Renewable and Sustainable Energy Reviews 58 (2016) 565–573

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

LCA databases focused on construction materials: A review

A. Martínez-Rocamora *, J. Solís-Guzmán, M. Marrero

Department of Building Construction II, School of Building Engineering, University of Seville, Av. Reina Mercedes, 4-a, 41012 Seville, Spain

A R T I C L E I N F O

Article history:
Received 29 January 2014
Received in revised form
3 September 2015
Accepted 27 December 2015
Available online 14 January 2016

Keywords:
LCA database
Construction materials
Building construction
Database transparency

A B S T R A C T

Evaluation of the environmental impact caused by construction materials frequently presents such obstacles as the mismatch between the construction project location and where the LCA database was made, lack of transparency, and/or the unsuitability of the data to the building project conditions, thereby making it necessary to establish a state-of-the-art review for researchers in order to facilitate selection between the wide variety of databases available.

A review of existent LCA databases containing data for building materials has been performed. A list of features and criteria for their evaluation is developed, and subsequently applied in order to compare the various databases. Their methodology, documentation, data quality and comprehensiveness are thereby analysed. Despite the existence of a considerable number of databases, only a few contain data on construction materials. Some projects have been abandoned and several more can be considered incomplete. However, GaBi Database and Ecoinvent stand out for their integrity, usability and dedicated resources.

A starting point in the selection of an LCA database for construction materials is provided. With all the information gathered herein, researchers are equipped to make a well-founded choice, and the selection process is certainly improved.

Contents

* Corresponding author. Tel: +34 675041010.
E-mail addresses: rocamora@us.es (A. Martínez-Rocamora), jaimesolis@us.es (J. Solís-Guzmán), madelyn@us.es (M. Marrero).

http://dx.doi.org/10.1016/j.rser.2015.12.243
1364-0321/

1. Introduction

Since environmental management standards UNE-EN ISO 14040 and UNE-EN ISO 14044 were released in 2006, a large number of LCA databases have been developed. Several of these databases can be used in the study of the environmental impact caused by construction materials during the building process; however, on reviewing these studies, several major problems are found, such as the mismatching between locations of the LCA database and where the study was performed, lack of transparency, and/or the unsuitability of the data to the building project conditions [1–3].

Each LCA database is developed by an enterprise or organism located in a specific country or territory, and the modelled processes are based on its manufacturing characteristics. Thus, when researchers carry out a study using an LCA database from another country, the results may well be incorrect. Other databases, such as BEDEC, do not provide users with original data sources [4]. Furthermore, most LCA databases use a cradle-to-gate model, thereby omitting to analyse other stages of the life cycle of the building. On the other hand, this omission makes it easier, if the database transparency allows it, to add transport of materials to the construction site as well as construction and demolition waste (CDW) to landfills or treatment plants, while avoiding duplication.

Despite the problems mentioned, huge leaps in the development of LCA methodology have been achieved over the last decade, and database quality assurance, consistency and harmonization of methods all contribute towards this progress [5]. The wide variety of LCA software solutions and their content has been reviewed in several occasions. Rice et al. [6] carried out a comparative of European LCA software where they considered 15 factors to evaluate their performance. It was concluded that, in 1997, the four packages that offered advantages over the rest were The Boustead Model, TEAM, PEMS 3.0, and SimaPro 3.1. Zabalza Bribián et al. [7] present a brief state-of-the-art with a list of existing LCA tools, analysing their potential users, drivers and barriers, and applications to the building sector.

More recently, Takano et al. [8] compared the results in terms of GHG emissions obtained for three buildings using five different LCA databases (GaBi and Ecoinvent 3.0, among others). The relative differences regarding the whole building reached 33%, while regarding some materials individually differences up to 183% were identified. Islam et al. [9] presented a summary table with some of the LCA software and databases around the world, declaring that Athena is the most suitable for its use in US and Canada, as Ecoinvent is for Europe and AusLCI for Australia. It was observed that the hi-tech improvements in the building industry cause big changes which make data quality in LCA studies on buildings a major concern.

A significant number of LCA assessment of building processes and materials have been carried out for at least two decades. Almost all of them can be found in several reviews published in the latest years. Some review papers focus on LCA studies [10] or life cycle energy analysis (LCEA) [11,12]. Sharma et al. [13] separate the studies on residential or commercial buildings. Nevertheless, most reviews highlight the importance of separating LCA studies on whole construction processes or, on the other hand, on materials and constructive solutions, since the assessment methodology must be adapted [1,14–16]. Lately, the LCA of buildings is being brought to a higher level, analysing the complete life cycle of buildings, including the construction phase, operation and maintenance, and finally demolition scenarios [17,18].

As it can be seen, LCA has become the most common way to quantify the (un)sustainability of buildings, but there is a general concern about the reliability of LCA databases. In order to evaluate the current situation, a state-of-the-art review is presented in this paper, which may help users make a better-founded selection for the most suitable LCA database in accordance with their needs. Therefore, features and criteria for the evaluation of LCA databases are presented, as well as a scoring system for their comparison. Subsequently, a review of 10 databases is developed based on a set of features and criteria previously defined, and a comparative analysis of these databases is performed. Finally, some examples are shown of the application of the comparison system proposed, for different construction materials.

2. Main features for the evaluation of LCA databases

In order to compare the various LCA databases, a set of decisive features is proposed. The six chosen features are: scope, completeness, transparency, comprehensiveness, update and licence. These features are described below, and some are divided into several criteria (see structure in Fig. 1). Hereafter, in figures and tables, main features are written in capital letters and criteria or 'sub-features' in lower case:

1. The *scope* of an LCA database is first the *territory* where manufacturing processes take place (e.g. Switzerland, Europe, USA, North America, France), and secondly the *categories* of materials which are studied (such as metals, plastics, wood, and cement and concrete).

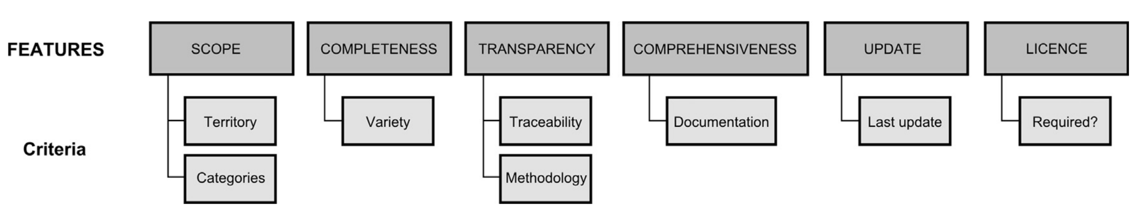

Fig. 1. Features and criteria for the evaluation of LCA databases.

2. *Completeness* shows how the families of materials are covered, and takes into account whether all the existent variations of materials within the categories are considered.
3. *Transparency* is the core of LCA [19,20]. Here, the *traceability* and the explicit outline of the *methodological process* through which the life cycle of the material is determined (flow diagrams and life-cycle inventories) will be evaluated. Traceability will be higher if literature references are shown.
4. *Comprehensiveness* measures the integrity of the information provided for each material. In addition to flow charts and inventories, a large amount of information is normally provided on the factors affecting the analyses. These considerations are necessary in order to make modifications and adapt the data to other studies.
5. *Update* measures the proximity between the last update of the entries in the database and the project under evaluation.
6. The *licence* feature will indicate whether a paid licence is required in order to access the database.

The methodology, documentation, data quality, and completeness of LCA databases are analysed in the following section, and a state-of-the-art review for researchers and LCA practitioners alike is provided.

3. LCA databases for construction materials

From a list of more than 40 LCA databases, only those working with construction materials have been selected for this study. The European Commission's Institute for Environment and Sustainability provides a list of available LCA databases, and this has been taken as a starting point [21]. Furthermore, other researchers and organisms mention a number of existing databases whose inclusion makes the list more complete [22].

Several databases have been excluded from the study, mainly due to one or more of the following reasons: they do not contain data for construction materials; they have been abandoned; and/or they are also identified with another name already included in the list. The information gathered for the selected databases is shown below.

3.1. European databases

3.1.1. Ecoinvent

Ecoinvent [23] was developed by the Swiss Centre for Life Cycle Inventories. Due to its consistency and transparency, it has been included in SimaPro 8, and it is also possible to use it with GaBi 5 and Umberto 5. A cradle-to-gate model is applied in most of the LCA studies, which are based on downloadable reports [24–26]. In these reports, the methodology, flow charts, life cycle inventories, and literature references are presented.

Access to 100 out of its 4000 processes is granted with the demo version of SimaPro. On paying the full licence, Ecoinvent is perfectly suited for construction purposes, since every category of construction materials is included and developed with a high variety of products. Users can also consult it online and download the data directly.

3.1.2. ELCD database 3.1

Supported by the European Commission, ELCD comprises more than 300 entries including some key materials, transport, and waste management systems [27]. It was last updated in 2012. The database is accessible free of charge, and it is also included in SimaPro and GaBi.

This database was intended to complement other data sources in the ILCD Data Network. In addition to the fact that every item of process data complies with UNE-EN ISO 14040 and 14044, a methodological harmonization and an external review are foreseen. Flow diagrams, life cycle inventories, comments, literature references, and reviews can be consulted online.

On the other hand, its limited number of data sets for construction materials underlines its need to be complemented with other databases. Moreover, ELCD is already a data compilation from several sources, including Eurofer data sets, GaBi Database and PlasticsEurope, among others.

3.1.3. GaBi Database

GaBi Database, by PE INTERNATIONAL, is one of the biggest LCA databases on the current market [28]. More than 1000 processes for construction materials are included, some of them from PlasticsEurope, ELCD, or Eurofer, and are predominantly cradle-to-gate. This is a complete database which refers, among other processes, to construction materials, with enough variety within each category of products.

The process data is updated annually by 60 LCA experts from more than 20 countries. To provide the needed transparency, documentation of the processes can be consulted online, as well as their sources, inventory and flow diagram. Most data comes from a previous version of GaBi Database, complemented with monographic studies [29–31].

3.1.4. PlasticsEurope Eco-Profiles

Eco-Profiles were first developed by PlasticsEurope in 1991, and have been continuously updated. This is a free LCA database specialized in plastic materials [32]. Cradle-to-gate data for major polymers as they are produced in Europe is provided. This database is included in SimaPro under the name of Industry data v2.0, and in GaBi as PlasticsEurope. High quality reports [33–37] explain the methodology, complemented by intuitive flow charts and life cycle inventories for the different production stages. Eco-Profiles are calculated using average values from the industry, and then weighted depending on manufacturers' production. Raw material extraction, emissions to air and water, and waste generated are included, as well as transport derived from production, vehicle maintenance, and the replacement of batteries and tyres. Energy and emissions associated to the construction of manufacturing plants, and to human activities, such as food consumption and transport to work, are considered insignificant in comparison to industrial processes.

3.2. American databases

3.2.1. Athena database

Athena database is used by Athena Impact Estimator. This database includes data for construction materials, energy, transport, construction and demolition processes, maintenance, repairing, and waste disposal, some of which is taken from U.S.LCI Database [38]. The data reflects the manufacturing process in Canada and the U.S. A, classified by regions, by taking into account the differences in transport, energy mix and recycled material rates.

All categories of construction materials are included in a data set of around 70 products with variations. Since a licence is required for access to the database and software, it has been impossible to determine whether the documentation, reference reports, flow diagrams and inventories are shown.

3.2.2. U.S. Life Cycle Inventory Database

U.S. Life Cycle Inventory Database was developed in 2001 by the National Renewable Energy Laboratory of the U.S. Department of Energy [39]. It was last updated in 2009 through a meeting with data providers. Data follows cradle-to-gate, cradle-to-grave and gate-to-gate models, and takes into account input and output flows of energy and materials, exclusively for the U.S.A. This database focuses on metals, wood materials and plastics, which constitute approximately 80 out of the 600 processes included within the whole database. Flow charts are shown in some cases, as well as input and output inventories. However, its reports [40] are not clear regarding the energy sources employed for the manufacturing processes for the materials, since it is always assumed to be 100% from fossil fuel. This database comes with SimaPro and can also be consulted online.

3.3. National databases

3.3.1. Base Carbone

Created by the ADEME agency, and designed to determine greenhouse gas balances, the Base Carbone [41] provides data on CO_2-emission factors for France and its islands and colonies. Although it is stated that more than 17,000 elements are included in this database with more than 1300 materials among them, there is a repetition of entries for each of the mentioned territories, and hence a considerably lower number of materials is actually included. Apparently complete sets of metals, glass, plastics, and other construction materials are included. This free online database follows a cradle-to-grave model separated into life-cycle stages (including manufacture of new or recycled material, and end of life), with an output expressed in equivalent CO_2 kilograms per ton, as well as an uncertainty percentage for this value. Documentation and reports [42–44] are provided to support the data. The LCA inventories are limited and only gas emissions are shown, since this database is oriented towards equivalent CO_2 emissions. The methodology can be consulted following the cited reports, but is not shown within the database itself. The suitability of the database is linked to the reports instead of to the documentation provided.

3.3.2. BEDEC database

BEDEC is a Spanish structured database, created by the Institute of Technology of Construction in Catalonia (ITeC), containing economic and environmental information for more than half a million variations of construction elements [45]. Data for embodied energy, CO_2 emissions, and waste disposal are provided for each construction material; however no documentation is available and this constitutes its main inconvenience. The lack of traceability and outlining of the methodological process makes its data sets totally unverifiable.

It is only known [46] that the data is sourced from several organizations and enterprises (e.g. Puerto de Barcelona, Grohe, Isover, Porcelanosa, Roca sanitario, Texsa). Collaboration with the ICAEN, the Polytechnic University of Catalonia and the Technological Centre of Construction have also helped build up this database. Finally, data has also been completed with Ecoinvent 1.3 and information from manufacturers, but no visible link is available which would enable the real LCA studies to be consulted.

Data on the embodied energy of the materials considers the raw material extraction, transport from the origin to plant, and its transformation at the manufacturers. Neither is its transformation into a construction product nor its transport to the building site considered, and hence it can be assumed that BEDEC implements a cradle-to-gate model.

Despite all these problems, this is the most widely used database in Spain for environmental studies of a building construction process [4,47], since it matches very well with the variety of construction elements used, which makes it simple to use when the evaluator wishes to study an entire building.

3.3.3. CPM LCA database

CPM LCA database [48], previously known as LCAiT, was developed in 1998 by the Swedish Centre for Environmental Assessment of Product and Material Systems and was last updated in 2008. This database, maintained by the University of Chalmers, contains information for approximately 700 processes, and three assessment methodologies (EPS, EDIP and Eco-indicator 99) are implemented to calculate their impact. Manufacturing processes for construction materials are included, although certain elements have not been updated for years (e.g. reference studies for cement, concrete, and reinforcement steel bars were published in 1996 and 1997 and remain untouched).

Transparency is achieved, with life cycle inventories, literature references and comprehensive documentation expressing the sources of each element of the studied process. However, the processes focus on very specific production stages, thereby rendering it more complicated to apply this database for the building process.

3.3.4. ProBas

With more than 7000 unitary processes, ProBas is a free online well-structured database, which can also be managed with GEMIS 4.8 [49]. Around 700 construction materials are included, belonging to all category types [50]. It is a complete database, showing references, life cycle inventories and brief information about each entry. Most data comes from the Öko-institut, whose headquarters are in Freiburg im Breisgau, Germany, complemented with LCA studies [32,51,52]. Unfortunately ProBas is only available in German, which highly restricts the number of potential users.

3.4. Input–Output databases

Input–Output databases contain a set of simple or unitary processes used for modelling more complex processes, such as the manufacturing of construction materials. The most widely known Input–Output databases are the Dutch Input-Output, EU and Danish Input-Output, Japanese Input-Output and US Input-Output. Furthermore, certain LCA databases use self-made definitions of unitary processes.

3.5. Other databases

Other databases have apparently disappeared, or their privacy policies prohibit sufficient information from being gathered to be included in this study. These are enumerated below:

1. BEAT database [53].
2. Buwal 250 [54].
3. Database DEAM [55].
4. DIM 1.0 [56].
5. Ecodesign X Pro database v1.0 [57].
6. IVAM LCA database [58].

4. Results and discussion

4.1. Comparative analysis

Once the databases have been reviewed, and following the information gathered about them, an evaluation based on the features described in Section 2 is performed (see Table 1). The scoring system is as follows:

–: The feature is not accomplished.

+: The feature is partially or sometimes accomplished.

Table 1
Comparison of LCA databases based on previously described features (see Section 2).

FEATURE	Criterion	Ecoinvent	ELCD	GaBi	PlasticsEurope	Athena	U.S.LCI	Base Carbone	BEDEC	CPM LCA	ProBas
SCOPE	Territory	+++	+++	+++	+++	++	+	+	+	+	+
	Categories	+++	++	+++	+	+++	+++	+++	+++	++	+++
COMPLETENESS	Variety	+++	++	+++	+++	++	++	++	+++	++	+++
TRANSPARENCY	Traceability	+++	+++	+++	+++	N.A.	+	+++	–	+++	+++
	Methodology	+++	+++	+++	+++	N.A.	++	+	–	++	++
COMPREHENSIVENESS	Documentation	+++	+++	+++	+++	N.A.	+	+	–	+++	+
UPDATE	Last update	2012	2012	2012	2012	2012	2012	2013	2013	2008	2012
LICENCE	Required	Yes	No	Yes	No	Yes	No	No	No	No	No

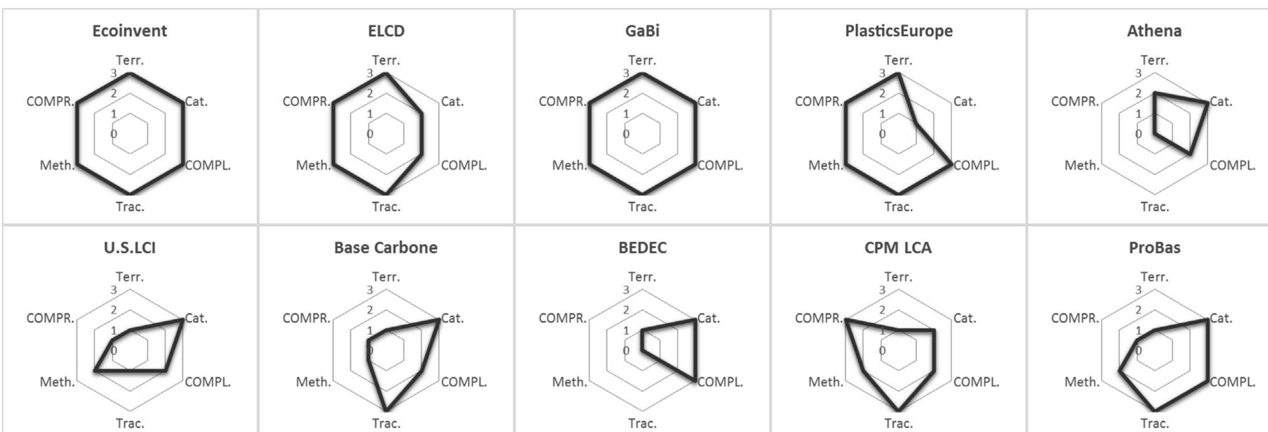

Fig. 2. Spider chart for the comparison of LCA databases based on previously described features (see Section 2). Legend Fig. 2: Terr=Territory; Cat=Categories; COMPL=Completeness; Trac=Traceability; Meth=Methodology outlining; COMPR=Comprehensiveness.

++: The feature is accomplished but could reach a higher level of completeness.

+++: The feature is completely accomplished.

N.A.: Not Accessible.

Licence and update features are not considered in the design of the final spider chart since they cannot be evaluated from 0 to 3. In the case of the territory criteria, one point indicates that the database is oriented for one country, two points for two countries, and three points for more than two countries or entire continents.

A spider chart is shown in Fig. 2 for each database in order to determine which databases accomplish more features and thus might be considered more complete and suitable than others. A database with a wider area in its spider chart means it is more complete. On the other hand, a database can be selected for an outstanding criterion or feature.

Finally, Ecoinvent and GaBi Database stand out for their completeness, and the dedicated resources to their development are evident. ELCD database 3.1 has been identified as the best free database, given that it is fed and complemented with high quality databases focused on other industry sectors, such as PlasticsEurope, Eurofer data sets (from the European Steel Association) and EAA (European Aluminium Association).

Currently, LCA practitioners have to choose a database which has not necessarily been developed according to the manufacturing characteristics of their country, and the data has to be adapted, or the errors that this will produce are simply assumed. One possible solution to this issue would be to develop parametric LCA software, capable of adjusting data, such as transport, distance, fuel, yield factors, and performance, for a particular case.

5. Examples of application

As an example, a project built in 2009 in Spain is used for the comparison. The construction project consists of two residential buildings with four floors above ground level and two more floors below, amounting to a total of 107 dwellings with parking spaces and storerooms [59].

The examples shown here are part of a further study to determine the variations produced in Ecological Footprint calculations for building construction when changing the LCA database used for each construction material [60]. Variations of 19% were detected in the final results for the Ecological Footprint of construction materials and of 8% for the total Ecological Footprint of the construction process when choosing other databases for only the six most energy-intensive materials, which were concrete, steel, adhesive paste, bricks, plasterboard, and aluminium (see Fig. 3). Six examples of this decision-making are presented below which, according to González-Vallejo et al. [61], represent more than 80% of the Ecological Footprint of materials in the dwelling construction process, regardless of the building type.

5.1. *Example 1: steel*

Five different sources for steel are used: Base Carbone, BEDEC, Ecoinvent, ELCD and Eurofer (see Table 2). Base Carbone only generates data for CO_2 emissions based on manufacturing processes in France, which is close to the project location. However, from the geographical standpoint, BEDEC is more suitable than Base Carbone because it is a Spanish database, despite its lack of transparency.

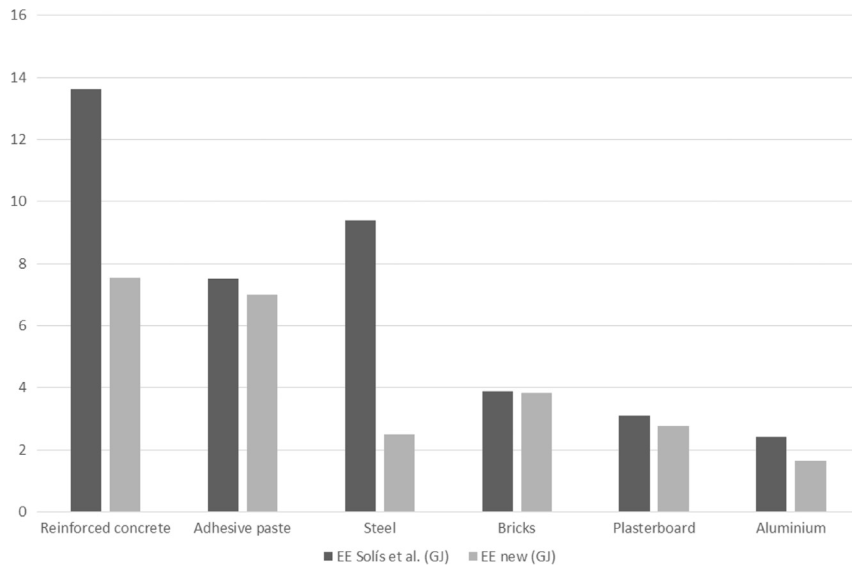

Fig. 3. Variations in embodied energy when changing the LCA database source.

Table 2
Embodied energy, emissions and energy mix of steel production from different LCA databases.

Steel			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	3.19	–
BEDEC	35.00	2.88	–
Ecoinvent	27.90	1.71	84.23% fossil 10.57% nuclear 4.30% hydroelectric
ELCD	10.60	1.03	100% fossil
Eurofer (WSA)	16.40	1.26	83.24% fossil 13.00% hydroelectric 2.36% nuclear

Ecoinvent data is supported by high quality reports, showing the methodology and Life Cycle Inventory. ELCD assumes an 80% average recycling ratio for reinforced steel bars and specifies that energy consumption is 100% from fossil fuels. The high recycling rate considered produces an embodied energy value significantly lower than other sources, although it has high transparency. Documentation is comprehensive and its original source is Eurofer, which is specialized in metals.

Data obtained directly from Eurofer is given by the World Steel Association; however no documentation on the LCA is available to support it. Note that Eurofer direct data differs from that of ELCD, which is also taken from Eurofer (see Table 2). Given that ELCD data provides higher transparency while adjusting to the exact construction material, it presents the best data despite the difference in embodied energy as compared to the other sources.

5.2. *Example 2: PVC*

In this case, similar values are obtained from the seven sources consulted (see Table 3). This implies a high similarity in the LCA methodologies employed. As with steel, although data from BEDEC and Base Carbone are reasonably close to the project location, other more reliable sources are available, such as PlasticsEurope, which provide better documentation, transparency, and specialization in plastic materials.

Table 3
Embodied energy, emissions and energy mix of PVC production from different LCA databases.

PVC			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	2.16	–
BEDEC	70.00	10.33	–
Ecoinvent	60.90	2.02	78.82% fossil 19.87% nuclear 1.52% hydroelectric
ELCD	56.20	2.71	87.54% fossil 10.75% nuclear 1.45% hydroelectric
GaBi	61.10	2.36	86.20% fossil 12.50% hydroelectric 1.33% nuclear
PlasticsEurope (pipes)	67.90	3.24	87.04% fossil 9.91% nuclear 2.05% hydroelectric
PlasticsEurope (resin)	60.90	2.71	87.52% fossil 9.92% nuclear 2.22% hydroelectric
U.S.LCI	53.00	1.80	–

Their original sources also differ: data from ELCD and Ecoinvent come from Plastics Europe and the corresponding Ian Boustead's report [36]. GaBi does not provide any documentation to support its original source. There only remains, therefore, data from PlasticsEurope and U.S.LCI. These two represent the most complete sources, but PlasticsEurope is chosen because the project is located in Spain and U.S.LCI is made exclusively for the USA.

5.3. *Example 3: aluminium*

The embodied energy for primary aluminium is known to be one of the highest (about 200 MJ/kg) among construction materials, although a high recycling rate is also possible, which reduces this value. For example, 100%-recycled aluminium reaches 19 MJ/kg of embodied energy according to certain data sources. If an average global recycled content of 33% is assumed for aluminium production, then data from BEDEC and GaBi should be discarded for being too far from the estimated value (see Table 4).

Analysis on Ecoinvent is carried out for 68% of primary aluminium content, ELCD is for 78% recycled material content, and U.S. LCI is not documented. Data in Ecoinvent comes from the European Aluminium Association: a specialized organism that provides higher reliability, and whose recycling rate is also considered to be close to the global average rate. The methodology and documentation are exhaustively explained. The characteristics here explained show Ecoinvent to be the best source.

5.4. Example 4: concrete

Concrete is usually considered one of the most unsustainable materials. This is not completely correct. It is its need for reinforcing steel along with the huge quantities necessary for a building's structure what makes concrete probably the most unsustainable material. As it can be seen in Table 5, its embodied energy and emissions per kilogram are much lower than in other materials.

Data was collected from five different databases. Data from ELCD comes from PE International, the same source from GaBi Database, so they can both be considered the same. Base Carbone gives lower CO_2 emissions per kilogram, probably due to the energy mix used in France, which is more nuclear-based than in other countries. Ecoinvent and GaBi-ELCD have different sources and therefore it is reflected in the energy mix. In case a whole building process were under study, the scoring system established in this paper would suggest the use of Ecoinvent or GaBi Database since they are the most complete in terms of categories and variety of materials. Otherwise BEDEC could be chosen for its proximity despite a high deviation from the other values has been detected, which could be due to an outdated source.

Table 4
Embodied energy, emissions and energy mix of aluminium production from different LCA databases.

Aluminium			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	9.827	–
BEDEC	161.44	9.26	–
Ecoinvent	136.00	8.54	66.17% fossil 16.76% hydroelectric 16.69% nuclear
ELCD	43.80	2.39	61.87% fossil 22.69% nuclear 13.86% hydroelectric
GaBi (EAA)	15.50	0.726	63.20% fossil 29.30% nuclear 2.45% hydroelectric
GaBi (PE)	17.70	0.891	63.50% fossil 28.70% nuclear 4.88% hydroelectric
U.S.LCI	76.70	7.13	100% fossil

Table 5
Embodied energy, emissions and energy mix of concrete production from different LCA databases.

Concrete			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	0.088	–
BEDEC	0.437	0.0745	–
Ecoinvent	0.618	0.112	75.00% fossil 19.20% nuclear 5.15% hydroelectric
ELCD (PE Int.)	0.658	0.121	84.60% fossil 13.20% nuclear 1.33% wind power
GaBi	0.635	0.118	83.11% fossil 10.62% nuclear 5.34% hydroelectric

5.5. Example 5: ceramic bricks

Ceramic bricks are more energy intensive than concrete due to the high-temperature burning treatment needed for their manufacture process. This fact, along with the high quantity used in a building (if its envelope is brick wall), make ceramic bricks one of the most impacting materials in the whole building process.

Only four data sources were available from the databases reviewed (see Table 6), since bricks are not included in ELCD or U.S.LCI. Data from BEDEC represents an average value for bricks, whether they are vertically or horizontally perforated. As in the other cases, no documents to support the study are provided, and its only favourable point is the database's location.

The value from Ecoinvent comes from a study where twelve factories from Germany, Austria and Switzerland are covered. The documentation shows a comprehensive study as well as reliable references. The whole cradle-to-gate life cycle from raw materials extraction to packing and storage is included. The embodied energy data from GaBi shows a considerable deviation from the rest. Base Carbone shows even higher emissions. It is noticeable the variation in the manufacturing processes from a location to another. In this case, probably BEDEC would be a better option due to the location factor, being bricks usually a local material.

5.6. Example 6: expanded polystyrene (EPS)

EPS is a plastic recyclable product frequently used as an insulation material. According to the National Association of EPS in Spain, this material can be easily recycled forming new blocks which may contain up to 50% of recycled EPS. Currently, other recycling technologies exist, such as mechanical densification to compact it, or the application of special solving agents in order to ease its transport and reprocessing.

As it can be seen in Table 7, the data from BEDEC shows an extreme deviation from the rest in terms of CO_2 emissions, and with no documentation to explain this fact, it should be discarded. The value obtained from ELCD comes from an LCA study by Boustead [37], like the data from PlasticsEurope, but different

Table 6
Embodied energy, emissions and energy mix of ceramic bricks production from different LCA databases.

Ceramic bricks			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	0.294	–
BEDEC	2.77	0.210	–
Ecoinvent	2.84	0.220	83.80% fossil 7.87% biomass 7.20% nuclear
GaBi	3.80	0.230	73.68% fossil 21.57% nuclear 3.76% hydroelectric

Table 7
Embodied energy, emissions and energy mix of EPS production from different LCA databases.

Expanded polystyrene (EPS)			
Database	Embodied energy (MJ/kg)	Emissions ($kgCO_2$/kg)	Energy mix
Base Carbone	–	2.824	–
BEDEC	117.00	17.27	–
Ecoinvent	106.00	4.20	92.20% fossil 6.83% nuclear
GaBi	72.50	2.11	96.59% fossil 3.01% nuclear
ELCD	85.40	3.38	96.37% fossil 3.20% nuclear
PlasticsEurope	93.30	3.39	95.71% fossil 2.93% nuclear 1.24% hydroelectric

assumptions must have been taken which would justify the variation among them.

On the other hand, the data from GaBi does not provide any documentation on the methodology, references or assumptions. The study by Ecoinvent considered the thermoforming process from two factories in Switzerland, and a product density of 30 kg/m^3 with a thermal conductivity of 0.035–0.040 W/m K, and higher values are obtained. Again, if a single product analysis were carried out, PlasticsEurope would be considered the most reliable source. Otherwise, when analyzing a whole building construction process, Ecoinvent would be a better option.

6. Conclusions

The present study provides a starting point in the selection of an LCA database for construction materials. With all the information gathered herein, researchers are equipped to make a well-founded choice, and the possibility of choosing a more suitable database for their studies is certainly increased.

Transparency and all its derived features remain decisive in this comparison, since this is the most important element to consider when working in LCA. Otherwise excellent databases, such as BEDEC and U.S.LCI, have been adversely affected in the ranking due to their lack of documentation and references in certain cases.

On the other hand, Ecoinvent and GaBi Database are identified as the most complete LCA databases according to the features defined for the study. ELCD is considered the best free database, standing out due to the fact that it merges data from several industry databases, such as PlasticsEurope, Eurofer data sets, and EAA.

Nevertheless it is important to note that the objectives of the evaluator determine, to a great extent, the appropriate database. In order to compare two construction materials, a precise database with high ratings on 'traceability', 'methodology' and 'comprehensiveness' should be used. However, if the evaluator intends to study a complete building, a database containing as many construction products as possible should be chosen, in which case 'categories' and 'completeness' would become key characteristics.

As stated in Section 3, large databases sometimes feed on smaller databases (some borrowed data from PlasticsEurope, Eco-Profiles and U.S.LCI Database). It has been detected that databases tend to merge in order to generate more complete data sets, which is totally positive for the development of databases with a greater territory scope, as well as for an increased capacity in categories and content of materials.

In a further analysis, partially described in Section 5, it has been detected that results on Cumulative Energy Demand (CED) (for the same material) noticeably fluctuate depending on the database used. It does not seem possible that the manufacturing characteristics for the different countries, where the LCA studies have been made, may vary that much, which makes it necessary for in-depth research into the sources to be carried out.

References

[1] Zabalza Bribián I, Valero Capilla A, Aranda Usón A. Life cycle assessment of building materials: comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. Build Environ 2011;46(5):1133–40.
[2] López-Mesa B. Análisis de ciclo de vida de sistemas constructivos/Life Cycle Assessment of construction systems. In: Proceedings of the conference on sustainability in edification. Barcelona, Spain: 2011.
[3] Reap J, Roman F, Duncan S, Bras B. A survey of unresolved problems in life cycle assessment. Int J Life Cycle Assess 2008;13:290–300.
[4] Mercader Moyano MªP. Cuantificación de los recursos consumidos y emisiones de CO_2 producidas en las construcciones de Andalucía y sus implicaciones en el protocolo de Kyoto/Quantification of consumed resources and CO_2 emissions in buildings of Andalusia and its implications for the Kyoto protocol (Dissertation). University of Seville; 2010. Available online via ⟨http://fondosdigitales.us.es/tesis/tesis/1256/cuantificacion-de-los-recursos-consumidos-y-emisiones-de-co2-producidas-en-las-construcciones-de-andalucia-y-sus-implicaciones-en-el-protocolo-de-kioto/⟩; 2015 [accessed 27.08.15].
[5] Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, et al. Recent developments in life cycle assessment. J Environ Manag 2009;91(1):1–21.
[6] Rice G, Clift R, Burns R. LCA software review. comparison of currently available European LCA software. Int J Life Cycle Assess 1997;2(1):53–9.
[7] Zabalza Bribián I, Aranda Usón A, Scarpellini S. Life cycle assessment in buildings: state-of-the-art and simplified LCA methodology as a complement for building certification. Build Environ 2009;44:2510–20.
[8] Takano A, Winter S, Hughes M, Linkosalmi L. Comparison of life cycle assessment databases: a case study on building assessment. Build Environ 2014;79:20–30.
[9] Islam H, Jollands M, Setunge S. Life cycle assessment and life cycle cost implication of residential buildings – a review. Renew Sustain Energy Rev 2015;42:129–40.
[10] Buyle M, Braet J, Audenaert A. Life cycle assessment in the construction sector: a review. Renew Sustain Energy Rev 2013;26:379–88.
[11] Cabeza LF, Rincón L, Vilariño V, Pérez G, Castell A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review. Renew Sustain Energy Rev 2014;29:394–416.
[12] Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: an overview. Energy Build 2010;42:1592–600.
[13] Sharma A, Saxena A, Sethi M, Shree V, Varun G. Life cycle assessment of buildings: a review. Renew Sustain Energy Rev 2011;15:871–5.
[14] Ortiz O, Castells F, Sonnemann G. Sustainability in the construction industry: a review of recent developments based on LCA. Constr Build Mater 2009;23:28–39.
[15] Singh A, Berghorn G, Joshi S, Syal M. Review of life-cycle asessment applications in building construction. J Archit Eng 2011;17(1):15–23.
[16] Chau CK, Leung TM, Ng WY. A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. Appl Energy 2015;143:395–413.
[17] Asdrubali F, Baldassarri C, Fthenakis V. Life cycle analysis in the construction sector: guiding the optimization of conventional Italian buildings. Energy Build 2013;64:73–89.
[18] Zhang X, Shen L, Zhang L. Life cycle assessment of the air emissions during building construction process: a case study in Hong Kong. Renew Sustain Energy Rev 2013;17:160–9.
[19] ISO, International Standard Organization. Environmental management-Life cycle assessment – principles and framework (ISO 14040:2006).
[20] ISO, International Standard Organization. Environmental management – life cycle assessment – requirements and guidelines (ISO 14044:2006).
[21] European Commission. List of LCA databases by the European Commission. ⟨http://www.epa.gov/nrmrl/std/lca/resources.html#Software⟩; 2015 [accessed 25.08.15].
[22] Ihobe S.A. Análisis de ciclo de vida y huella de carbono. Departamento de Medio Ambiente, Planificación Territorial, Agricultura y Pesca. Gobierno vasco/life cycle assessment and carbon footprint. Department of Environment, Territorial Planning, Agriculture and Fishing. Basque Government; 2009.
[23] Ecoinvent Centre. Ecoinvent website. ⟨http://www.ecoinvent.org/database/database.html⟩; 2015 [accessed 25.08.15].
[24] Classen M, Althaus HJ, Blaser S, Scharnhorst W. Life cycle inventories of metals, Final report Ecoinvent data v2.1, No. 10. Swiss Centre for Life Cycle Inventories; 2009.

[25] Kellenberger D, Althaus HJ, Künniger T, Lehmann M. Life cycle inventories of building products, Final report ecoinvent Data v2.0 No. 7. Swiss Centre for Life Cycle Inventories; 2007.
[26] Hischier R. Life cycle inventories of packaging and graphical papers, Ecoinvent-Report No. 11. Swiss Centre for Life Cycle Inventories; 2007.
[27] ELCD. European reference life-cycle database (ELCD 3.1) website. ⟨http://eplca.jrc.ec.europa.eu/ELCD3/index.xhtml⟩; 2015 [accessed 24.08.15].
[28] PE INTERNATIONAL. GaBi Database website. Construction Materials extension. ⟨http://www.gabi-software.com/support/gabi/gabi-database-2014-lci-documentation/extension-database-xiv-construction-materials/⟩; 2015 [accessed 30.08.15].
[29] EAA. Life cycle inventory data for aluminium production and transformation processes in Europe (Critical review included). Brussels, Belgium: 2008.
[30] Bruck M. Ökobilanz Ziegel-Ökologische Bewertung von Mauerziegeln/LCA brick-ecological assessment of bricks. In: Proceedings of the Internationaler Sachverstaendigenkreis fuer Ausbau und Fassade/International Experts Conference on Finishing and Facades (D.A.CH). Zürich, Switzerland: 2004.
[31] Büchel KH, Moretto HH, Woditsch P. Industrial inorganic chemistry. Weinheim, Germany: Wiley-VCH Verlag GmbH; 2000.
[32] PlasticsEurope. PlasticsEurope Eco-Profiles website. ⟨http://www.plasticseurope.org/plastics-sustainability-14017/eco-profiles.aspx⟩; 2015 [accessed 25.08.15].
[33] TNO. Eco-profiles of the European Plastics Industry: Pipe extrusion. PlasticsEurope; 2010.
[34] Boustead I. Eco-profiles of the European plastics industry – high density polyethylene (HDPE). PlasticsEurope; 2005.
[35] Boustead I. Eco-profiles of the European plastics industry – methodology. PlasticsEurope; 2005.
[36] Ostermayer A, Giegrich J. Eco-profiles of the European plastics industry – polyvinylchloride (PVC) (suspension polymerization). ECVM and PlasticsEurope; 2006.
[37] Boustead I. Eco-profiles of the European plastics industry – polystyrene (expandable) (EPS). PlasticsEurope; 2006.
[38] Athena SMI. Athena database content. ⟨http://www.calculatelca.com/wp-content/uploads/2012/10/LCI_Databases_Products.pdf⟩; 2015 [accessed 31.08.15].
[39] U.S. Life cycle inventory database. National Renewable Energy Laboratory. ⟨https://www.lcacommons.gov/nrel/search⟩; 2015 [accessed 31.08.15].
[40] Franklin Associates. Cradle-to-Gate life cycle inventory of nine plastic resins and four polyurethane precursors. Prairie Village, Kansas, USA: The Plastics Division of the American Chemistry Council; 2010.
[41] ADEME. Base Carbone website. ⟨http://www.basecarbone.fr/⟩; 2015 [accessed 31.08.15].
[42] Boustead I. Eco-profiles in the European industry – LCA-reports, Polyvinyl chloride – PVC injection moulding. PlasticsEurope; 1998.
[43] J. Keniry. Aluminium smelting greenhouse footprint and sustainability. The Minerals, Metals & Materials Society; 2008.
[44] CEREN. Contenu énergétique des produits de base de l´industrie, les matériaux de construction. / Energy content of industrial products, construction materials; 1999.
[45] ITeC. BEDEC website. ⟨http://www.itec.es/nouBedec.e/bedec.aspx⟩; 2015 [accessed 31.08.15].
[46] ITeC. BEDEC. Contenido y criterios/Contents and criteria. ⟨http://docs1.itec.cat/e/Guia.criterios.bedec.pdf⟩; 2015 [accessed 01.09.15].
[47] Marrero M, Martínez-Escobar L, Mercader-Moyano MP, Leiva-Fernández C. Minimización del Impacto Ambiental en la Ejecución de Fachadas Mediante el Empleo de Materiales Reciclados / Environmental impact minimization of façade construction through recycled materials use. Inf Constr 2013;65 (529):89–97.
[48] CPM. CPM LCA Database website. ⟨http://cpmdatabase.cpm.chalmers.se/Start.asp⟩; 2015 [accessed 01.09.15].
[49] IINAS. GEMIS – Global emissions model for integrated systems website. ⟨http://www.iinas.org/gemis.html⟩; 2015 [accessed 01.09.15].
[50] ProBas. ProBas database website. Materials and products. ⟨http://www.probas.umweltbundesamt.de/php/prozesskategorien.php?topic_id=8589934592⟩; 2015 [accessed 01.09.15].
[51] Hantsche U. Abschätzung des kumulierten Energieaufwandes und der damit verbundenen Emissionen zur Herstellung ausgewählter Baumaterialien, In: Kumulierte Energie- und Stoffbilanzen / Assessment of the cumulative energy consumption and related emissions for the production of selected construction materials. In: Cumulated energy and material balances. VDI-Berichte, vol. 1093. Düsseldorf: 1993.
[52] DACH. Ökobilanz Ziegel-Ökologische Bewertung von Mauerziegeln sowie ökologische und betriebswirtschaftliche Bewertung von Ziegel-Außenwandkonstruktionen/LCA brick-ecological assessment of bricks and ecological and economic assessment of brick exterior wall constructions. Kanzlei Dr. Bruck. Wien: 1996.
[53] BEAT. BEAT 2002 website. ⟨http://www.sbi.dk/en/publications/programs_models/beat-2002⟩; 2013 [accessed 03.12.13].
[54] FOEN. Federal Office for the Environment website. ⟨http://www.bafu.admin.ch/index.html?lang=en⟩; 2015 [accessed 01.09.15].
[55] Ecobilan. DEAM database website. ⟨http://ecobilan.pwc.fr/fr/boite-a-outils/deam.jhtml⟩; 2015 [accessed 01.09.15].
[56] Ecosmes. eVerdee tool website. ⟨http://www.ecosmes.net/everdee/login2?idlanguage=null⟩; 2015 [accessed 01.09.15].
[57] EcoMundo. Ecodesign X-Pro software website. ⟨http://www.ecomundo.eu/en/software/ecodesign/xpro.html⟩; 2013 [accessed 01.12.13].
[58] IVAM. IVAM database website. ⟨http://www.ivam.uva.nl/?id=2&L=1⟩; 2015 [accessed 01.09.15].
[59] Solís-Guzmán J, Marrero M, Ramírez-de-Arellano A. Methodology for determining the ecological footprint of the construction of residential buildings in Andalusia (Spain). Ecol Indic 2013;25:239–49.
[60] Martínez-Rocamora A. Influencia de las bases de datos de ACV en el cálculo de la huella ecológica en edificación / Influence of LCA databases in the calculation of the Ecological Footprint in building construction (Master thesis). University of Seville: 2012.
[61] González-Vallejo P, Marrero M, Solís-Guzmán J. The ecological footprint of dwelling construction in Spain. Ecol Indic 2015;52:75–84.