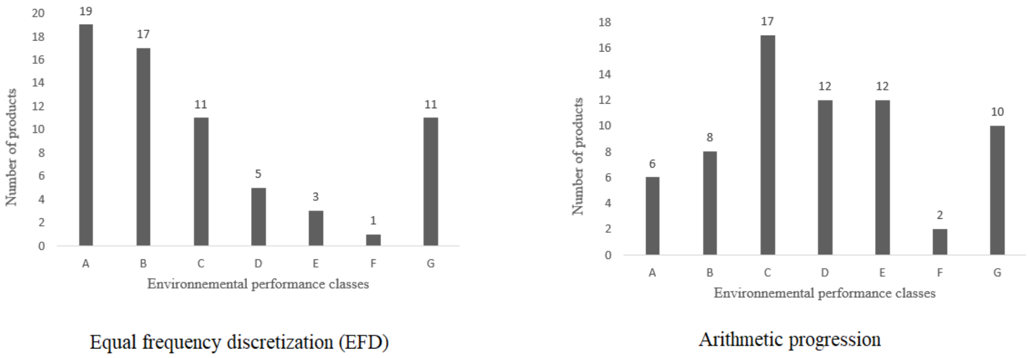

Figure 5. Number of EPDs per environnemental class according to the discretization methods for windows

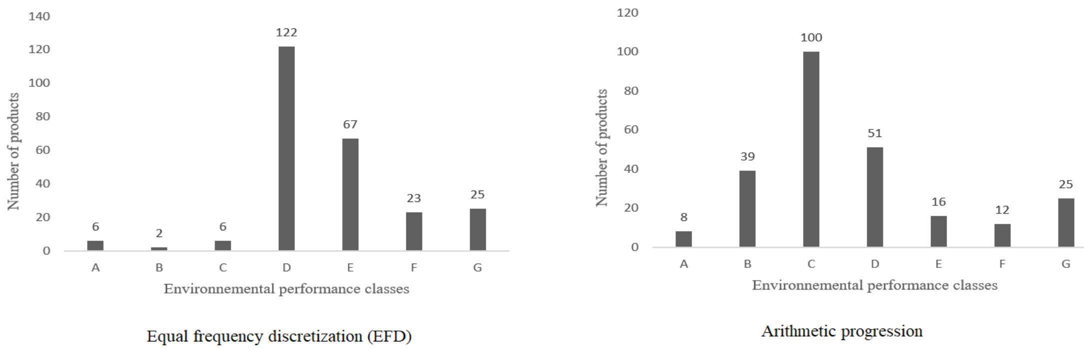

Figure 6. Number of EPDs per environnemental class according to the discretization methods for insulation materials

The results of discretization of the proposed method using arithmetic progression were compared with those obtained following an equal frequency discretization. As shown in figures 5 and 6, one can notice a better progression of the number of EPDs per classes using arithmetic progression, from class A where expect the few best performers to class D where we find average performance EPDs. The arithmetic progression follows an almost Gaussian distribution with a large part of EPDs that are found in classes C, D and E.

6. Discussion

This paper proposes a methodology to compare environnemental performance of materials and products based on their environnemental declarations. The INIES database was selected as a case study to test the proposed method. Results carried out show that this method allow to compare 80% of EPDs on average within each product family available in INIES. However, it’s applicability depends on the uniformity of the functional unit within the selected EPD databases. Moreover, literature review shows that there are different Product Category Rules defined by EPD program operators for the production of EPDs. Thus, future research is needed to examine the applicability of this method in the scope of other EPD databases.

Concerning the determination of the performance classes, the results show that the method of discretization by arithmetic progression allowed a better distribution contrary to the equidistance method. Another promising finding was that this method performs well even in case of skewed data.

It should be noted that the comparison indicator was calculated on the basis of a single impact category such as the global warming potential presented in this paper. Future research should consider the potential effects of other impact categories to develop multi-criteria score by weighting all impact categories. Moreover, in conjunction with this comparison method, it is also necessary to take into consideration how the material is implemented in the building by comparing macro component elements to avoid inaccurate and misleading comparisons. Thus, it will be important that future research investigate the development of scoring methodologies at macro component and building scales.

Another important point is the need for assessing the usability potential and design guidance of the proposed method by building specifiers, architects and engineers, to see how far it ease the environmental comparison of building products

7. Conclusion

Literature review in this work shows that comparison of EPDs is not a trivial task. Our findings obtained by analyzing the INIES database show that despite the existence of product rules, EPDs may have different functional units which makes them difficult to compare.

This work was aimed to propose a new approach for making robust comparisons between EPDs. For this, we used the French national database INIES. The methodology adopted in this study was conducted according to three steps. The first phase consisted of collecting EPDs and assessing the quality of available data. This first step shows that despite the use of product category rules, some EPDs have different functional units since the products have different lifespans and performances. Furthermore, some EPDs contains outliers or missing values for certain indicators that were excluded at this stage. Following this, the most suitable EPDs selected within each product family have been normalized according to their functional units and compared using environmental performance classes.

In this paper, we presented detailed results for two product families: windows and insulation materials. The use of the three-step methodology explained in section 3 make it possible to compare all windows and 79% of insulation materials. To facilitate the comparison, we have divided the products into environmental performance classes within each product family by discretizing the GWP values according to an arithmetic progression approach. This method allows a better distribution even in the case of non-uniform values. This work might be valuable for building specifiers that need to compare EPDs in their daily work looking to fasten this process.

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