ANNEX 72

EBC
Energy in Building and Communities Programme

International Energy Agency

World Building Life-Cycle Based Databases and Repositories for the Building and Construction Sector

Energy in Buildings and Communities Programme

February 2023

Technology Collaboration Programme
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Photo on front page: Construction site in Chennai (Madras), India, Sivakumar Palaniappan © 2023

Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)

Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
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Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems

Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

Introduction

As manufacturing process is getting more advanced, it is common that building materials which are not produced in the same territory, or even manufactured at overseas factories are used in construction fields. In this case, the database must reflect the actual construction materials and activities in order to accurately calculate the environmental impacts caused by a building product, elements and building systems. Under such circumstances in which multinational products are imported and built or manufactured using overseas raw materials, it is necessary to check the current status of available LCA databases not only within the country, but also overseas databases. It is also important to find out compatibility with existing LCA design tools used in the construction sector, including BIM. In addition, although many guidance and international standards have been developed on how to establish LCA databases, still it is necessary to check if these databases are really compliant to the internationally agreed guidelines and standards.

Objectives and contents of the report

This report provides an overview of the currently existing life-cycle based databases and repositories, which can be applied to building and construction sectors, and provided by major countries, organisations and global consulting companies. The report comprises the following parts:

- Analysis on general aspects of world's life-cycle based databases (chapter 2)
- Analysis on applicable LCA databases and their quality check for building and construction sectors (chapter 3)
- Comparison of environmental impacts between similar products in same category of EPD programs (chapter 4)
- Analysis on limitation and suggestions of Current LCA database in building and construction sectors (chapter 5)

General aspects of world's life-cycle based databases

Most of the databases were provided in the form of life cycle inventories (60%). The surveyed LCA related databases mostly contain generic datasets (56%). The most widely used method is process based LCA (75%). The main standards applied to the databases are ISO 14020 series, ISO 14040 series, ISO 14064 and ISO 14067 (40%). More than half of the data used to build unit process data was from industry (53%). More than half of the databases cover all life cycle stage, i.e. cradle-to-grave (51%). Greenhouse gas emissions, were addressed by 44% of the LCA databases and repositories. It is the environmental impact category quantified most often.

Applicable LCA databases and their quality check

As a result of investigating nearly 100 databases and repositories, it was very rare to follow the internationally common LCI data format such as ILCD or EcoSpold. In some cases, specific results were provided in pdf, excel for product level comparison only, or to check only the values through the web. On the other hand, some databases have been developed with compatibility with various LCA tools to allow LCA study at the building level.

Most LCI and LCA databases and repositories reflect the market conditions of their own country and target the domestic market. Even all evaluation processes are transparently presented, some unit process data can be hidden due to confidentiality issues. Datasets with low data quality does not always mean that there is a large error. But LCA study will be more accurate if the user is in a position to independently identify the most appropriate dataset. All contents related to data quality should be documented and disclosed so that the user can select a database or repository suitable for his or her purpose.

Comparison of environmental impacts between similar products in EPD programs

Various units such as length, weight, volume and area are used in building product EPD. Even in the same product category, it is found cases that length, area, and weight units are applied simultaneously. It is difficult to perform a fair comparison between similar products on their environmental impacts if only EPD results are documented in the database and published without considering these different assumption and without presenting the unit process modelling.

Suggestions of current LCA database in building and construction sectors

On a product level, the differences between LCA data from databases and repositories may be little significant per same declared unit. On the other hand, since the difference can cause a major exaggerated evaluation in a building scale during a whole life cycle stage, the evaluator needs to check and utilize how the product data was developed. It is necessary to unify the LCA methodology in detail and to improve the data quality in order for such users to use the database or repository correctly. It is necessary to describe available data sources which help database developer to apply similar data collection method. In addition, database developers should disclose data quality information so that users can improve the accuracy of evaluation results by selecting the most appropriate datasets. In order to compare between similar products, the results of LCA study should be expressed with a sufficient number of environmental indicators according to international trends.

Table of content

Abbreviations

Abbreviations	Meaning
EPD	Environmental Product Declaration
ILCD	International Reference Life Cycle Data System
GHG	Greenhouse Gas
GWP	Global Warming Potential
LCA	Life cycle Assessment
LCI	Life cycle Inventory
PCR	Product Category Rules
PEP	Product Environmental Profiles

Definitions

Definitions of energy performance according to EN 15603:2008 (Official Journal of the EU, 19.4. 2012, p. C 115/9) and econcept (embodied energy):

Energy source: source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

Energy carrier: substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.

System boundary: boundary that includes within it all areas associated with the building (both inside and outside the building) where energy is consumed or produced.

Energy need for heating or cooling: heat to be delivered to or extracted from a conditioned space to maintain intended temperature conditions during a given period of time.

Energy need for domestic hot water: heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point.

Energy use for space heating or cooling or domestic hot water: energy input to the heating, cooling or hot water system to satisfy the energy need for heating, cooling or hot water respectively.

Energy use for ventilation: electrical energy input to the ventilation system for air transport and heat recovery (not including the energy input for preheating the air).

Energy use for lighting: electrical energy input to the lighting system.

Renewable energy: energy from sources that are not depleted by extraction, such as solar energy (thermal and photovoltaic), wind, water power, renewed biomass. (definition different from the one used in Directive 2010/31/EU).

Delivered energy: energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (heating, cooling, ventilation, domestic hot water, lighting, appliances, etc.).

Embodied energy: Comprises the cumulated primary energy demand for production, transportation and disposal of building components, appliances, renewable energy generation units and building construction measures within building renovation.

Embodied carbon: The greenhouse gas emissions caused by a product are sometimes characterized as “embodied carbon”. It does not mean the carbon really embodied in the product itself. It is used in a metaphorical sense to describe the greenhouse gas emissions caused by life cycle stages of a product other than the operation (embodied in a virtual sense).

Exported energy: Energy, expressed per energy carrier, delivered by the technical building systems through the system boundary and used outside the system boundary.

Primary energy: Energy found in the nature that has not been subject to any conversion or transformation process. It is energy contained in raw fuels and other forms of energy received as input. It can be non-renewable or renewable.

Definitions of building life cycle according to ISO 14040:2006:

LCA: Life cycle assessment: compilation and evaluation of the imputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

LCIA: Life cycle impact assessment: phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

unit process: smallest element considered in the life cycle inventory analysis for which input and output data are quantified.

unit process data: Input and output data of a unit process, typically including fuel, electricity and water consumption, raw and working material demand, demand for transport and waste management services as well as discharge of wastes and waste water and pollutants emissions to air and soil.

Definitions of system types according to UN Environment (2011):

Cradle to gate: An assessment that includes part of the product's life cycle, including material acquisition through the production of the studied product and excluding the use or end-of-life stages.

Cradle to grave: A cradle-to-grave assessment considers impacts at each stage of a product's life cycle, from the time natural resources are extracted from the ground and processed through each subsequent stage of manufacturing, transportation, product use, recycling, and ultimately, disposal.

Gate to gate: A dataset which reports the flows to and from a factory. These flows include fuel, electricity and water consumption, raw and working material demand, demand for transport and waste management services as well as discharge of wastes and waste water and pollutants emissions to air and soil. Sometimes the term "unit process" is used (see above).

Aggregated dataset (accumulated system dataset): An activity dataset showing the aggregated environmental exchanges and impacts of the product system related to one specific product from the activity.

1. Introduction

1.1 Background

As Paleari[1] said that only measurable things can be managed, Life cycle Assessment (LCA) database in the building sector is getting more important to calculate the environmental loads that occur during the life cycle of a building relatively accurately. This information is very helpful in developing more efficient sustainable policies and certifications by predicting and comparing environmental loads by scenarios reflecting reality in industry. Building rating schemes and national legislations integrating Life Cycle Assessment at a building level as a tool is more and more being implemented in order to make better decisions which improve the environmental performance of buildings. Increasing digitalization of the construction sector will make it easier to make such assessments.

Since the 2000s, LCA databases have been eagerly developed in depth and variety by global consulting companies or government-led in major countries. Consequently, by the end of 2019, many network resources have been launched to easily access databases from various countries through the internet. However, as manufacturing process is getting more advanced, the construction field often utilizes building materials which are not produced in the same territory, or even manufactured at overseas factories. In this case, the accuracy of environmental performance could decrease if the environmental load from a building is calculated with a database developed in irrelevant countries or academic research. In order to accurately calculate the environmental impacts caused by a building product such as bricks, building elements such as windows, building technologies such as ventilation systems, or building's entire life cycle, the database must reflect the actual construction materials and activities.

Under such circumstances in which multinational products are imported and built or manufactured using overseas raw materials, it is necessary to check the current status of available LCA databases not only within the country, but also overseas databases. It is also important to find out compatibility with existing LCA design tools used in the construction sector, including BIM. In addition, although many guidance and international standards have been developed on how to establish LCA databases, still it is necessary to check if these databases are really compliant to the internationally agreed guidelines and standards. It is possible to encourage usage of LCA databases in building and construction industry by confirming what LCA methodology the databases follow, what their data gaps are, and what level of data quality they offer.

Therefore, this report provides an overview of the Life-cycle based databases and repositories provided by major countries, organisations and global consulting companies. Weaknesses and limitations of the currently existing LCA databases will be analyzed as well as common elementary flow lists, core data formats, LCI methods, review and documentation requirements. As a result, proper driving forces and recommendations will be proposed for more reliable data application to allow for more accurate and comparable LCA in the building sector.

[1] Paleari, M., et. Al. 2016. "The assessment of the relevance of building components and life phases for the environmental profile of nearly zero-energy buildings: life cycle assessment of a multifamily building in Italy." The International Journal of Life Cycle Assessment, 1–24. DOI: 10.1007/s11367-016-1133-6.

1.2 Objectives

The goals and objectives of this report can be summarized as follows.

First an Analysis on Applicable LCA database for Building and Construction sectors is given. This analysis comprises a General survey on existing global, regional, national and industry based life-cycle based databases. The current status and trends in LCA databases is summarised and selected available LCA databases in the building and construction sectors are characterised using data quality indicators.

Second, Environmental product declarations (EPD) and LCA of building materials, building elements and buildings are analysed and discussed. It comprises a general survey on EPD registered in global and national EPD programs. A summary and comparison of current trends in national EPD programs and LCA probgrams for building materials are provided. Finally life cycle related environmental impacts as reported in EPDs of construction products in the same category are compared.

Third, weaknesses and limitations of current LCA databases, EPD programs and LCI databases in the building and construction sectors are analysed. Suggestions are made for ways on how to increase the compatibility of LCI/LCA databases in the building and construction sectors.

1.3 Research methods

Wide and vast online investigation has been executed, visiting all known or suspected national LCA databases projects globally, to characterize in detail their database projects. It is researched factors related database quality check such as periods of data development, organization and its characteristics, sources of unit data aggregation, and so on. In order to examine the trends of global LCA database development, first of all, this report reviewed carefully a total of 95 life-cycle based databases in 25 countries from 1980 to 2020, covering all kinds of industrial sectors, developed by companies, research centers and governmental bodies.

The literature survey was conducted with the following items:

– International Standards and European Standards
– Guidelines from international organization such as UN Environment and European Commission
– Research reports
– Publications and dissertations

Among the investigated databases, there were LCI database, LCA database and studies, EPDs and guidelines. It has been also found some other types of databases with thousands to tens of thousands of datasets that can be specifically applied to agriculture and food sector (e.g. Worldwide LCA food database), chemical sector (e.g. EstiMol), energy sectors (e.g. IEA GHG CO2 Emissions Database). Some databases were explained that they used the LCA method, but it was difficult to confirm the details of methodologies.

Although many databases were investigated, in order to check the characteristics and quality of LCA databases for building and construction sectors, any databases which did not use the traditional methodology such as process-based LCA or that were constructed in a form other than LCA research data, LCA and LCI databases were excluded. Excluded databases were social LCA, GHG protocol, database of emissions factors, and food and agricultural LCAs. In the evaluation methodology, databases created using Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT) were also excluded. On the other hands, environmental profiles, which measure the impacts of construction material, product or building system through lifecycle, were included for the survey because this type of database is specialized in the building and construction sector. Embodied energy and embodied

carbon databases for building products and elements were also included in this study for the same reason.
The contents analysed to derive the characteristics of the database are shown in Table 1.

Table 1 List of frequently used abbreviations

Contents analyzed for life-cycle based databases	
Name of Database	Number of datasets
Categories: Generic/Specific/Building & construction sector	
Released date / Last update	Geographical boundary
Language of website and database	Websites
Purpose of database and main users	Organization name / type / role
Methodology	Applied standards
Data source(s)	Data collection methods
Allocation	Unit process
Data format	Indicators for LCA results
Related certifications and programs	Related LCA software

In this report, the terms process-based LCA, Input-Output LCA, LCA database and LCI database are used. The terms are explained below.
Process-based LCA refers to the LCA approach described in the international standards ISO 14040 and 14040. It relies on bottom-up data on specific processes needed in the supply chain of products or services. Input-Output LCA refers to an LCA approach which relies on macro-economic and environmentally extended input-output tables, some of them being multiregional such as Exiobase.
LCA databases contain datasets with life cycle related environmental impact category indicator results such as greenhouse gas emissions per kg of concrete. The underlying LCI results and/or life cycle inventory unit process data usually are not available. LCI databases offer access to the life cycle inventory unit process data and thus offer maximum transparency. In some cases LCI databases additionally offer life cycle inventory results and environmental impact category indicator results.

2. World Life-cycle based Databases

2.1 General aspects

First of all, in order to screen the LCA databases applicable to the building and construction sectors, 59 life-cycle based databases from 19 countries that are currently available online were surveyed. As seen in Figure 1, most of the databases were provided in the form of life cycle inventory (60%). About 29% of databases were LCA study results or LCA evaluation results using construction-related LCI databases. This includes databases that collect the results of an independent verification process, such as EPD. The other databases include Environmental profile, environmental footprint, and embodied energy and carbon databases (11%).

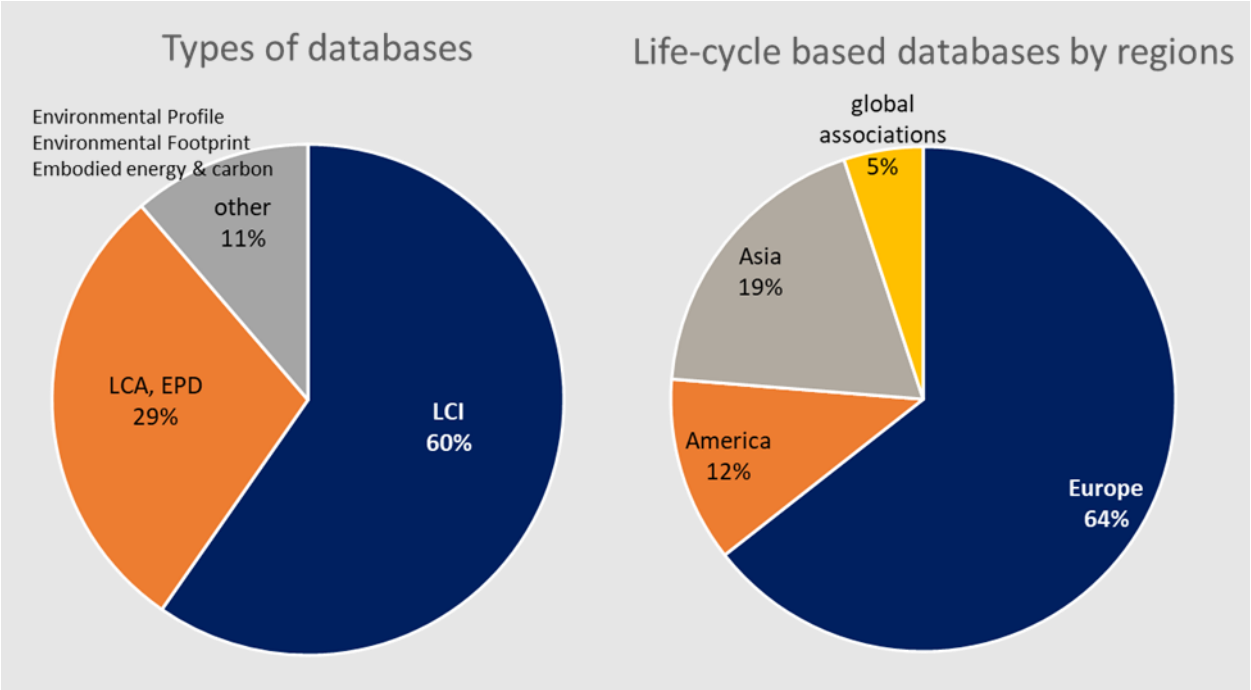


Figure 1 Life-cycle based databases by types and regions

Among the surveyed databases, 38 life-cycle based databases were developed in Europe, accounting for about 64% of the total. The remaining databases were developed 12% in the North and South Americas (7 databases), 19% in Asia (11 databases) and 5% in global level (3 databases). More features of regional databases will be covered in detail in Section 2.2.

Next, the overall characteristics were identified. The characteristics examined include the number of datasets, types of datasets, released time, applied LCA methodologies and standards, origin of data sources and life cycle stages. These details of characteristics will be the basis for determining the credibility of LCA databases developed by different organizations. The characteristics of the databases reviewed in general are as follows:

2.1.1 Number of datasets

Figure 2shows number of datasets in life-cycle based database. The databases with more than 1,000 datasets accounted for 31% of the total. These databases are GaBi database (Germany), ÖKOBAUDAT (Germany), ecoinvent database (Switzerland), INIES (France), BEDEC (Spain), U.S. Life-Cycle Inventory Database and IDEA (Japan). Among these, all databases have developed based on only process-based LCA methodology, except BEDEC, US Inventory database and IDEA, which were applied I-O LCA methodology. INIES and ÖKOBAUDAT platform (EPD repository) are construction-related LCA databases. The KBOB recommendation 2009/1:2016 developed in Switzerland offers LCA data for building and construction sector, although contains slightly less than 1000 datasets.

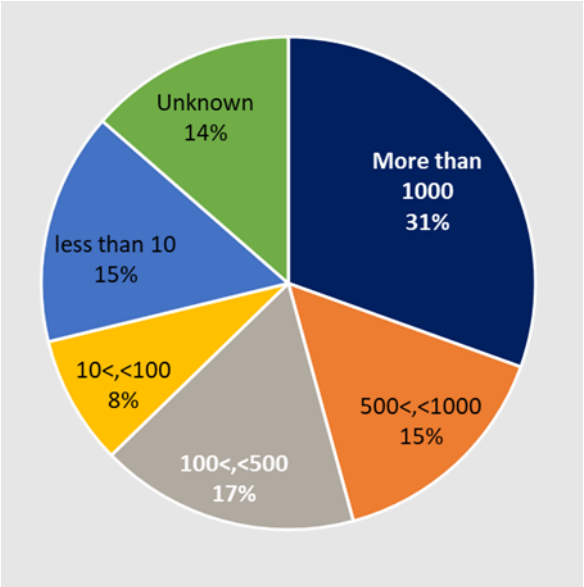


Figure 2 Number of datasets in databases

2.1.2 Categories of datasets

More than half of the surveyed LCA related databases contains datasets from all kinds of industrial sectors such as energy carriers and technologies, transportation, materials production, packaging and waste treatment (see Figure 3). However, it is revealed that 19% of the databases contains only datasets in specific sectors such as metal, energy and fuel, chemical substance and transportation. LCA databases for building materials and elements was found to account for about 25% of the databases.

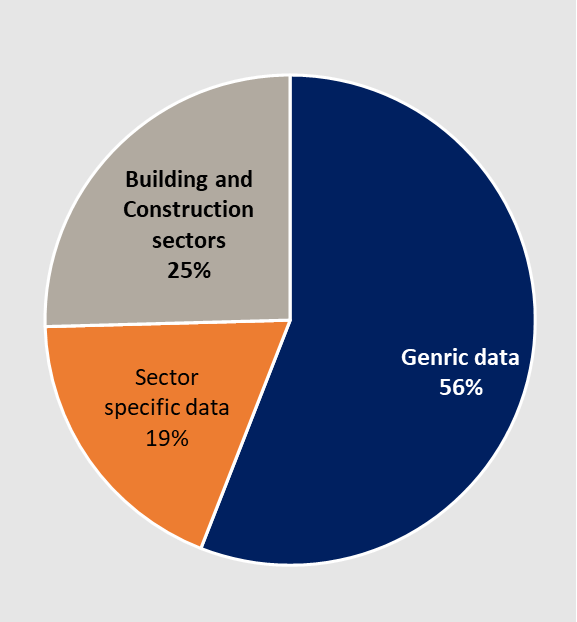


Figure 3 Categories of datasets

2.1.3 Released time

The first LCI database dedicated to building and construction sectors was developed at Bath University, United Kingdom since 1977. It is Inventory of Carbon and Energy database containing more than 400 datasets about embodied energy and embodied carbon of building materials. Embodied energy and carbon were calculated with basic data collected from literature such as other LCI reports, Journals, and books. Depending on the building materials, three types of different life cycles stages were used: cradle-to-gate, cradle-to-site and cradle-to-grave.

One of the earliest forms of LCA database in generic sector was developed with the name of EIME (Environmental Improvement Made Easy) at LCIE Département CODDE, France since 1996. This database was developed for Life Cycle Analysis and ecodesign software to evaluate environmental profiles of

products and services[2]. EIME database is still available online. It contains more than 16,600 environmental data, and the evaluation results can be identified by more than 70 environmental indicators. Data collection for unit process data is utilized both industrial data sources and external LCI databases such as ecoinvent[3], BUWAL, DEAM, EAA or IISI database.

2.1.4 LCA Approach

The most widely used method is process based LCA (see Figure 4). About 75% of the databases is based on this LCA methodology. The IO-LCA method accounts for 11% of screened databases, confirming that this is the most frequently applied of the non-traditional methods. In addition to the ISO 14040 series, there were databases using European standards such as EN 15804 and CEN TC350, ILCD, environmental profile or even IPCC guidelines (14%).

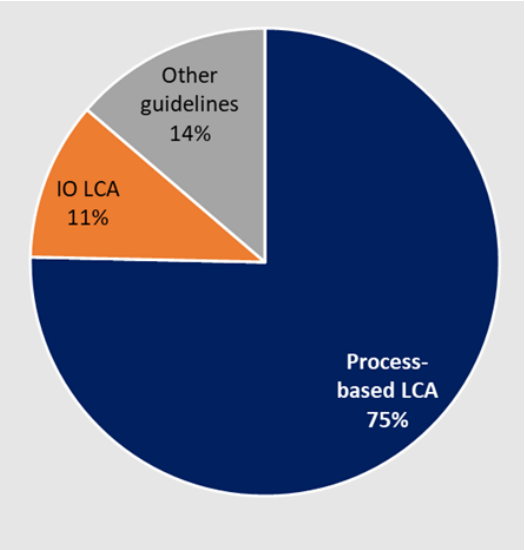


Figure 4 Applied LCA methodologies

2.1.5 Applied Standards

The main standards applied to the LCI and LCA databases are ISO 14020 series, ISO 14040 series, ISO 14064 and ISO 14067 (see Figure 5). It accounts for 50% of all applied standards. About 18% of surveyed databases did not disclose the standards used for database development. European standards such as EN 15804 are indicated for only 10% of the databases. The remaining applied standards and guidelines are GHG related standards such as PAS 2050 and GHG protocols or environmental performance guidelines such as PEF guides and ILCD handbooks.

[2] http://codde.fr/en/our-software/eime-en/eime-presentation

[3] Ecoinvent database and its predecessor are one of the first general application database, first published in 1994. This database published on unit process level since its first version.

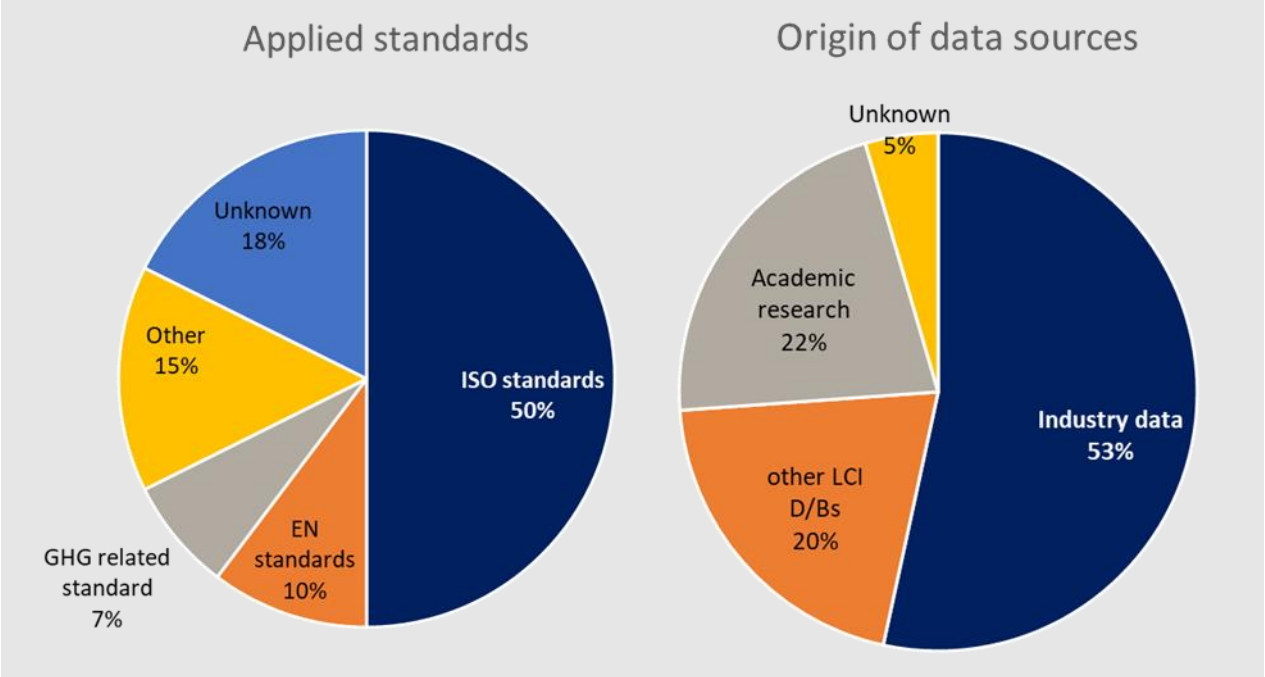


Figure 5 Applied standards and guidelines for life-cycle based databases and their origin of data sources "GHG related standards" (7 %) include PAS 2050 and the GHG protocol; "Other standards" (15 %) include PEF guideline and the ILCD handbook.

2.1.6 Unit Process data development

The origin of data sources used to build unit process data[4] was the most used industry data (53%), followed by external LCI databases built by other organizations (20%) and academic research (22%). There were also about 5% of databases which did not indicate the data sources used.

2.1.7 Aggregated process data development[5]

Nearly half of the databases cover all life cycle stage, cradle-to-grave (see Figure 6). Since the system boundaries of the surveyed databases were largely divided into cradle-to-grave and cradle-to-gate, the "gate-to-gate" option could not be surveyed. The next most chosen life cycle stage is the cradle-to-gate (35%). 12% of total have chosen more detailed lifecycles such as cradle-to-consumer or cradle-to-site.

2.1.8 Indicators for the results

Most of the environmental impacts were presented in the form of greenhouse gas emissions (44%, see Figure 6), and primary energy consumption are also utilized by 27%. In addition to these most popular environmental indicators, it is also widely used the seven major environmental impacts proposed by Environmental Product Declaration namely global warming, depletion of resources (elements and fossil fuels), eutrophication, acidification for soil and water, ozone depletion, photochemical ozone creation (27%).

[4] see explanation of the term in the Section „Definitions".
[5] also termed „aggregated dataset"; see explanation of the term as well as the terms „cradle-to-grave", „cradle-to-gate" and „gate-to-gate" in the Section „Definitions".

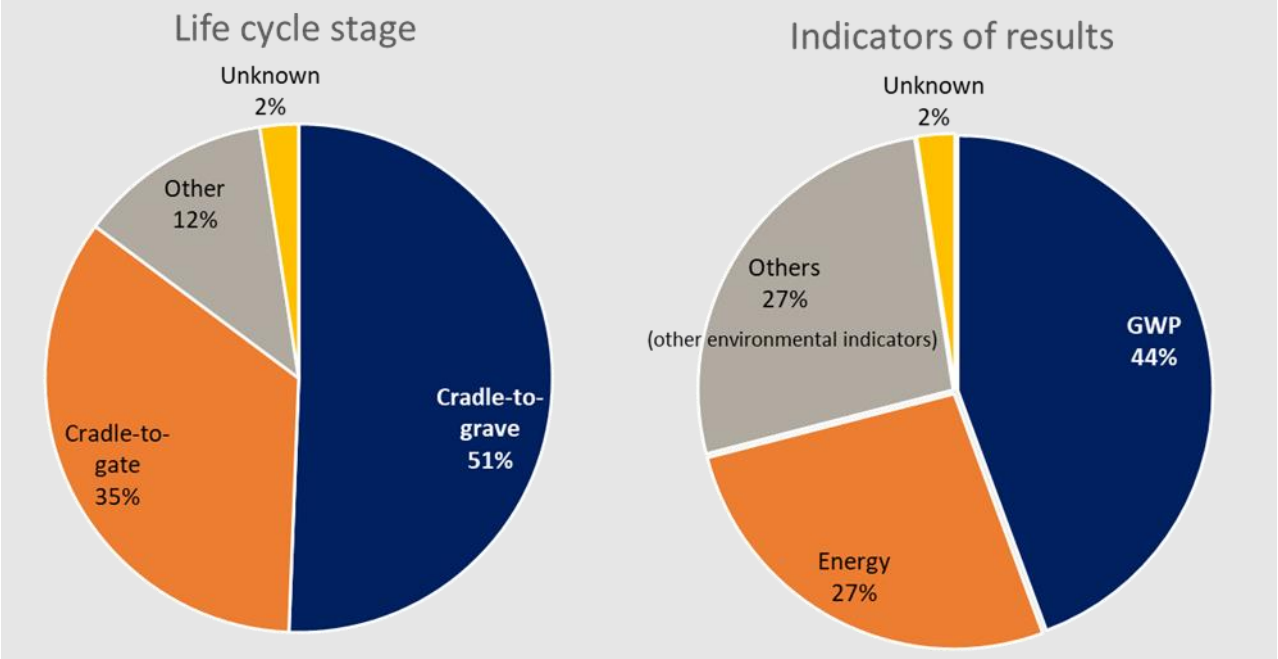


Figure 6 Life cycle stage and indicator of environmental results

2.2 General Status of Life-cycle Based Databases by Region

2.2.1 By global associations

Since the mid-1990s, life-cycle based databases for specific sectors have been developed by several international organizations (see Figure 7). Still, there is no global level of LCA databases applicable to the building and construction field. Only three LCI databases developed by global institutes and associations were found for steel and zinc industry products.

Databases developed by international organizations are usually in the form of emission factors libraries (e.g. IPCC Emissions Factor Database) or GHG emissions inventories (e.g. Greenhouse Gas Protocol). International Energy Agency (IEA) developed IEA GHG CO2 emissions database during 1996 to 2003. It contains 1400 datasets available for overall industry and agriculture in addition to energy and transportation. IEA GHG emissions database is a global database of large stationary point sources of CO2 emissions from publicly available sources. Its data sources are various such as external LCI databases from other LCA software, academic research and industrial data. Life cycle covers cradle to grave, and the evaluation result appears only as CO2. The database was developed before the international standards were established for LCA evaluation method, so care should be taken when using it in the building and construction sector. Detailed features of the LCI databases built at the global level can be found in the following Table 2.

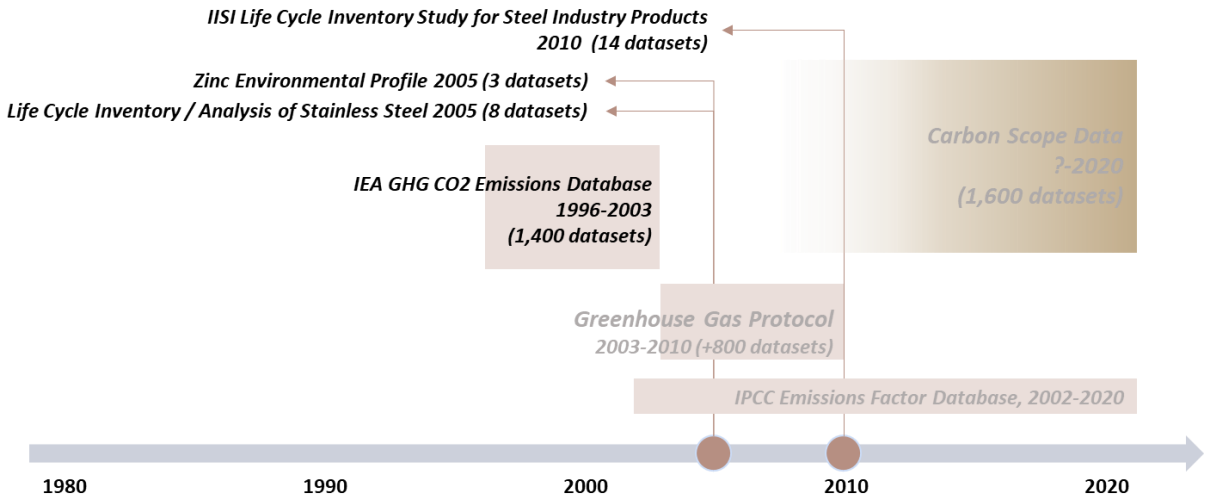


Figure 7 LCI and emissions databases developed by global unions

Table 2 Detailed features of the LCI databases of global level

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO 14040s	PAS2050	GHG Protocol	Other	
1	Global	IISI Life Cycle Inventory Study for Steel Industry Products	International Iron and Steel Institute (IISI)	Process-based LCA	○				Environmental assessment
2	Global(Europe, Japan, Korea, USA)	Life Cycle Inventory / Analysis of Stainless Steel	International Stainless Steel Federation (ISSF)	Process-based LCA	○				Environmental assessment
3	Global	Zinc Environmental Profile	International Zinc Association (IZA)	Process-based LCA	○				Environmental assessment

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Global	IISI Life Cycle Inventory Study for Steel Industry Products			○		○				○		Unknown
2	Global(Europe, Japan, Korea, USA)	Life Cycle Inventory / Analysis of Stainless Steel			○			○			○		Unknown
3	Global	Zinc Environmental Profile			○		○				○		PDF

2.2.2 By European associations

The first life-cycle based database at European level began in the form of an environmental profile. It was started from Eco-Profiles of the European Plastics Industry, which contains about 100 datasets were developed from 1992 to 2010 (see Figure 8). In 2013, the environmental profiles for six aluminum products were reported by European Aluminum Association[6]. These Product Environmental Profiles originated to Life Cycle Assessment and designed as a standard format for reporting products impacts. Since 2012, A Product Environmental Footprint (PEF) has been developed by the European Commission in cooperation with companies and sustainability experts. The Environmental Footprint database contains more than 5,000 generic datasets. The PEF aims to determine all relevant environmental and health impacts as well as resource-related burdens caused by a product. For the calculation, the entire life cycle of the products is considered, from raw material procurement to disposal.

[6] Environmental Profile Report for the European Aluminum Industry. https://www.european-aluminium.eu/media/1329/environmental-profile-report-for-the-european-aluminium-industry.pdf

At the European level, there is no LCI database that can be directly applied to building and construction sectors. Instead, two LCI databases for the European energy and manufacturing system were developed: NEEDS LCI database (2009) and European Reference Life Cycle Database 2.0(2006-2010). The NEEDS LCI database contains 9 datasets of international industrial life cycle inventory data on future electricity and material supply systems, future transport services. The European Reference Life Cycle Database 2.0(ELCD), developed by the Joint Research Center in the European Commission, contains more than 300 generic datasets on EU-level of materials, energy carriers, transport, and waste management. Its data sources were various including industrial data, academic research and external LCI databases, based on the process-based LCA methodology.

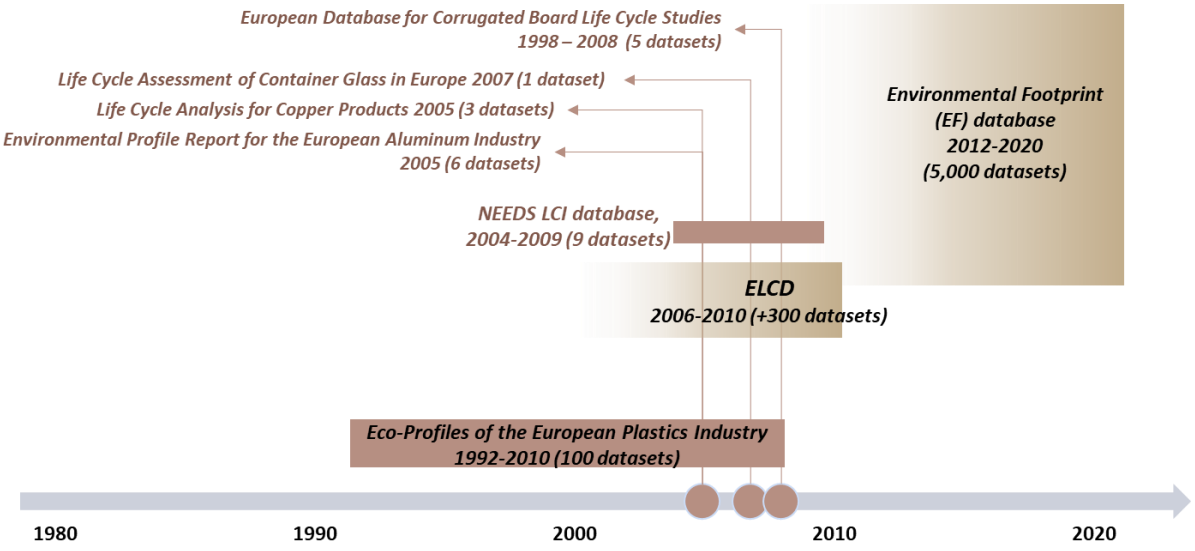


Figure 8 Development periods of LCI and LCA databases of European associations and number of datasets

On the other hand, there found three LCA databases on metal products: Life Cycle Analysis for Copper Products (2005, 3 datasets), Life Cycle Assessment of Container Glass in Europe (2007, 1 dataset), European Database for Corrugated Board Life Cycle Studies (2009, 5 datasets). These sector specific databases contain one to five datasets on construction materials.
Detailed features of the databases built at the European level is described in the following Table 3. Most databases follow the process-based LCA approach as specified in the ISO 14040/14044 standards. They are offered for environmental assessment. All databases contain industry data and offer greenhouse gas emissions (global warming potential, GWP).

Table 3 Detailed features of the LCI and LCA databases of European level

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO 14040s	PAS2050	GHG Protocol	Other	
1	Europe	Eco-Profiles of the European Plastics Industry	PlasticsEurope	Process-based LCA (bottom-up)	○				Environmental assessment
2	Europe	Environmental Footprint (EF) database	European commission	Process-based LCA				PEF	environmental assessment and labeling
3	Europe	Environmental Profile Report for the European Aluminum Industry	European Aluminum Association	Process-based LCA	○				Environmental assessment
4	Europe	European Database for Corrugated Board Life Cycle Studies, 2009	European Federation of Corrugated Board Manufacturers	Process-based LCA Attributional modelling	○				Environmental assessment
5	Europe	European Reference Life Cycle Database 2.0(ELCD)	European commission – Joint Research Centre	Process-based LCA	○				Environmental assessment
6	EU 27 plus Switzerland and Turkey	Life Cycle Assessment of Container Glass in Europe	European Container Glass Association	Process-based LCA Attributional modelling	○				Environmental assessment
7	Europe (EU 25)	Life Cycle Analysis for Copper Products	European Copper Institute	Process-based LCA Attributional modelling	Unknown				Environmental assessment
8	Europe	NEEDS LCI database	NEEDS (New Energy Externalities Developments for Sustainability)	Hybrid LCA, LCC Impact Pathway Approach (IPA)	Unknown				LCC of energy policies and of future energy systems

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Europe	Eco-Profiles of the European Plastics Industry	ELCD, Ecoinvent		○		○			○	○	○	Microsoft office, Adobe Reader
2	Europe	Environmental Footprint (EF) database			○		-	-	-		○		Various
3	Europe	Environmental Profile Report for the European Aluminum Industry			○			○			○		Web browser, PDF
4	Europe	European Database for Corrugated Board Life Cycle Studies, 2009			○			○			○		Web browser, PDF, EcoSpold
5	Europe	European Reference Life Cycle Database 2.0(ELCD)	○	○	○			○			○		Web browser
6	EU 27 plus Switzerland and Turkey	Life Cycle Assessment of Container Glass in Europe	○		○				Cradle-to-cradle		○		Web browser, ILCD format
7	Europe (EU 25)	Life Cycle Analysis for Copper Products			○		○				○		Web browser, PDF
8	Europe	NEEDS LCI database	○		○			○		○	○	Economic Social Indicators	EcoSenseWeb tool, PDF

2.3 General status of life-cycle based databases by countries in Europe

2.3.1 General aspects

A total of 38 life-cycle based databases were developed in the European region (see Figure 9). The Switzerland has developed 8 databases with the largest number, followed by United Kingdom and Germany with 5 databases, 4 with France and 3 with Netherlands. In other countries, one national database has been developed. As seen in figure XX, about 56% of databases contains generic datasets and 37% contains datasets for building and construction. Most of the databases were provided in the form of life cycle inventory (52%). About 42% of databases were LCA study results, LCA evaluation and EPD.

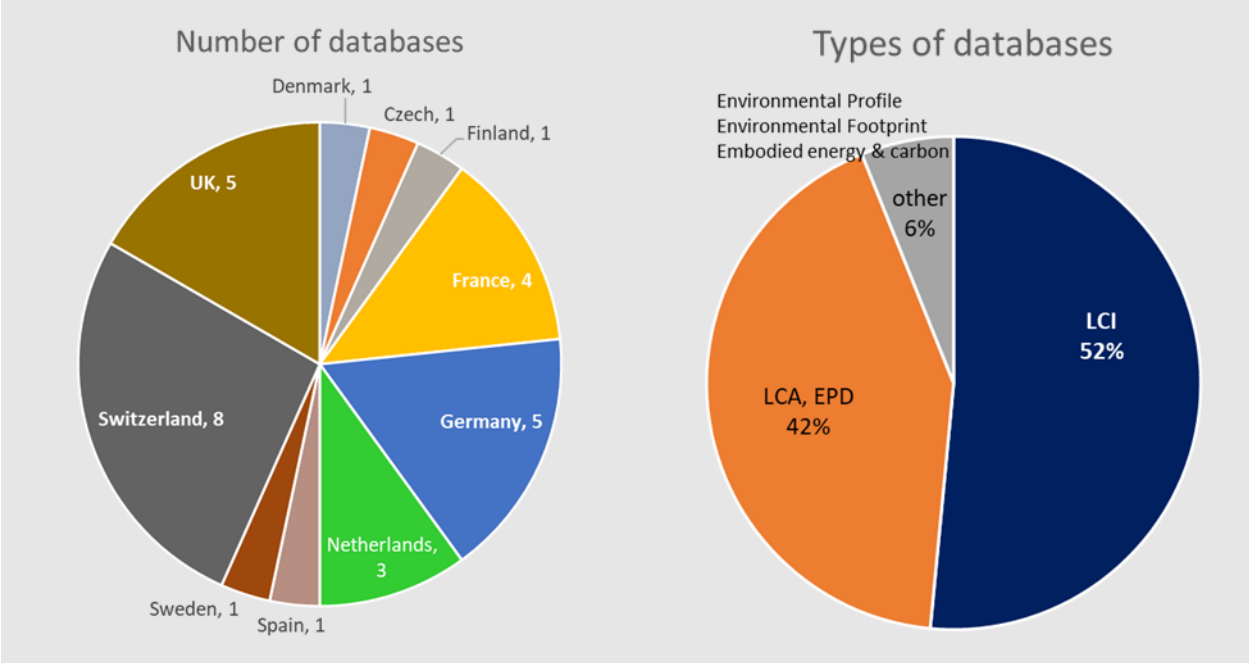


Figure 9 Number of databases developed in Europe and types of databases

The most applied methodologies were identified in the order of process-based LCA (73%, see Figure 10), other guidelines (16%) and IO LCA (11%). In Europe, ISO standards accounted for 46% of the total and European standards and related guidelines (e.g. ILCD, environmental footprint and PCR) accounted for 36%. The main data sources accounted for 43% of industrial data, 26% of other external LCA databases, and 20% of academic research. The system boundary is that more than half of the database (56%) adopts the cradle-to-grave life cycle. Global Warming Potential is the most commonly used indicator for the environmental impact. (41%). Next, the results of environmental impact are presented with energy indicators (27%) and other environmental indicators (29%).

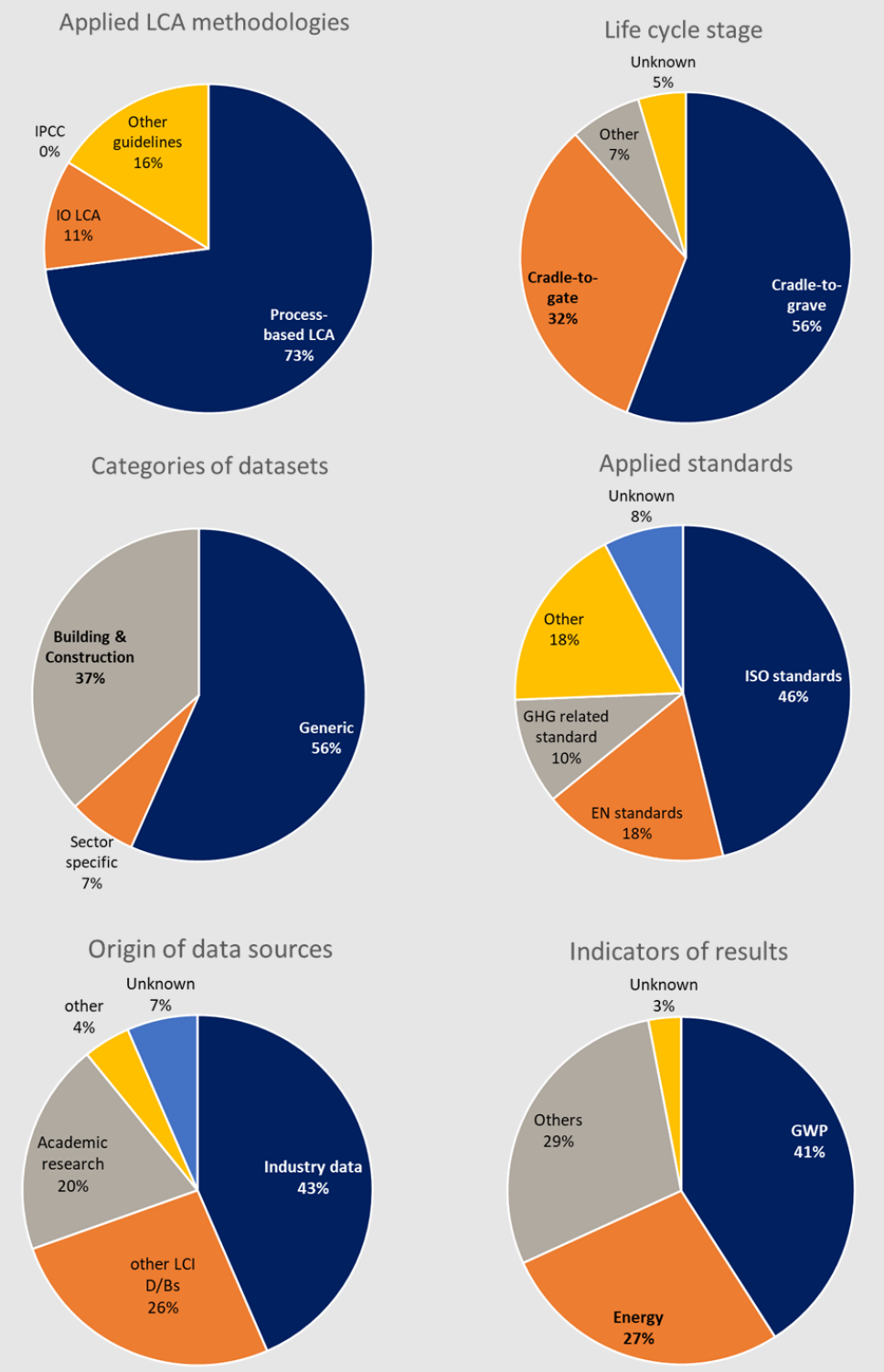


Figure 10 Detailed trends of databases developed in Europe
"Other guidelines" (top left): national protocols and the like
"Other life cycle stages" (top right): e.g. gate to gate.
"Other applied standards" (middle right): e.g. PEF guide, ILCD handbook
"Other origin of data sources" (bottom left): e.g. national statistics, public topical databases (emission factors handbook for industrial processes or means of transport)
"Other indicators of results" (bottom right): e.g. acidification, eutrophication, ozone depletion.

2.3.2 Switzerland

In Switzerland, a number of generic LCI databases have been developed (see Figure 11). Other LCI databases dedicated to packaging production, agriculture, and food with many datasets.

The world famous LCI database, not only in Switzerland, is Ecoinvent. Ecoinvent contains around 17,000 LCI datasets in various economic sectors such as energy supply, agriculture, transport, biofuels and biomaterials, bulk and specialty chemicals, construction materials, wood, and waste treatment. The datasets can be used in a broad range of environmental studies including Life Cycle Assessment (LCA), Environmental Product Declaration (EPD) and Design for Environmental or Carbon Footprint.

Another well-known LCI database is ESU LCI database. ESU-services offers several data for life cycle assessment in electronic format in order to facilitate data collection. All datasets are created according to a file format called EcoSpold that has been developed within the ecoinvent. The EcoSpold format follows the guidelines of ISO 14048 and its XML-files can be directly implemented in many commercial LCA software products (e.g. SimaPro, openLCA, Umberto and GaBi). Unit process raw data (UPR) are sold for 300 CHF each.

In addition, some LCI databases such as LC-Inventories or UVEK LCI data DQRv2:2016, 2018 and 2022 were developed starting from the ecoinvent background database v2.2 in various publicly funded projects. These databases are used by the Swiss Federal Administration.

There is one building-specific LCA database, KBOB recommendation 2009/1:2022, developed in Switzerland. The database is based on and an excerpt of the UVEK LCI data DQRv2:2022 and contains life cycle assessment data on construction materials, building technology, energy provision, transport and disposal processes. The data is available in pdf document for the average environmental impact of the construction materials in Swiss market. Also the data is available in Excel version for manufacturer-specific and manufacturer region-specific data on selected construction materials.

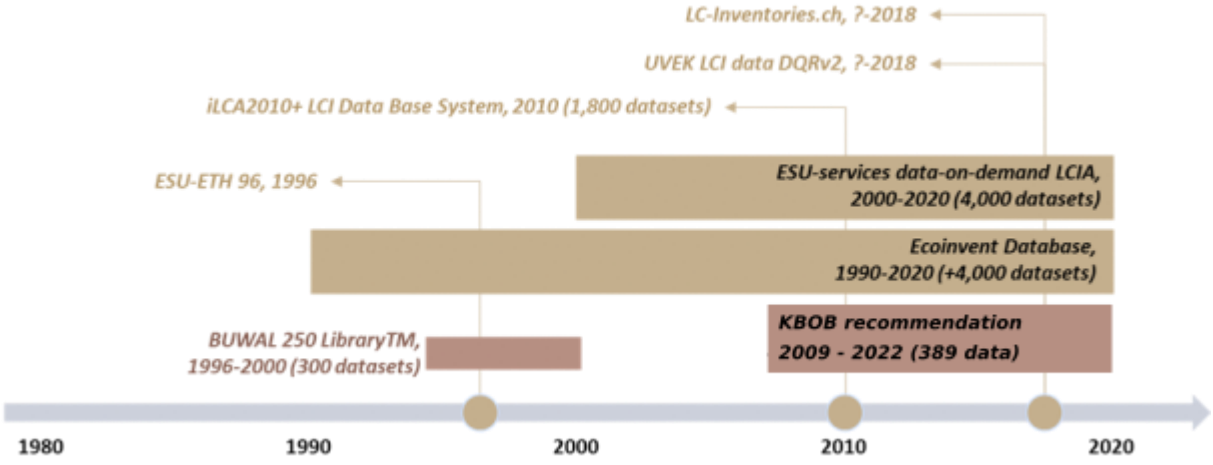


Figure 11 Development periods of databases and number of datasets in Switzerland

Detailed features of the databases developed in Switzerland are described in the following Table 4. All databases are process-based and most of them refer to the ISO standards 14040/14044. They are used for environmental assessments. They contain industry data and their scope is often cradle to grave. The impact assessment covers primary energy, greenhouse gas emissions and other environmental impacts.

Table 4 Detailed features of the databases developed in Switzerland

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Switzerland	BUWAL 250 LibraryTM	Swiss Packaging Institute	Process-based LCA	ISO 14040s				Packaging production
2	Global	Ecoinvent Database v2.2	Swiss Centre for Life Cycle Inventories	Process-based LCA, other	ISO 14040s				Environmental assessment
3	Switzerland, Europe	ESU-ETH 96	ETH Zürich	Process-based LCA	Unknown				Environmental assessment
4	Switzerland, Europe, Global	ESU-services data-on-demand LCIA	ESU-services Ltd.	Process-based LCA	ISO 14040 ISO 14067		PAS 2050 WRI		Environmental assessment
5	Global	iLCA2010+ LCI Data Base System	Gruner-Team Sustainability	Process-based LCA	Unknown				Environmental assessment
6	Switzerland, Europe, Global	LC-Inventories.ch	Swiss Federal Office of the Environment, (SFOE)	Process-based LCA	ISO 14040s				Environmental assessment
7	Switzerland, Europe, Global	UVEK LCI data DQRv2 : 2018	Platform Life Cycle Assessment in the construction sector	Process-based LCA	ISO 14040s				Environmental assessment
8	Switzerland	KBOB recommendation 2009/1:2016	KBOB	Process-based LCA	ISO 14040s				Environmental assessment

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Switzerland	BUWAL 250 LibraryTM			○			○			○		Excel, PDF, SimaPro
2	Global	Ecoinvent Database v2.2	○	○	○			○		○	○	○	Ecoinvent, Excel
3	Switzerland, Europe	ESU-ETH 96	Unknown					○			○		EcoSpold, SimaPro, Umberto, GaBi
4	Switzerland, Europe, Global	ESU-services data-on-demand LCIA	○	○	○		○	○		○	○	○	EcoSpold, Excel, SimaPro, Umberto, GaBi
5	Global	iLCA2010+ LCI Data Base System	○				Unknown			Unknown			Various formats
6	Switzerland, Europe, Global	LC-Inventories.ch		○	○			○		○	○	○	Ecoinvent, OpenLCA
7	Switzerland, Europe, Global	UVEK LCI data DQRv2 : 2018		○	○			○		○	○	○	Ecoinvent, OpenLCA
8	Switzerland	KBOB recommendation 2009/1:2016			○			○		○	○	○	PDF, Excel

2.3.3 United Kingdom

As the UK operates a variety of certification systems and programs to review the environmental impacts of products and services, several operating organizations have developed LCI databases that can be used specifically across industries including building and construction sectors (see Figure 12). Since BREEAM recognizes and encourages the use of appropriate LCA tools for building applications, five LCI database have been developed for use exclusively in the building and construction sector.

The first construction-specific LCI database released in the UK is the Bath Inventory of Carbon and Energy database developed by Bath University. It was created from a large review of the literature and contains data of embodied energy and carbon of building materials. Also known as Bath ICE, this database has been updated at periodic intervals until today under the name ICE database. Green Book Live is a free online database designed to identify products and service that reduce their impact on the environment. It contains a wide range of products and services, from commercial building products and services to domestic energy efficiency products. The RICS Building Carbon database has been created to provide a source of data that can be compared in detail in order to reduce carbon emissions from a building. EuGeos' 15804-IA Database released by EuGeos at unknown period is an extended version of Ecoinvent to allow calculation of the indicators required in construction product EPD to meet European standard EN

15804. It can be used for verified ISO 14025-compliant EPD Programs, but it is not a pre-verified EPD tool. Detailed features of the life-cycle based databases developed in United Kingdom can be found in the following Table 5. All databases are process-based. They refer to a variety of ISO, EN and other standards and are used for a variety of different purposes. The sources of data are diverse but their scope is always cradle to grave and partly additionally cradle to gate (or cradle to site). They cover further environmental impacts besides primary energy and greenhouse gas emissions..

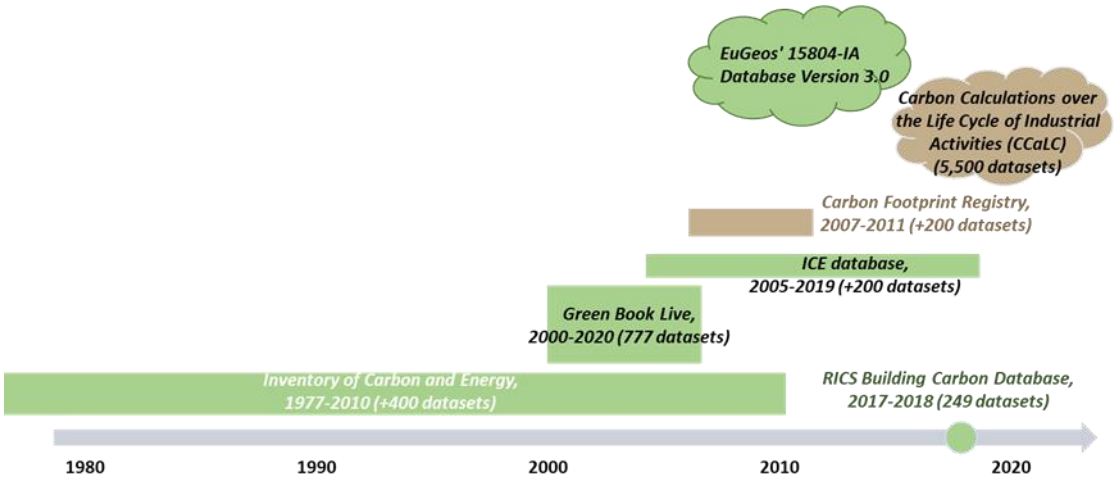


Figure 12 Development periods of databases and number of datasets in UK

Table 5 Detailed features of the databases developed in UK

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Global	Carbon Calculations over the Life Cycle of Industrial Activities (CCaLC)	The University of Manchester	Process-based LCA	-	-	-	-	CCaLC software tool
2	UK	EuGeos' 15804-IA Database Version 3.0	EuGeos	Process-based LCA CML 2012 baseline (EN 15804)	ISO14025	EN 15804		CEN TC350	Construction material EPD
3	UK	Green Book Live	Building Research Establishment	Eco-profile	ISO14025 ISO 14040				Information of Environmental performance
4	Global	ICE database (The Inventory of Carbon and Energy)	Circular Ecology, SERT at University of Bath	Process-based LCA	ISO 14040 ISO/CD 14067		PAS 2050 IPCC	French Environm-ental labelling	Embodied Energy & Carbon of construction materials
5	UK	RICS Building Carbon Database	UK GBC	Process-based LCA		EN 15978			embodied carbon data for whole building

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Global	Carbon Calculations over the Life Cycle of Industrial Activities (CCaLC)	CCaLC, ILCD, Ecoinvent				○	○		Unknown			Excel
2	UK	EuGeos' 15804-IA Database Version 3.0			○			○		○	○	○	Ecoinvent
3	UK	Green Book Live			○			○		○	○	○	Web browser, PDF
4	Global	ICE database (The Inventory of Carbon and Energy)	○	○			○	○	Cradle-to-site		○		Web browser
5	UK	RICS Building Carbon Database	Unknown				○	○	Cradle-to-site		○		Web browser

2.3.4 Germany

Germany is not only well known for LCA software ‘Gabi’, but also for well-established database of environmental and social information on a variety of sectors, from energy and chemicals to the Social LCA

database (see Figure 13). Each LCI database has huge datasets developed with profound research on both academic and industrial fields.

The generic LCI databases are GaBi Databases, openLCA LCIA methods v2.0.4, EstiMol, and ProBas. Gabi is the one of the world's best LCA software. OpenLCA LCIA methods is a packages of environmental impact assessment methods for use with different databases available in the openLCA Nexus system. EstiMol, a database for estimate LCI(A) data from the molecular structure of chemicals, provides cradle-to-gate Global Warming Potential (GWP), Cumulated Energy Demand (CED) and EcoIndicator 99 for roughly 14.000 substances. ProBas, the abbreviation of Process-oriented basic data for environmental management instruments, is a web portal library for life cycle data launched by The Federal Environment Agency and the International Institute for Sustainability Analysis and Strategies (IINAS).

Germany has an extensive database of applications in building and construction sectors. The ÖKO-BAUDAT platform contains over 1300 EPD datasets for building materials, provided by the German Federal Ministry of the Interior, Construction and Home Affairs (BMI). The ÖKOBAUDAT database is combined with the Sustainable Building Assessment System (BNB). The platform offers building materials, construction, transport, energy and disposal processes for the life cycle assessment of buildings in accordance with DIN EN 15804 since 2013. ÖKOBAUDAT also offers both generic datasets and company or association-specific datasets from environmental product declarations. ÖKOBAUDAT database are based on the “GaBi” and “ecoinvent” background database.

Detailed features of the databases developed in Germany are described in the following Table 6. All databases are process-based. They refer to a variety of ISO, EN and other standards and are used for a variety of different purposes. The main source is industry data and their scope is cradle to grave in most cases and partly additionally cradle to gate. They cover further environmental impacts besides primary energy and greenhouse gas emissions..

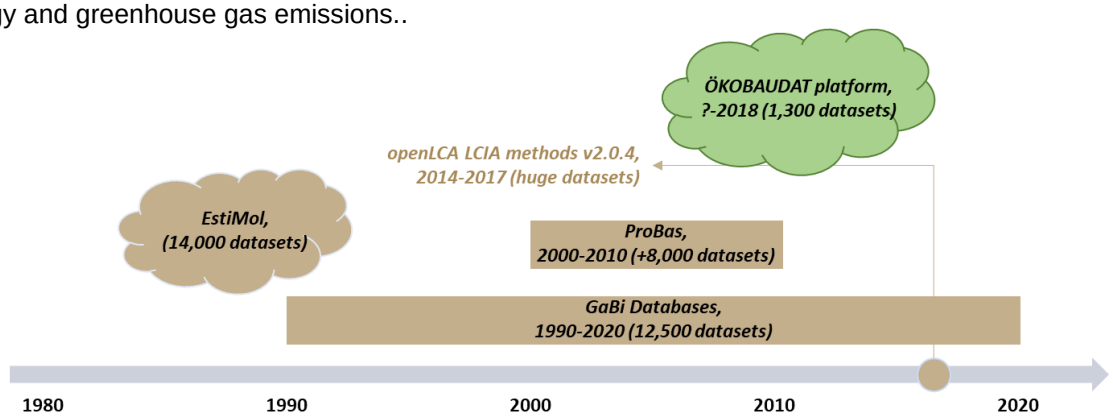


Figure 13 Development periods of LCI/EPD databases and number of datasets in Germany

Table 6 Detailed features of the databases developed in Germany

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Germany	EstiMol	ifu Hamburg	Process-based LCA	-	-	-	-	Chemical substance
2	Germany	GaBi Databases	Thinkstep	Process-based LCA Attributional modelling	ISO 14044, ISO 14064 and ISO 14025	○		ILCD, EF	Gabi software
3	Germany	ÖKOBAUDAT platform	BMUB	Process-based LCA		DIN EN 15804		PCR	Building LCA
4	Global	openLCA LCIA methods v2.0.4	?	Process-based LCA	○				
5	Germany	ProBas	Federal Environment Agency - Germany	Process-based LCA	ISO 14040s				IT-supported project

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Germany	EstiMol			○		○			○	○		Ecoinvent, Gabi, Umberto
2	Germany	GaBi Databases			○		○	○		○	○	○	GaBi
3	Germany	ÖKOBAUDAT platform			○			○		○	○	○	XML-Format, OpenLCA, SimaPro
4	Global	openLCA LCIA methods v2.0.4	○			ILCD, EF	○	○		○	○	○	ecospold, .olca, .zolca
5	Germany	ProBas	○	○			○	○			○		Web Browser, PDF

2.3.5 France

French government has eagerly operated various LCI databases in order to promote many environmental implementations with ambitious agenda of planning measures to reduce environmental impact on earth (see Figure 14). There were identified 1 generic LCI databases (DEAM), 1 generic LCA database (EIME) and 2 building and construction LCA databases (INIES and DIOGEN) for this research. The oldest LCA database is the EIME (Environmental Improvement Made Easy) database developed by CODDE, center of expertise specialized in LCA and Eco-design for over 20 years. EIME is a tool to execute LCA studies for eco-design, Environmental Product Declaration, self-declaration and environmental labeling. DEAM, an abbreviation of Data for Environmental Analsys and Management, are Ecobilan Group's general catalogue of data that can be purchased for use with TEAM software.

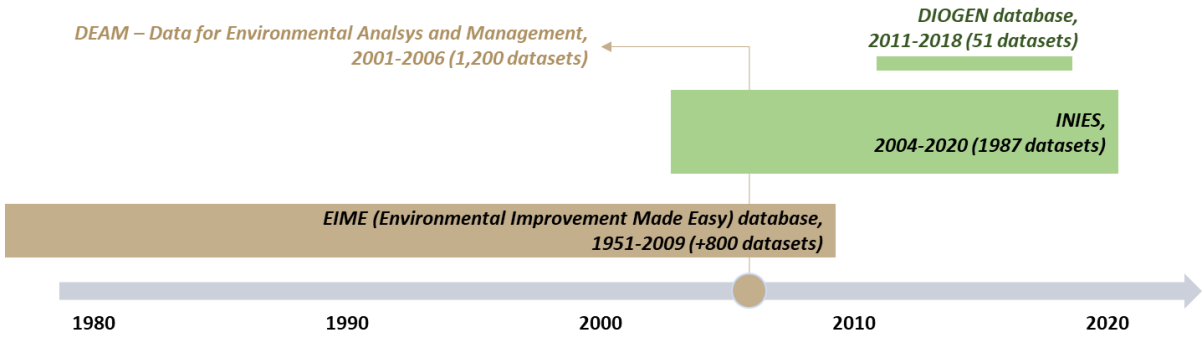


Figure 14 Development periods of databases and number of datasets in France

Interestingly, in France, it is confirmed that there has developed and operated two massive LCA databases for building and construction sectors. INIES is the French national reference database of environmental and health declarations for building products, Product Environmental Profiles (PEP) for

Equipment, data about services (energy, water, etc.) and material life cycle inventories. All information for unit process data is provided voluntarily by manufacturers and associations in compliant with French regulatory requirements and the French and European standards. A significant portion of database is audited by an independent third party. The another building specified LCA database is DIOGEN database provided by The French Association for Construction AFPC. DIOGEN database offers in form of downloadable files such as PDF, excel or Ciogen, the environmental impacts from building materials in civil engineering works. The database is corresponding to cradle-to-gate which covers steps A1 to A3 of standard NF EN 15804. Unit process data is also reviewed by a committee of experts.
Detailed features of the databases developed in France are described in the following Table 7. All except one of the databases are process-based. They refer to a variety of ISO, EN and other standards and are used for a variety of different purposes. The main source is industry data and their scope is cradle to gate in most cases and partly additionally cradle to grave. They cover further environmental impacts besides primary energy and greenhouse gas emissions.

Table 7 Detailed features of the LCI/LCA databases developed in France

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	France	DEAM – Data for Environmental Analysis and Management	Ecobilane (PwC)	Process-based LCA Hybrid LCA	ISO 14064		GHG Protocol	Directive No.2003/87/CE	for TEAM software
2	Europe (EU 25)	EIME (Environmental Improvement Made Easy) database V11.0	Bureau Veritas – CODDE	Process-based LCA	ISO 14040s				Environmental profiles of products and services
3	France	INIES	ADEME	Process-based LCA		NF EN 15804+A1; NF EN 15804/CN		AFNOR NF P 01-010	Building LCA
4	France	DIOGEN database	AFGC	Process-based LCA		NF 01-010 P; NF EN 15,804 + A1			Construction LCA

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	France	DEAM – Data for Environmental Analysis and Management	Unknown				○	○			○	○	TEAM software, PDF
2	Europe (EU 25)	EIME (Environmental Improvement Made Easy) database V11.0	Boustead Model BUWAL DEAM; EAA; IISI	○	○		○				○		Web Browser
3	France	INIES			○		○	○		○	○	○	Web Browser, FDES sheets
4	France	DIOGEN database	Ecoinvent		○		○			○	○	○	PDF, excel, Ciogen

2.3.6 Netherlands

Although many LCI or LCA databases have not been developed in the Netherlands, there have been developed important concepts and tools in LCA history (see Figure 15). For examples, the IVAM database consists of about 1350 processes, leading to more than 350 materials which can be used for LCA studies in various sectors since 2004. CML-IA provided by CML, the Institute of Environmental Sciences at Leiden University, is an extremely flexible software tool. This tool allows user to control every detailed LCA analysis including IO-based and hybrid LCA, LCC and eco-efficiency analysis. Because CMLCA contains no data nor impact assessment data, the user should purchase commercial LCI database. The same university also released E3IOT database which contains a high resolution, environmentally extended input output table for Europe which covers production, consumption and waste management sectors.

The national LCA database of building and construction is the Nationale milieudatabase (NMD). The NMD has been established for clear calculation of the environmental performance of buildings and civil engineering works in the Dutch context. The database is divided into 2 sub structures which are product profile cards (B&U) and item cards (GWW) of building products and building elements. There are three categories of product information which can be distinguished in the product card database: the proprietary data reviewed by third party experts (category 1), brand-specific data reviewed by third party (category 2), and brand-specific data without verification according to SBK protocol (category 3). Dutch companies can register and edit category 1 and 2 data, with having responsible for their own data. Detailed features of the databases developed in Netherlands are described in the following Table 8. Two databases are process-based, one is hybrid. They refer to the ISO 14040 and the EN 15978 standards and are used for environmental assessments and building LCAs. The sources are industry data and other LCI databases and their scope is cradle to grave and partly additionally cradle to gate. Two of the three databases cover further environmental impacts besides primary energy and greenhouse gas emissions.

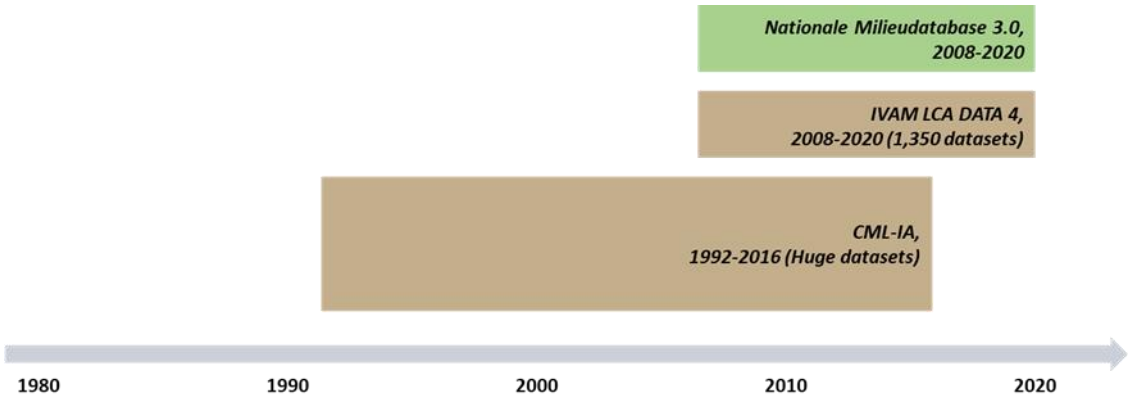


Figure 15 Development periods of LCI databases and number of datasets in Netherlands

Table 8 Detailed features of the LCI databases developed in Netherlands

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Global	CML-IA	Institute of Environmental Sciences (CML)	Process based LCA, IO LCA, Hybrid LCA, S-LCA	○				Environmental assessment
2	Netherlands, Europe, Global	IVAM LCA DATA 4	Universiteit van Amsterdam	Process-based LCA	ISO 14040s				Environmental assessment
3	Netherlands	Nationale Milieudatabase 3.0	STICHTING BOUWKWALITEIT	Process-based LCA		EN 15804; EN 15978			Building LCA

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Global	CML-IA	Ecoinvent, ELCD			Environmentally Extended Input-Output Tables	○	○		○	○	○	CMLCA format, Excel
2	Netherlands, Europe, Global	IVAM LCA DATA 4		○	○			○			○		SimaPro
3	Netherlands	Nationale Milieudatabase 3.0	Ecoinvent		○			○		○	○	○	OneclickLCA

2.3.7 Rest of countries in Europe

Life-cycle based databases developed in countries other than those previously discussed were identified in the Czech Republic, Denmark, Finland, Italy, Spain and Sweden (see Figure 16). Italian National LCI Database is temporary unavailable. EDIP method and LCA Food database were developed in Denmark. Especially, the EDIP method, which is very well known to LCA experts, includes a characterization step, where inventory data are transformed into potential contributions to the various environmental impact categories comprised by the method. Another well-known SPINE@CPM Database is developed by the Swedish Life Cycle Center, which formerly called CPM. All LCI datasets can be imported with three formats: the SPINE format, ISO/TS 14048 LCA data documentation format and the ILCD format. Users can confirm the results of impact assessment with three models: EPS, EDIP, and ECO-Indicator.

Two additional building-specific LCA databases have been found in rest of European countries. Envimat is the first Czech interactive catalog of building materials and structures to assess and compare their environmental impacts. The datasets were created from Ecoinvent's largest international database of building materials. More datasets will be added from Czech EPD. BEDEC database, Spanish construction-specific environmental data, contains more than 10,000 datasets created from 18 national LCI databases and EPD programs as Environdec, INIES, PEP Ecopassport, NMD (Nationale Milieudatabase) and Ökobaudat. All datasets have been prepared by ITeC. ITeC also offers the TCQi GMA software to perform LCA calculation more easily.

Detailed features of the life-cycle based databases built developed in the rest of European countries are described in the following Table 9. The databases are partly process-based, partly input-output based. They refer to a variety of ISO, EN and other standards and are used for a variety of different purposes. The main source is industry data and their scope is cradle to grave in most cases. They cover further environmental impacts besides primary energy and greenhouse gas emissions. One database offers cost data.

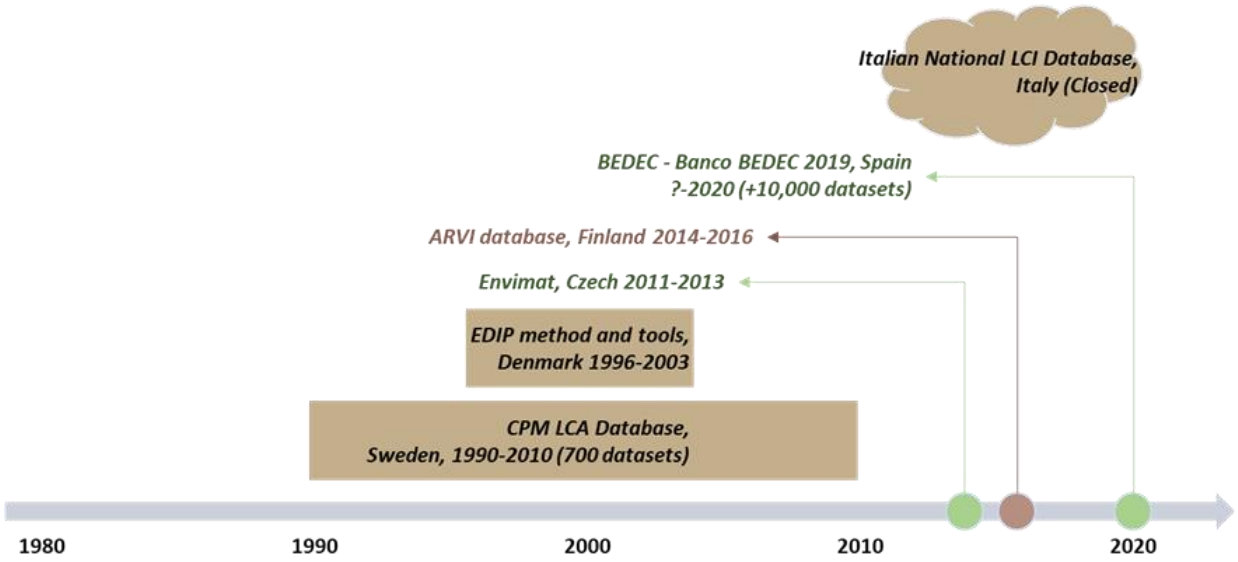


Figure 16 Development periods of life-cycle based databases and number of datasets in rest of European countries

Table 9 Detailed features of the databases developed in the rest of European countries

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Czech	Envimat	Faculty of Civil Engineering CTU Prague	Depend on importing LCI DB	ISO 14020s ISO 14040s	CSN EN ISO 14031; CSN EN 15643-1; CSN EN 15643-2			Building LCA
2	Denmark	EDIP method and tools	FORCE Technology, IPU	IO LCA	-	-	-	○	Environmental assessment
3	Finland	ARVI database	CLIC Innovation LTD	Process-based LCA	Unknown				Environmental assessment
4	Spain	BEDEC - Banco BEDEC 2019	ITeC	Building material information	-	-	-	○	BIM, Building LCA
5	Sweden, Europe, Global	CPM LCA Database	CPM at Chalmers University of Technology	Process-based LCA	ISO 14040s				SPINE@CPM database

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Czech	Envimat	Ecoinvent, EPD, IBO, ICE, INIES, Ökobau.dat				○	○		○	○	○	Web Browser
2	Denmark	EDIP method and tools	Gabi, Ecoinvent, ELCD		○		Unknown			○	○	○	GaBi
3	Finland	ARVI database			○			○		○	○	○	Ecoinvent 3
4	Spain	BEDEC - Banco BEDEC 2019			○				○			Detail, Cost	Web Browser
5	Sweden, Europe, Global	CPM LCA Database		○	○			○			○		Web Browser

2.4 General Status of Life-cycle Based Databases by countries in Americas

The life-cycle based database, developed in the countries of the Americas, examined 15 in five countries (Figure 17). In Brazil, Columbia and Chile, some special fields of LCI database have been created at the academic level. However, national LCI is under development, or consulted by LCA specialist companies using overseas LCI databases in these countries. Although individual companies are using their international EPD program to certify their products, they cannot use the national LCI database.

The United States is the one of leading countries in LCI and LCA database development. There were investigated 4 national and academic LCI and LCA databases: 2 generic LCI databases, 1 generic LCA database and 1 building specific LCA databases. The databases with the largest datasets in the United States is U.S. Life-Cycle Inventory Database developed by the National Renewable Energy Laboratory (NREL), and the Federal LCA Commons developed in collaboration with several US government departments such as USDA, EPA and DOE. U.S. Life-Cycle Inventory Database offers individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows that are associated with material production in the U.S. The Federal LCA Commons is a type of data platform for interagency collaboration and data discovery by using openLCA Collaboration Server application. The Minnesota Building Materials database is for the commercial and residential building construction industry in Minnesota. It is created by the manufacturer submitting profile and LCA results of products through an approved data entry form.

In Canada, there are no many databases with over 500 datasets, but Athena Life Cycle Inventory Product Databases, a well-known database applicable to the building and construction sectors, could be

investigated. The database contains datasets not only for building materials but also for every energy and material flows during building's entire life cycle stage including detailed on-site construction works. Detailed features of the LCI databases developed in North America are described in the following Table 10.

Table 10 Detailed features of the databases developed in North America

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	USA, Canada	Athena Life Cycle Inventory Product Databases	Athena Institute	Process-based LCA	ISO 14040s				Building LCA
2	Canada	Canadian Raw Materials Database	University of Waterloo, Environment Canada, Environment and Plastics Industry Council	Process-based LCA				CSA PLUS 1116	Environmental assessment
3	Quebec (Canada)	Quebec LCI Database	CIRAIG	Process-based LCA	Unknown				Environmental assessment
4	USA	Franklin US LCI Database	Franklin Associates	Process-based LCA	-	-	-	-	Environmental assessment
5	Minnesota (USA)	Minnesota Building Materials Database	University of Minnesota	Process-based LCA	Unknown				Building LCA
6	USA	Federal LCA Commons	USDA, EPA, DOE	Process-based LCA	ISO 14040s				Combination of US LCI D/Bs
7	USA	U.S. Life-Cycle Inventory Database V1.6.0	National Renewable Energy Laboratory	Process-based LCA Various	ISO 14040s				Environmental assessment

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	USA, Canada	Athena Life Cycle Inventory Product Databases		○	○			○		○	○	○	Impact Estimator
2	Canada	Canadian Raw Materials Database			○			○			○		Web Browser, PDF
3	Quebec (Canada)	Quebec LCI Database		○	○			○		Unknown			ecoinvent
4	USA	Franklin US LCI Database	Unknown					○			○		SimaPro
5	Minnesota (USA)	Minnesota Building Materials Database			○			○		○	○	+Cost Health	Webr, Excel BEES, Athena, Li fecycle Thinking
6	USA	Federal LCA Commons		○	○			○		○	○	○	openLCA, ILCD format
7	USA	U.S. Life-Cycle Inventory Database V1.6.0		○	○		○	○		○	○	○	EcoSpold

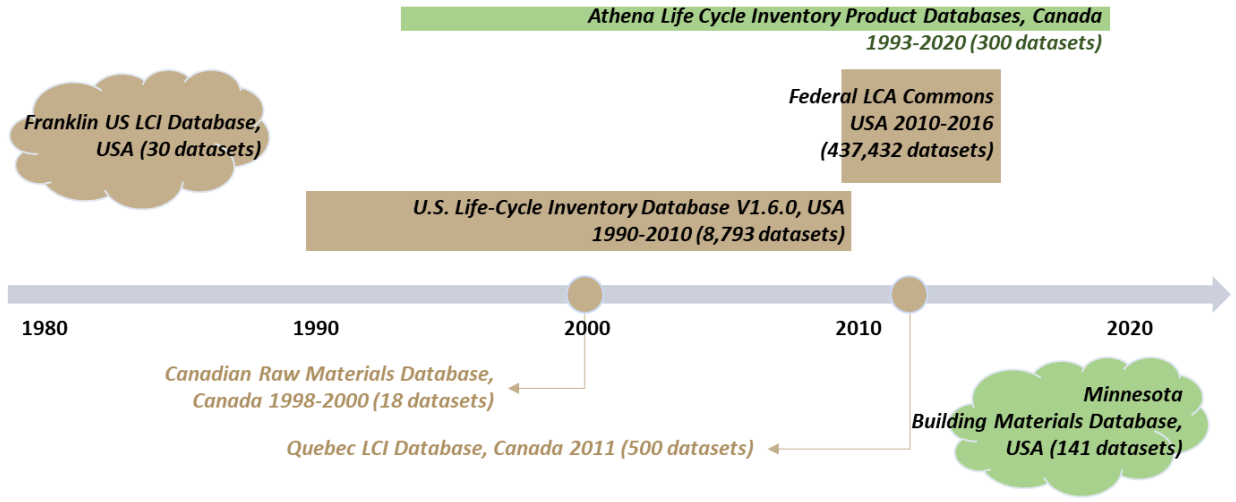


Figure 17 Development periods of life-cycle based databases and number of datasets in Americas

2.5 General Status of Life-cycle Based Databases by countries in Asia

Eight notable LCI databases and two LCA databases were identified in Asia (see Figure 18). In Asia, all are generic databases, with the exception of the two building-specific LCI databases developed in Australia and New Zealand. Since the 1990s, Australia, Japan, and Korea have been starting to build LCI databases in accordance with international standards and trends. Among the surveyed Asian databases, only Japanese LCI databases were using non-conventional LCA methodologies such as IO-LCA and hybrid LCA methods. In China, the national LCI database has been established since 2009, but online access was not possible. Databases developed in Taiwan are currently unavailable. Malaysia also established national databases with 181 generic datasets in 2010, in harmony with the GaBi conformity system, the ILCD Data Network, and the UNEP SETAC Life Cycle Initiative. The Thai National Life Cycle Inventory Database was developed as important basic information that helps to support the country's environmental and trade activities in 2006 by the National Metal and Materials Technology Center.

The Evah OzLCI2019 Database has been created by the Evah Institute with openLCA impact assessment methods (LCIA methods). The database inventory groups cover 958 supply chains including building materials and equipment limited to Australian territory. BRANZ CO2NSTRUCT database is developed to evaluate environmental impact of New Zealand whole-building from a life-cycle perspective. It is annually updated values for embodied greenhouse gas and energy of construction materials. Free excel-based tool called LCAQuick is provided to conveniently perform LCA calculations.

Detailed features of the databases developed in Asia are described in the following Table 11.

Table 11 Detailed features of the databases developed in Asia

No.	Geographical boundary	Name of LCA Database	Organization	Methodologies	Standards				Purpose
					ISO	EN	GHG protocol	Other	
1	Australia	Australian National Life Cycle Inventory Database (AusLCI)	Australian Life Cycle Assessment Society (ALCAS)	Process-based LCA	ISO 14040s				Environmental assessment
2	Australia	Evah OzLCI2019 Free Database	Evah Institute	Process-based LCA	ISO 14040s				Building LCA
3	China	Chinese Life Cycle Database (CLCD)	Sichuan University IKE Environmental Technology CO	Process-based LCA	ISO 14040s				Environmental assessment
4	China	eFootprint	IKE Environmental Technology CO	Process-based LCA				PEF	Cerfications
5	Japan, Grobal	Inventory Database for Environmental Analysis (IDEA v2)	AIST/JEMAI	Process-based LCA Hybrid LCA Attributional modelling	ISO 14040s				Environmental assessment
6	Japan	JLCA-LCA database	Life cycle assessment society of Japan	Process-based LCA	Unknown				Environmental assessment
7	Korea	Korea LCI database	Korea Environmental Industry & Technology Institute	Process-based LCA	ISO 14020s ISO 14040s ISO 14064, ISO 14067		GHG Protocol		Environmental assessment
8	Malaysia	The Malaysia Life Cycle Inventory Database (MYLCID)	SIRIM	Process-based LCA	Unknown				Environmental assessment
9	New Zealand	BRANZ CO 2 NSTRUCT	BRANZ	Process-based LCA	Unknown				Building LCA
10	New Zealand	LIFE CYCLE INVENTORY DATASETS	New Zealand Life Cycle Management Centre	Process-based LCA	Unknown				Unknown
11	Thailand	Thai National Life Cycle Inventory Database	MTEC	Process-based LCA	Unknown				Environmental assessment

No.	Geographical boundary	Name of LCA Database	Origin of Data sources				Life Cycle Stage			Indicators of Results			Data format
			Other LCI DB	Academic research	Industry data	Others	Cradle-to-gate	Cradle-to-grave	others	Energy	GWP	Others	
1	Australia	Australian National Life Cycle Inventory Database (AusLCI)	Ecoinvent, US LCI, LCA Digital Commons		○		○			○	○	○	XML ecospold 2, Excel, Open LCA
2	Australia	Evah OzLCI2019 Free Database			○			○		○	○	○	openLCA
3	China	Chinese Life Cycle Database (CLCD)		○	○		○				○		CLCD, Ecospold ILCD format, eBalance
4	China	eFootprint	CLCD, ELCD				○	○	○	○	○	○	Web Browser
5	Japan, Grobal	Inventory Database for Environmental Analysis (IDEA v2)		○	○		○		Gate-to-gate		○		IDEA format, MiLCA, SimaPro
6	Japan	JLCA-LCA database		○	○		○		Gate-to-gate	○	○	○	LIME
7	Korea	Korea LCI database			○		○	○	Gate-to-gate	○	○	○	Total, PDF
8	Malaysia	The Malaysia Life Cycle Inventory Database (MYLCID)			○		○		Gate-to-gate	○	○	○	ILCD, Gabi
9	New Zealand	BRANZ CO 2 NSTRUCT			○		○			○	○		LCAQuick
10	New Zealand	LIFE CYCLE INVENTORY DATASETS			○			○		○	○	○	ILCD format
11	Thailand	Thai National Life Cycle Inventory Database			○		○	○	Gate-to-gate	○	○	○	GaBi, SimaPro

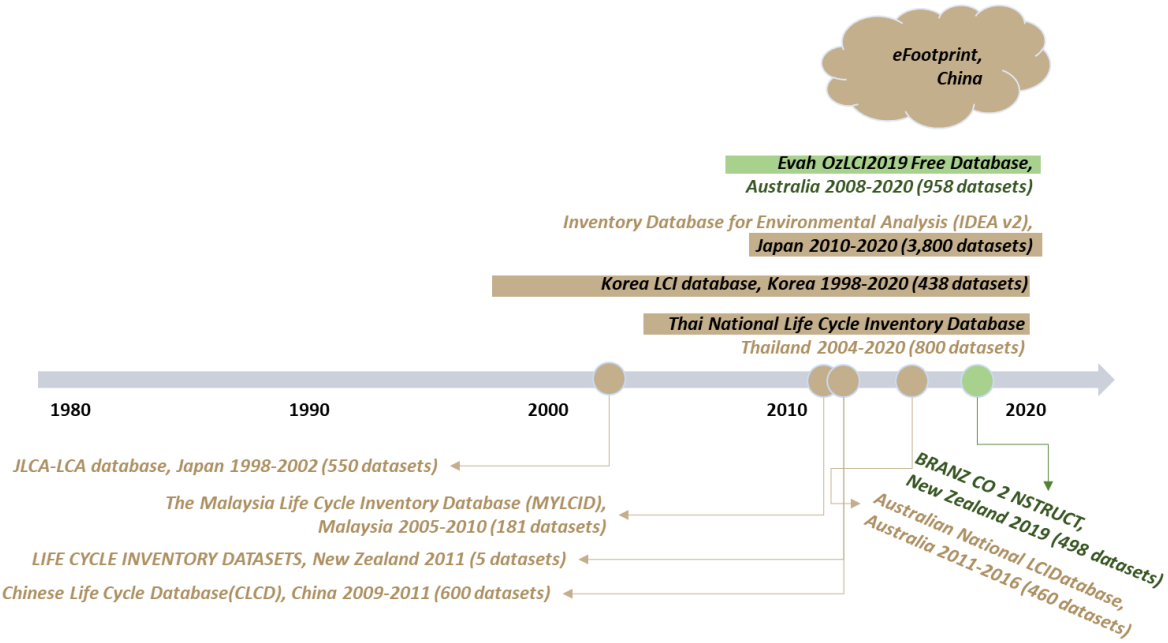


Figure 18 Development periods of databases and number of datasets in Asia

3. Data Quality of Building LCA databases

3.1 Data Quality Indicators

Looking at the trend of developing LCA database worldwide through almost 100 databases, LCA databases tends to be more composed of generic datasets than sector specific datasets. 46 databases, more than half of total, were composed of generic datasets, and 18 databases related to building and construction sectors. Among them, it is selected 14 building-specific databases which open detailed information publicly. The list of databases that have been analysed is shown in Table 12.

Table 12 List of examined building-specific LCI and LCA databases

No.	Country	Name	Organization	Organisation type
1	Czech	Envimat	Faculty of Civil Engineering CTU Prague	Academic (research center)
2	**France**	**INIES**	**ADEME**	**Governmental body**
3	France	DIOGEN database	AFGC	Association
4	**Germany**	**ÖKOBAUDAT platform**	**BMUB**	**Governmental body**
5	**Nether-lands**	**Nationale Milieudatabase 3.0**	**STICHTING BOUWKWALITEIT**	**Governmental body**
6	Spain	BEDEC - Banco BEDEC 2019	ITeC	Association
7	UK	EuGeos' 15804-IA Database Version 3.0	EuGeos	Company
8	UK	ICE database (the inventory of carbon and energy)	Circular Ecology, University of Bath, Sustainable Energy Reserach Team	Academic (research center)
9	UK	RICS Building Carbon Database	UK Green Building Council	Association
10	Canada	Athena Life Cycle Inventory Product Databases	Athena Institute	Non-profit research center
11	USA	Minnesota Building Materials Database	College of Architecture and Landscape Architecture University of Minnesota	Academic (research center)
12	Australia	Evah OzLCI2019 Free Database	Evah Institute	Company
13	New Zea-land	BRANZ CO2NSTRUCT	BRANZ	Academic (research center)
14	Switzerland	KBOB recommendation 2009/1:2022	KBOB	Association

In order to use this building-specific LCA databases more accurately to measure the environmental performance of building, it is essential to examine a data quality of each database. The data quality issue is a key for wider adoption building LCA database in construction industry and building certifications. According to the ISO 14044 standard, the requirements of data quality and its description are followed:

– a) time-related coverage: age of data and the minimum length of time over which data should be collected;

– b) geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;
– c) technology coverage: specific technology or technology mix;
– d) precision: measure of the variability of the data values for each data expressed (e.g. variance);
– e) completeness: percentage of flow that is measured or estimated;
– f) representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);
– g) consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
– h) reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
– i) sources of the data;
– j) uncertainty of the information (e.g. data, models and assumptions).

In this regard, guidance published by some authoritative organizations has proposed more specific criteria for assessing data quality. For instance, “Global Guidance Principles for Life Cycle Assessment Databases” developed by UNEP[7] stated that common criteria for topics such as unit process data development, aggregated process data development, adaptive LCA approaches, data review and documentation in order to exchange databases worldwide and increase credibility of data. Topics related to the analysis conducted in this report are as follows:

– Unit process data development: data collection approach, specified data modelling, and adequate documentation
– Aggregated process data development: life cycle stage (cradle-to-gate, cradle-to-grave), validating procedures for combining unit process data into multi-process datasets, and specifying on additional information
– Data review and documentation: overall management roles and responsibility on necessary documentation for primary data and supplemental characteristics
– Adaptive LCA approaches: addressing LCA aspects such as environmentally-extended input- output table or hybrid method

In addition, “LCI data quality guidance” published by US EPA suggested a data quality indicator (DQI) as quantitative or qualitative terms for defining data characteristics. Since ISO 14044 standard does not very specify about data quality analysis, the guidance presented a pedigree matrix. By using the pedigree matrix, the ISO requirements of data quality can be limitedly assessed at the flow and the process level.[8] The pedigree matrix captures the representativeness through the indicators of temporal, geographical, technological coverage and data collection method at the flow level. Source of data is assessed with the reliability indicator at the flow level. Completeness is addressed at the process level which can be a combination of many different flows from various sources. Uncertainty is excluded from the matrix but it is partly addressed through quantitative meta data.

Considering those influential standard and guidance, the following related issues selected and analysed to improve the applicability of LCA database in the construction field.
– General issues: number of datasets, periods of dataset development, categories of datasets (generic/sector-specific/building) and geographical coverage for data usage.
– Completeness issues: cut-off percentage of mass and energy flows, and information whether data is measured or estimated.

[7] UNEP/SETAC Life Cycle Initiative. 2011. "Global Guidance Principles for Life Cycle Assessment Databases" UNEP
[8] pp. 14. "Guidance on Data Quality Assessment for Life Cycle Inventory Data" United States Environmental Protection Agency (EPA). 2016. (www.epa.gov/research)

– Representativeness issues: temporal coverage, geographical coverage, technological coverage, and data collection methods.
– Source of data: source of unit process data collection.
– Consistency issues: LCA methods, assumptions, unit process modelling, defining functions and reference flows, and data format.
– Uncertainty issues: description of any omission, limitation or data gap.

Table 13 shows the main items used to characterise the 15 selected databases.

Table 13 Main characteristics used to describe life-cycle based databases for building and construction sectors

No.	Requirement	Indicators	
1	General information	Number of datasets	Number of building materials, goods and services in database
		Purpose	
		Website	
		Language	
		Last update	Database age
		Geographic boundary for data usage	Targeted user group and geographical area
2	Completeness	Cut-off criteria	The amount of ignored flow in system boundary
		Data information	Verified data based on measurements, calculation or estimation
3	Representativeness*	Temporal coverage	Less than 3 years difference / 6 years / 10 years / 15 years / more than 15 years
		Geographical coverage	Data from same area of study / related area of study / different or unknown area of study
		Technological coverage	All technology categories (process design, operating conditions, material quality and process scale) are equivalent or not
		Data collection methods	Representative data from relevant market, over an adequate period
4	Consistency**	LCA methods	Process-based LCA, IO, Hybrid LCA and the other methods
		Assumptions	Documented description of assumptions in data aggregation or unit process modelling
		Unit process modelling	Selection of secondary data / Scenarios of defining mathematical relations between raw data (attributional approach / consequential approach)
		Data format	Specified data format to be used under same standard or same nomenclature
5	Source of the data	Source of unit process data collection	
6	Uncertainty	Documented description of any omission, limitation or data gap	
7	Technical parameters	E.g. weight [kg], thermal conductivity coefficient [w / mK]	
8	Environmental parameters	E.g. Global Warming Potential - GWP [kg CO2eq]	

* This indicator has been specified based on "Guidance on Data Quality Assessment for Life Cycle Inventory Data"
** This indicator has been specified based on "Global Guidance Principles for Life Cycle Assessment Databases"

3.2 Characterisation of Life-cycle based Databases for Building and Construction Sectors

3.2.1 Envimat (Czech)

Envimat is an online tool for evaluating and comparing building structures. It was developed to calculate the embodied 7energy and embodied carbon of building products and structures in the Czech market using EPD and Ecoinvent database. Users can sign up for paid membership and directly enter the information of the product or structure that they want to check the environmental results. The Envimat database is characterised in Table 14.

Table 14 Characterisation of Envimat (Czech)

No.	Requirement	Indicators	
1	General information	Number of datasets	Loading external database(EPD & Ecoinvent)
		Purpose	Online tool for evaluating and comparing the building structure
		Website	http://www.envimat.cz/
		Language	Czech
		Last update	since 2013 - today
		Geographic boundary for data usage	Czech market
2	Completeness	Cut-off criteria	Not specified, but depending on user
		Data information	The majority of data was calculated from Ecoinvent and EPD. Calculated methodology was based on the EPA proposal.
3	Representativeness*	Temporal coverage	Not specified, but depending on user
		Geographical coverage	Czech, Switzerland, Europe, Global
		Technological coverage	Not specified, but depending on user
		Data collection methods	Industrial data. (User or manufacturers inputting values directly)
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	Not specified, but depending on user
		Unit process modelling	Attributional approach
		Data format	Web Browser
5	Source of the Data	Ecoinvent, EPD, IBO DB, ICE (Bath University), SIA D 123, INIES, Ökobau.dat, Czech manufacturer data	
6	Uncertainty	Not specified, but depending on user	
7	Technical parameters	Thermal conductivity coefficient λ [W / mK] Heat transfer coefficient U [W / m2K] Weight m [kg]	
8	Environmental parameters	Primary energy consumption - PEI [MJ] (Tied energy) Global warming potential - GWP [kg CO 2, eq.] (Coupled CO 2 emissions , eq.) Environmental acidification potential - AP [g SO 2, eq.] (Bound SO 2 emissions , eq.) Ground-level ozone formation potential - POCP [g C 2 H 4, eq.] Ozone depletion potential - ODP [g CFC 2, eq.] Environmental eutrophication potential - EP [g PO 4 3- eq.]	

3.2.2 INIES (France)

INIES is the French national reference database of both environmental and heath declarations in order to evaluate performance of products, equipment, and services in building and construction sectors. The environmental and health information is documented and managed in FDES format which is the official data format developed in French context. The database is operated by a technical committee chaired by AIMCC, and a supervisory board chaired by Alliance HQE-GBC. The INIES database is characterised in Table 15.

Table 15 Characterisation of INIES (France)

No.	Requirement	Indicators	
1	General information	Number of datasets	1987
		Purpose	Inventory of environmental and health reference data for building product, equipment, service
		Website	http://www.inies.fr/home/
		Language	French, English
		Last update	since 2004 - today
		Geographic boundary for data usage	French market
2	Completeness	Cut-off criteria	accordance with NF EN 15804. No specific information available online
		Data information	
3	Representativeness*	Temporal coverage	accordance with NF EN 15804. No specific information available online
		Geographical coverage	
		Technological coverage	
		Data collection methods	
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	accordance with NF accordance with NF EN 15804. No specific information available online 15804
		Unit process modelling	Attributional approach
		Data format	FDES (standardized document showing the results of a product's life cycle analysis as well as health information in the French context)
5	Source of the Data	French manufacturer data	
6	Uncertainty	Not specified.	
7	Technical parameters	Indoor quality, Health information	
8	Environmental parameters	Global warming potential / Depletion of the ozone layer / Acidification of soil and water Eutrophication / Photochemical ozone formation / Depletion of abiotic resources Water pollution / Air pollution / Use of renewable resources / Use of non-resources renewable Use of secondary material / Net use of fresh water / Waste categories / Components for reuse / Materials for recycling / Materials for recovery of energy / Energy supplied to the outside	

3.2.3 DIOGEN (France)

DIOGEN database is a group of environmental information for the materials used in the civil engineering works following NF EN 15804 standard. DIOGEN is Intended for all the actors of civil engineering including engineers, technicians, architects, teachers or students. Environmental information is limited to cradle-to-gate stage, corresponding to steps A1-A3 of the standard. There is no allocation applied to any co-products in DIOGEN database. The DIOGEN database is characterised in Table 16.

Table 16 Characterisation of DIOGEN (France)

No.	Requirement	Indicators	
1	General information	Number of datasets	51
		Purpose	Offering environmental information of construction materials
		Website	http://www.diogen.fr/
		Language	French, English, German, Portuguese, Spanish
		Last update	since 2011 - 2018
		Geographic boundary for data usage	French market
2	Completeness	Cut-off criteria	All mass and energy flow were included.
		Data information	The majority of data was calculated from Ecoinvent supplemented with data provided manufacturer. Values calculated according to B500B
3	Representativeness*	Temporal coverage	within the last 3 years
		Geographical coverage	France, Switzerland, Europe, Global
		Technological coverage	French industry
		Data collection methods	Generic data: averaged data for an upstream evaluation Specific data: producer or company data corresponding to an identifiable production Constructed data: data calculated within the DIOGEN group
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	Technology process, Production process and chain, additional data
		Unit process modelling	Attributional approach
		Data format	PDF, excel, Ciogen (Dedicated software to DIOGEN)
5	Source of the Data	French manufacturer data, Ecoinvent	
6	Uncertainty	Technological assumptions (allocation and system limitation) were documented.	
7	Technical parameters	None	
8	Environmental parameters	Environmental impacts according to NF P01-010 Consumption of energy resources / Resource depletion / Total water consumption / Solid waste Climate change / Atmospheric acidification / Air pollution / Water pollution Destruction of the stratospheric ozone layer / Photochemical ozone formation	

3.2.4 ÖKOBAUDAT platform (Germany)

ÖKOBAUDAT platform was developed by the Federal Ministry of the Interior, Construction and Home Affairs (BMI) in order to provides all stakeholders with a unified database for the life cycle assessment of buildings. The platform is not intended for the creation of product life cycle assessments. The data from the ÖKOBAUDAT database are based on dataset from EPD program operators and the “GaBi” background database in accordance with DIN EN 15804. The “ecoinvent” background database can be used as an “Additional dataset”. The owner of each dataset is responsible for content and values. The ÖKOBAUDAT database is characterised in Table 17.

Table 17 Characterisation of ÖKOBAUDAT platform (Germany)

No.	Requirement	Indicators	
1	General information	Number of datasets	1,018
		Purpose	Providing an unified database for the LCA study of buildings (not for creation of product LCA)
		Website	www.oekobaudat.de.
		Language	German, English
		Last update	since 2013 - today
		Geographic boundary for data usage	German market
2	Completeness	Cut-off criteria	accordance with EPD program
		Data information	DIN EN 15804-compliant life cycle assessment data for life cycle assessments at building level
3	Representativeness*	Temporal coverage	accordance with EPD program
		Geographical coverage	accordance with EPD program
		Technological coverage	accordance with EPD program
		Data collection methods	generic data records and company, and association-specific data records from environmental product declarations.
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	Cradle-to-grave
		Unit process modelling	Attributional approach
		Data format	ILCD + EPD format, XML-Format, OpenLCA, SimaPro
5	Source of the Data	EPD, German manufacturer data, GaBi” background database, Ecoinvent background database as an additional data	
6	Uncertainty	Responsibility for content and values remains with the owner of the data records.	
7	Technical parameters	None	
8	Environmental parameters	7 environmental Indicators (GWP, ODP, POCP, AP, EP, ADPE, ADPF) accordance with EPD program	

3.2.5 Nationale Milieudatabase (Netherlands)

Nationale Milieudatabase is the National Environmental Database of all information regarding the environmental performance assessment method for buildings and civil engineering works. First, the basic profile with environmental information per building material is generated from the Process database that calculated with SimaPro. Then, environmental performance of a whole building is calculated on the basis of these basic environmental profiles in accordance with EN 15804 and EN 15978 incorporating scenarios applicable to the Netherlands. There is no official norms or restriction of assessing environmental impacts from building, so that every market party member should make agreement about the desired level of quality in regarding with the results. For example, there is no specific lifespan of a building. However, the specific lifespan of a building can be declared under user's own responsibility. In addition, the assessment results of building can be utilized for sustainable procurement or official certifications such as BREEAM-NL. The Nationale Milieudatabase is characterised in Table 18.

Table 18 Characterisation of Nationale Milieudatabase (Netherlands)

No.	Requirement	Indicators	
1	General information	Number of datasets	Loading external database(SimaPro)
		Purpose	Database of construction products and building elements
		Website	https://milieudatabase.nl/
		Language	Dutch
		Last update	since 2008 - today
		Geographic boundary for data usage	Dutch market
2	Completeness	Cut-off criteria	accordance with NF EN 15804. No specific information available online
		Data information	The basic profile database with environmental information per building material is generated on the basis of the Process database from SimaPro.
3	Representativeness*	Temporal coverage	accordance with NF EN 15804. No specific information available online
		Geographical coverage	
		Technological coverage	
		Data collection methods	
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	accordance with NF EN 15804. No specific information available online
		Unit process modelling	
		Data format	Execl, OneclickLCA
5	Source of the Data	SimaPro, Ecoinent, Duch manufacturer data	
6	Uncertainty	accordance with NF EN 15804. No specific information available online	
7	Technical parameters	None	
8	Environmental parameters	11 environmental indicators on building components and construction works	

3.2.6 Banco BEDEC (Spain)

The origin of BEDEC dates back to year 1983. The first BEDEC, meaning “Structured Data Bank of Construction Elements”, was published by Barcelona City Council. Since then ITeC has been committed to update and modify the contents with more various topics reflecting market needs. All the database has been generated and combined with the TCQi GMA software. The environmental information of building products provided in this database is taken from all existing national databases or national EPD programs. Therefore, data quality will depend on the source from which the dataset was created. ITeC also offer a solution to calculate LCA in a building level with exported IFC format from any types of BIM software in the market. The Banco BEDEC database is characterised in Table 19.

Table 19 Characterisation of Banco BEDEC (Spain)

No.	Requirement	Indicators	
1	General information	Number of datasets	3,325
		Purpose	Providing technical, environmental and economic information regarding all kind of elements used in construction
		Website	https://metabase.itec.cat/vide/es/bedec
		Language	Spanish, Catalan
		Last update	since 1983 - today
		Geographic boundary for data usage	Spanish market
2	Completeness	Cut-off criteria	Depending on external database
		Data information	Depending on external database
3	Representativeness*	Temporal coverage	Depending on external database
		Geographical coverage	Depending on external database
		Technological coverage	Depending on external database
		Data collection methods	Depending on external database
4	Consistency**	LCA methods	Various
		Assumptions	Depending on external database
		Unit process modelling	Depending on external database
		Data format	BIM format, PDF
5	Source of the Data	BEDEC generic construction materials database, world EPD programs, Australia: Building Products Innovation Council – BPIC LCI, AusLCI, MRPI, Ökobaudat, SCS Global, UL Environment, BRE, INIES, CSA Group, IERE Earthsure, FPInnovations, NREL, NRMCA, NSF, SCS Global	
6	Uncertainty	Depending on external database	
7	Technical parameters	Price, Material composition of product, Physical property	
8	Environmental parameters	Energy consumption, CO2 emissions, Raw material consumption, Recycling	

3.2.7 EuGeos' 15804-IA Database (United Kingdom)

EPD is getting more important in the UK construction sector. It is because BREEAM scheme gives credits when building product EPD is applied in building design. In response to these needs, a company called EuGeos has developed an database exclusively focused on building EPDs using the ecoinvent database. EuGeos' 15804-IA Database is a version of ecoinvent v3.2 extended to allow calculation of the indicators required in construction product EPD to satisfy European standard EN 15804. The database has been configured to be only used via openLCA. The EuGeos' 15804-IA Database is characterised in Table 20.

Table 20 Characterisation of EuGeos' 15804-IA Database (United Kingdom)

No.	Requirement	Indicators	
1	General information	Number of datasets	14,889
		Purpose	EPD for construction materials
		Website	http://www.eugeos.co.uk/lifecycle_assessment/epd.html
		Language	English
		Last update	1980 - 2017
		Geographic boundary for data usage	Europe
2	Completeness	Cut-off criteria	accordance with EN 15804. No specific information available online
		Data information	
3	Representativeness*	Temporal coverage	accordance with EN 15804. No specific information available online
		Geographical coverage	
		Technological coverage	
		Data collection methods	
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	accordance with EN 15804. No specific information available online
		Unit process modelling	impact categories at a midpoint level (CML 2012 baseline w/o LT)
		Data format	OpenLCA
5	Source of the Data	Ecoinvent	
6	Uncertainty	accordance with EN 15804. No specific information available online	
7	Technical parameters	None	
8	Environmental parameters	7 Environmental indicators(GWP, ODP, POCP, AP, EP, ADPE, ADPF) accordance with EN 15804	

3.2.8 Inventory of Carbon and Energy (United Kingdom)

Inventory of Carbon and Energy (ICE) database is the embodied energy and embodied carbon database created by the University of Bath. The purpose of the database is to provide an inventory of embodied energy and embodied carbon coefficients for building materials. The ICE database once contained more than 400 materials such as bricks, cement, concrete, glass, timber, plastic, metals and minerals. It is developed from a wide literature survey. The recent version of the database has been released in 2019, containing around 200 selected construction materials. The majority of the aggregated data was for embodied energy, so that its coefficient is more accurate than that of embodied carbon. Many of the embodied carbon coefficients within the database were estimated by the authors. The substitute values had to be estimated using the typical fuel mix in relevant UK industrial context. Nonetheless, the applied LCA method was not ideal, but it was tried to follow ISO 14040 series. The Inventory of Carbon and Energy is characterised in Table 21.

Table 21 Characterisation of Inventory of Carbon and Energy (United Kingdom)

No.	Requirement	Indicators	
1	General information	Number of datasets	+ 400
		Purpose	Database of embodied energy and carbon of building materials
		Website	https://ghgprotocol.org/Third-Party-Databases/Bath-ICE
		Language	English
		Last update	since 1977 - 2019
		Geographic boundary for data usage	UK market
2	Completeness	Cut-off criteria	applied to handling of recycling
		Data information	The values have been calculated to represent the average material purchased in this market.
3	Representativeness*	Temporal coverage	uncertain
		Geographical coverage	UK, European and global averages
		Technological coverage	accordance with ISO 14040
		Data collection methods	estimated from statistics
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	cradle-to-site, considering carbon sequestration
		Unit process modelling	unknown
		Data format	Web Browser, Excel, PDF
5	Source of the Data	Academic research, industry statistics, government publications, other LCA databases Athena Institute International; Boustead Model; BRE; FEFCO	
6	Uncertainty	uncertainty in the embodied carbon values related to electricity generation because historical changes in fuel mix and carbon coefficients	
7	Technical parameters	None	
8	Environmental parameters	Embodied carbon, embodied energy	

3.2.9 RICS Building Carbon Database (United Kingdom)

The RICS Building Carbon database is a latest evolutionary version of WRAP Embodied Carbon Database commissioned by UK GBC. The aim of the database is to help users to identify key point to reduce carbon emissions during all stages of a building's life cycle. Better understanding and consistent measurement of the entire life carbon emissions can draw the mitigation of carbon impact in the built environment.

The database is following EN 15978 which is a suite of standards and technical reports for the assessment of the sustainability of construction works at both product level and building level. The standard illustrates in detail about scenarios and modelling requirements for LCA evaluation from the construction stage to the end-of life stage during the building life cycle. Expected lifespan is suggested by building elements and building part. Because there is a guidance for exact rules and scenarios in LCA study, built projects can be compared with results, benchmarking and target setting to achieve carbon reductions. The RICS Building Carbon Database is characterised in Table 22.

Table 22 Characterisation of RICS Building Carbon Database (United Kingdom)

No.	Requirement	Indicators	
1	General information	Number of datasets	249
		Purpose	Database of embodied carbon data during all stages of a building's life cycle
		Website	https://www.rics.org/uk/products/data-products/insights/rics-building-carbon-database/
		Language	English
		Last update	2017 - 2019
		Geographic boundary for data usage	UK market
2	Completeness	Cut-off criteria	a minimum of 95% of the cost should be accounted. items less than 1 percent of the cost should be excluded.
		Data information	1. measurement 2.calculation 3.estimation
3	Representativeness*	Temporal coverage	accordance with EN 15978
		Geographical coverage	accordance with EN 15978
		Technological coverage	accordance with EN 15978
		Data collection methods	1. material delivery records, 2. BIM model, 3. Bill of quantities 4. estimations from consultants' drawings
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	infrastructure 120 years, building 60 years
		Unit process modelling	accordance with EN 15978
		Data format	Web Browser, excel
5	Source of the Data	EPD, datasets accordance with ISO 14025, 14040, and 14044, datasets accordance with PAS2050	
6	Uncertainty	decarbonization is not a mandatory requirement in carbon calculation. Uncertainty comes from environmental benefits beyond the life cycle.	
7	Technical parameters	None	
8	Environmental parameters	Embodied carbon	

3.2.10 Athena Life Cycle Inventory Product Databases (Canada)

Athena LCI product database is a set of comprehensive and comparable life cycle inventory database for building materials and products. The database follows the ISO 14040 series. Raw data for unit process data of each dataset was collected from actual manufacturing process, not from statistics of trade or government data sources. Athena LCI database has developed with consideration of manufacturing technology, transportation and electricity grid differences as well as recycled content differences for products fabricated in various regions. The data collection method or assumptions and uncertainty of most dataset are documented. Because of these sensitive considerations and active use of local data in early data developing phase, this database is now known as the highest quality regional construction data in North America. This database is built into all software developed by Athena institute. The software is Impact Estimator for buildings, EcoCalculator for building assembles, and Pavement LCA for life cycle cost assessment. The Athena Life Cycle Inventory Product Database is characterised in Table 23.

Table 23 Characterisation of Athena Life Cycle Inventory Product Database (Canada)

No.	Requirement	Indicators	
1	General information	Number of datasets	300
		Purpose	LCI database for building materials and products
		Website	http://www.athenasmi.org/our-software-data/lca-databases/
		Language	English
		Last update	since 1993 - today
		Geographic boundary for data usage	Canada, Global
2	Completeness	Cut-off criteria	accordance with ISO 14040 series
		Data information	Measurement and calculation , accordance with ISO 14040 series
3	Representativeness*	Temporal coverage	within the last 10 years
		Geographical coverage	Canada, USA
		Technological coverage	accordance with ISO 14040 series
		Data collection methods	Data from actual manufacturing process models in Canada and USA
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	accordance with ISO 14040 series
		Unit process modelling	
		Data format	Impact Estimator
5	Source of the Data	only industry data	
6	Uncertainty	accordance with ISO 14040 series	
7	Technical parameters	-	
8	Environmental parameters	1. acidification potential / 2. aquatic eutrophication potential / 3. global warming potential 4. human health particulate / 5. ozone depletion / 6. smog / 7. total primary energy consumption 8. non-renewable energy consumption / 9. fossil fuel consumption	

3.2.11 Minnesota Building Materials Database (USA)

The Minnesota Building Materials Database had been developed to evaluate, and disseminate usable information on sustainable materials, products, systems, and services for the commercial and residential building construction industry in Minnesota. The database released in the early 2000s, considered as an early version in the history of LCI database. The database was mainly developed using information from the Athena LCI database and BEES database. Insufficient information to calculated the unit process data was collected from government published energy statistics or field data from manufacture plants. Although there is not much information accessible online to check the data quality or applied international standards, it can be said that the database has great implications in terms of considering environmental benefits or the effects on human health due to the use of building products. The Minnesota Building Materials Database is characterised in Table 24.

Table 24 Characterisation of Minnesota Building Materials Database (USA)

No.	Requirement	Indicators	
1	General information	Number of datasets	141
		Purpose	information on sustainable materials, products, systems, and services for construction industry in Minnesota.
		Website	http://www.buildingmaterials.umn.edu/materials.html
		Language	English
		Last update	2004
		Geographic boundary for data usage	Minnesota, USA
2	Completeness	Cut-off criteria	unspecified
		Data information	Calculation and estimation
3	Representativeness*	Temporal coverage	unspecified
		Geographical coverage	USA, Canada
		Technological coverage	unspecified
		Data collection methods	1. Athena and BEES database 2.industry and literature
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	unspecified
		Unit process modelling	unspecified
		Data format	Web Browser, Excel, BEES, Athena software, Lifecycle Thinking
5	Source of the Data	Athena LCI database, BEES database, Industrial data, statistics, literature	
6	Uncertainty	unspecified	
7	Technical parameters	Properties, cost	
8	Environmental parameters	Energy, GWP, Solid waste, Air Index, Water Index, Resources, Benefits, hazards of ratings, health	

3.2.12 Evah OzLCI2019 Free Database (Australia)

Evah OzLCI2019 database has been developed by Evah Institute, a sustainability research center in Australia since 1995. The database is continually updated and currently contains a total of 958 generic datasets, of which 157 are related to construction materials. Although much of the information to review the quality of the database is not available online, it seems to be based on extensive documentation and overseas data. The Evah Institute uses and develops tools such as LCADesign and LCI databases compiled by: primary and secondary industry on local and overseas inventory data, national statistics, and literature. The LCI database can be used free of charge in the openLCA websites. The Evah OzLCI2019 Free Database is characterised in Table 25.

Table 25 Characterisation of Evah OzLCI2019 Free Database (Australia)

No.	Requirement	Indicators	
1	General information	Number of datasets	157 building products (958 total)
		Purpose	LCI database of building products with openLCA impact assessment methods (LCIA methods)
		Website	http://www.evah.com.au
		Language	English
		Last update	since 2008 - today
		Geographic boundary for data usage	Global
2	Completeness	Cut-off criteria	Not specified
		Data information	Estimation, calculation, measurement
3	Representativeness*	Temporal coverage	Various but not specified online
		Geographical coverage	Australia, Global
		Technological coverage	Various but not specified online
		Data collection methods	National statistics, literature, industry data and overseas database
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	Not specified
		Unit process modelling	Not specified
		Data format	openLCA, SimaPro, Oneclick LCA
5	Source of the Data	National statistics, literature, industry data and overseas database	
6	Uncertainty	Not specified	
7	Technical parameters	-	
8	Environmental parameters	Not specified	

3.2.13 BRANZ CO2NSTRUCT (New Zealand)

The BRANZ CO2NSTRUCT database is a set of embodied greenhouse gas emission and embodied energy, which is divided into from non-renewable and renewable resources. As implied by the word “Embodied”, the database limits the system boundary of construction products to cradle-to-gate. It doesn’t contain any environmental impacts from transportation nor any energy usage and waste by construction works. The dataset was mainly produced using the values of the national EPD programs, and insufficient information was supplemented in the Ecoinvent database and literature. The quality of each dataset was evaluated according to its own standards. The data quality class is divided into 10 steps from A to J. The best quality grade A means dataset was developed according to EN 15804 compliant EPD, specific product, and geographical scope includes New Zealand. The poorer quality and less reliable grade means that the dataset was based on unpublished result of modelling/assumptions with some known data gaps. The BRANZ CO2NSTRUCT database is characterised in Table 26.

Table 26 Characterisation of BRANZ CO2NSTRUCT (New Zealand)

No.	Requirement	Indicators	
1	General information	Number of datasets	498
		Purpose	Embodied greenhouse gas and energy for construction materials
		Website	https://www.branz.co.nz/co2nstruct
		Language	English
		Last update	2019
		Geographic boundary for data usage	New Zealand market
2	Completeness	Cut-off criteria	Not specified
		Data information	EPD, Calculation from overseas database, estimation from literature
3	Representativeness*	Temporal coverage	within the last 6 years
		Geographical coverage	World (overseas database)
		Technological coverage	within the last 6 years
		Data collection methods	Majority from EPD, modeling based Ecoinvent, insufficient information supplied from literature
4	Consistency**	LCA methods	Process-based LCA
		Assumptions	Embodied energy and carbon
		Unit process modelling	Not specified
		Data format	LCAQuick format, Excel
5	Source of the Data	EPD, Ecoinvent, literarute	
6	Uncertainty	Documented data quality check (grade A to J)	
7	Technical parameters	-	
8	Environmental parameters	Embodied energy (energy from non-renewable and renewable sources) Embodied CO2	

3.2.14 KBOB recommendation 2009/1:2022 (Switzerland)

The KBOB recommendation 2009/1:2022 is the Swiss national reference database used to evaluate the environmental performance of products, equipment, and services in the building and construction sector as well as for monitoring the greenhouse gas emissions and primary energy consumption of communities and cities that set official targets compliant with the 2000-Watt-Society. The environmental impacts are documented and managed in a easy to use Excel spreadheet format. The database is operated by an expert group of the platform “Life Cycle Assessment Data in the Construction Sector”, and a supervisory board chaired by KBOB. The KBOB database is characterised in Table 27.

Table 27 Characterisation of KBOB recommendation 2009/1:2022 (Switzerland)

No.	Requirement	Indicators	
1	General Information	Number of datasets	Construction materials: 250 Building technology: 50 Energy supply: 100 Transport services: 70 Waste management services: 210
		Purpose	LCA data used - in national certified design tools used to assess the environmental impacts of buildings and to prove compliance with Minergie-eco and SNBS requirements - to monitor progress of communities and cities which comitted themselves to the goals of the 2000-Watt-society
		Website	https://www.kbob.admin.ch/kbob/de/home/themen-leistungen/nachhaltiges-bauen/oekobilanzdaten_baubereich.html
		Language	German, French, Italian, English
		Last Update	Fall 2021
		Geographic boundary for data usage	Switzerland and Liechtenstein
2	Completeness	Cut-off criteria	no rigid percentage rule, cut-off decided based on the experience and knowledge of the LCI data provider
		Data information	
3	Representativeness	Temporal coverage	Data are of different age.
		Geographical coverage	In general datasets represent the market situation in Switzerland, i.e. domestic production and imports.
		Technological coverage	Data represent current (mix of) technologies.
		Data collection method	Environmental statistics, industry questionnaires, scientific literature
4	Consistency	LCA methods	Process-based LCA
		Assumptions	Where appropriate, data gaps are filled with conservative assumoptions.
		Unit process modelling	Attributional approach, allocation is based on economic and partly physical relationships. No credits are granted for by-products, energy recovery, nor recycled materials
		Data format	Excel workbook with UUID
5	Sources of the data	UVEK Life cycle inventory data DQRv2:2021, extensively updated LCI data according to data protocol of ecoinvent v1&v2.	
6	Uncertainty	Not quantified; quantifiable using the underlying LCI unit process datasets and a software capable of running Monte Carlo simulations	
7	Technical parameters	Reference units are mass (kg), energy (kWh), surface (m2) and others. Density is provided for construction materials	
8	Environmental parameters	1. Overall environmental impacts, expressed in Swiss eco-points 2021 according to the ecological scarcity method 2. Cumulative energy demand (upper heating value), renewable and non-renewable reported separately 3. greenhouse gas emissions according to the GWP100 published in the 5th IPCC assessment report; an RFI factor of 2.5 is applied on aircraft CO2 emissions.	

4. World EPD Programs

4.1 Current status of EPD programs

Because there exist not enough building-specific databases available to check all the technical details of the LCI database for environmental load assessment of the building's life cycle, more construction-related

LCA examples were surveyed through world's Environmental Product Declaration programs. It is meaningful to identify the trend of EPD certification in the construction field because many countries are encouraging the use of EPD-certified products within the green building certification system.

First, it was investigated the most recognized International EPD program. Then, an additional 48 national EPD programs were investigated out from 25 countries targeting domestic products. Among them, 27 web-accessible EPD programs were investigated in depth. The list of investigated national EPD program is stated inTable 28.

Table 28 List of examined national EPD programs

No.	Country	Name	**Organization**
1	Global	Environmental Product Declarations	Environdec
2	Global	The EPD Registry	EPD Registry™
3	Europe	European Aluminium EPD Programme	European Aluminium
4	Europe	PlasticsEurope	PlasticsEurope
5	Austria	Bau EPD	Bau-EPD GmbH
6	Czech	EPD	Cenia
7	Denmark	EPD Danmark	EPD Danmark
8	Finland	RTS EPD	The Building Information Foundation RTS sr
9	France	PEPecopassport®	PEP association
10	Germany	IBU	DGNB
11	Italy	EPD Italy	EPD Italy
12	Netherlands	MRPI®/EPD	MRPI
13	Norway	EPD Norge	EPD-Norge
14	Portugal	DAP Habitat	dap habitat
15	Slovenia	ZAG EPD	ZAG
16	Spain	DAP construcción	DAP cons
17	UK	UKCoMDat-UK Construction Materials EPD/LCA Database	Metsims Sustainability Consulting
19	UK	Wood for Good LCA database	Wood for Good
20	Canada	CSA EPD	CSA Group
21	USA	ASTM EPD	ASTM
22	USA	NSF EPD	NSF (The Public Health and Safety Organization)
23	Latin America	EPD Latin America	Hub Latin America
24	Australia	Australasian EPD	EPD AUSTRALASIA
25	Korea	Korea EPD	Korea Environmental Industry & Technology Institute
26	Turkey	EPD Turkey	EPD Turkey
27	Turkey	TurCoMDat-Turkish Construction Materials EPD/LCA Database	Metsims Sustainability Consulting

First of all, when looking at the category of products registered in the International EPD[9], it is confirmed that construction-related products account for 70% of the total (see Figure 19). As of February 2020, the total number of products registered in the International EPD System is 1,256, and of which 880 were listed as building and construction products. Looking at the detailed categories of construction-related products, insulation were the most registered building materials at 15%, followed by boards, steel & metal products, waterproofing & roofing materials, floor material and others. For more detailed registration rates by product, see Figure 20.

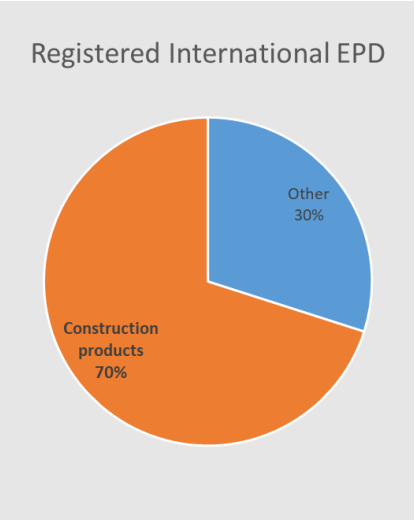


Figure 19 Percentage of construction products registered to the International EPD system

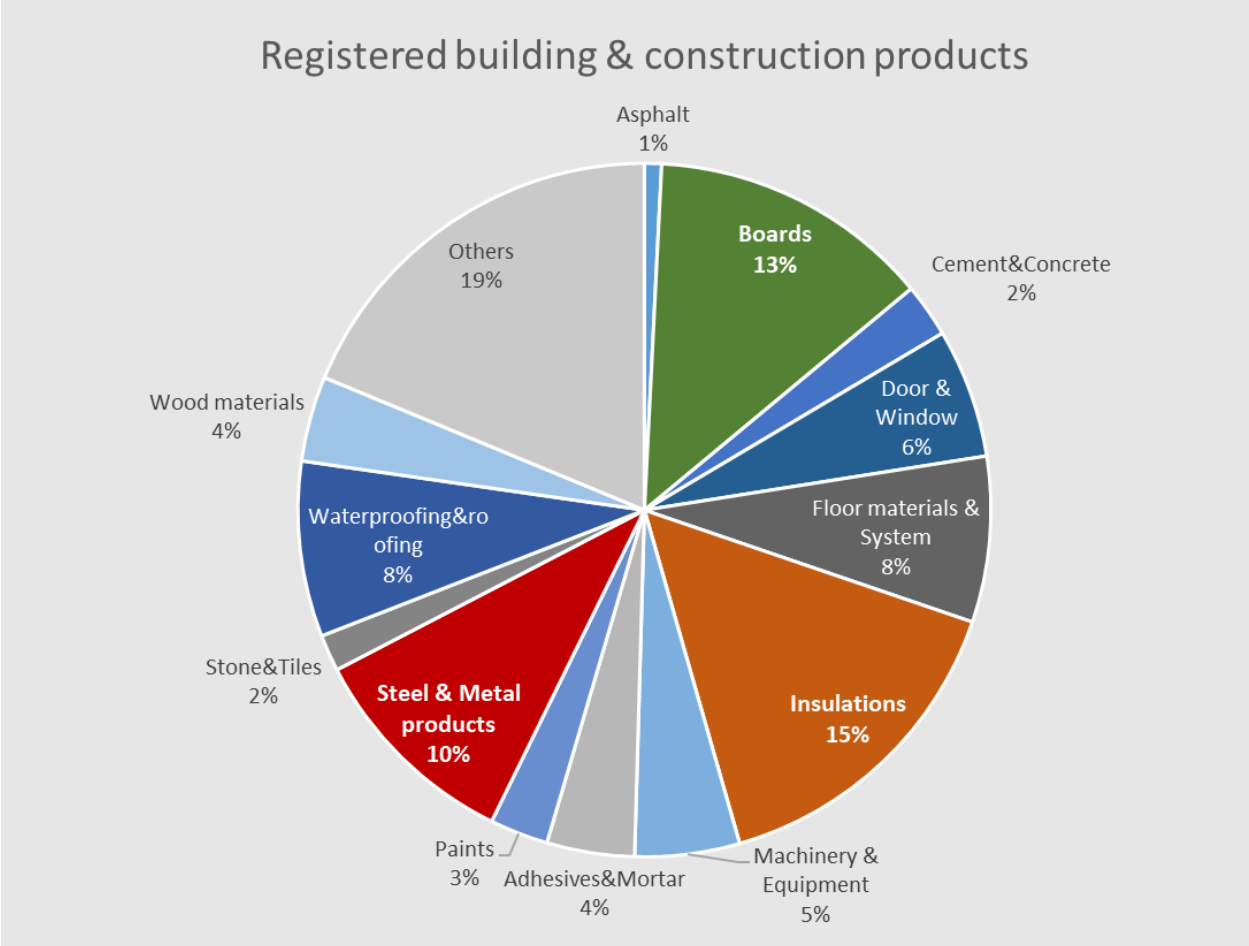


Figure 20 Building and construction products registered to International EPD system

[9] The International EPD System. (https://www.environdec.com/)

Looking at the rate of product category composition registered in the national EPD programs of 23 major countries and global associations in Figure 21, the rate of registration of building-related products increased to 79%. This tendency implies that as countries implement a number of environmental policies to encourage sustainability in building and construction sectors, the industries want more willingly to get official approvals of environmental performance in their products.

As showed in Figure 22, the countries with the most construction products registered in the national EPD were identified as France, Germany and Norway. The EPD Registry[10] is a searchable online library of EPD documents on construction products. Most products registered in France PEPecopassport® have been identified primarily as building equipment such as plumbing, electricity and HVAC.

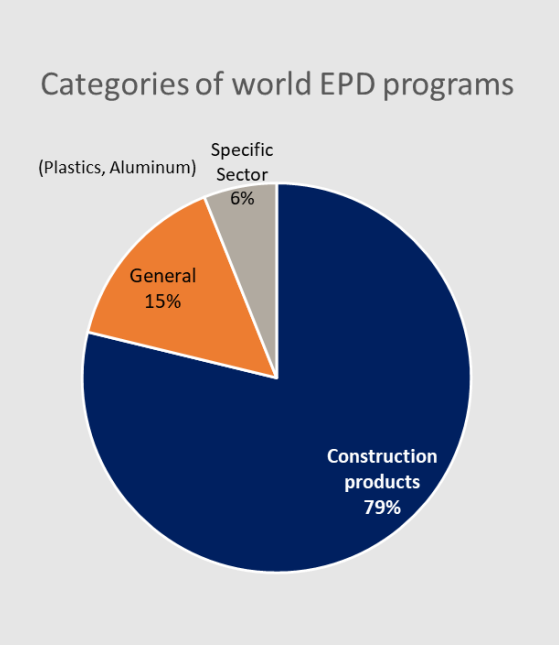


Figure 21 Percentage of construction products registered to national EPD programs

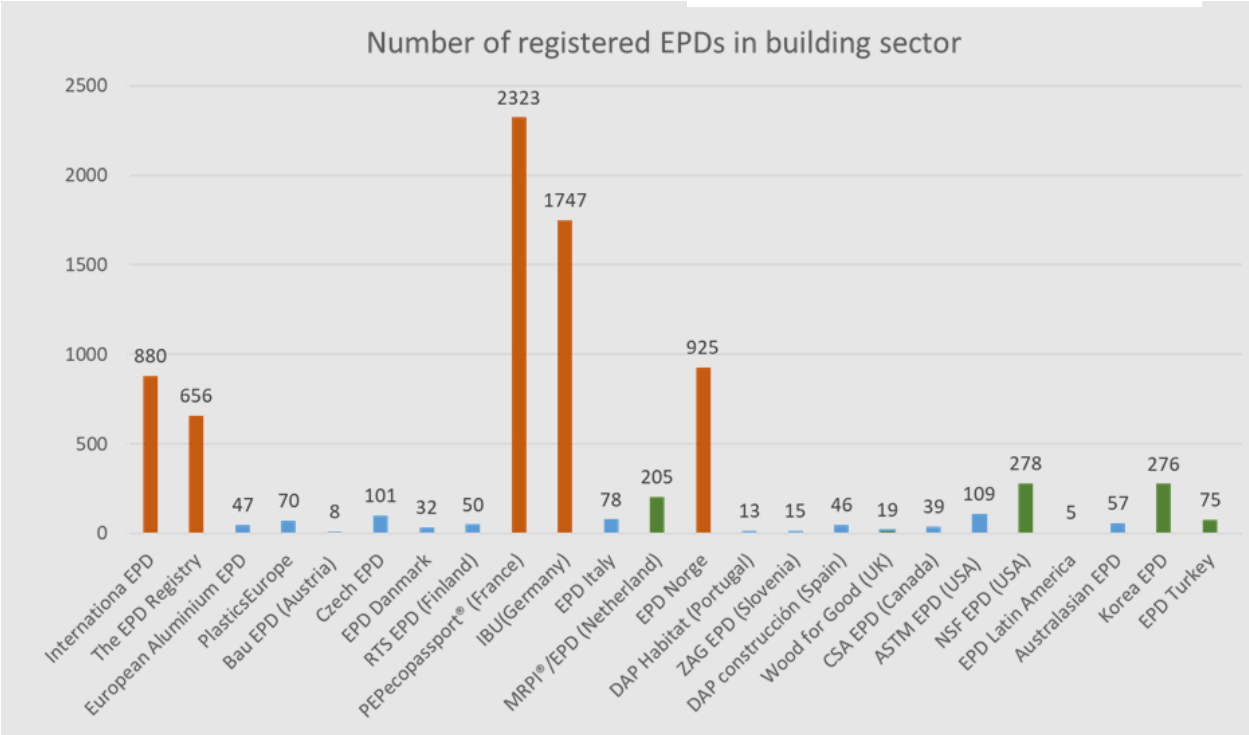


Figure 22 Number of registered national EPD programs in building and construction sector

The trend of registered EPD products in each country is showed in Figure 23. The most registered building products are cement and concrete (14%), followed by boards (10%), insulations (10%), doors & windows (10%), steel & metal products (8%), floor materials (8%) and other building materials. The types of building products with EPD certification in each individual country tend to be similar to the types of products registered in the International EPD system. However, concrete companies are more likely to apply

[10] e EPD Registry (https://www.theepdregistry.com/)

for certification to individual EPD systems in their countries than the International EPD system. This trend will help determine which products should be prioritized when developing PCR for building products.

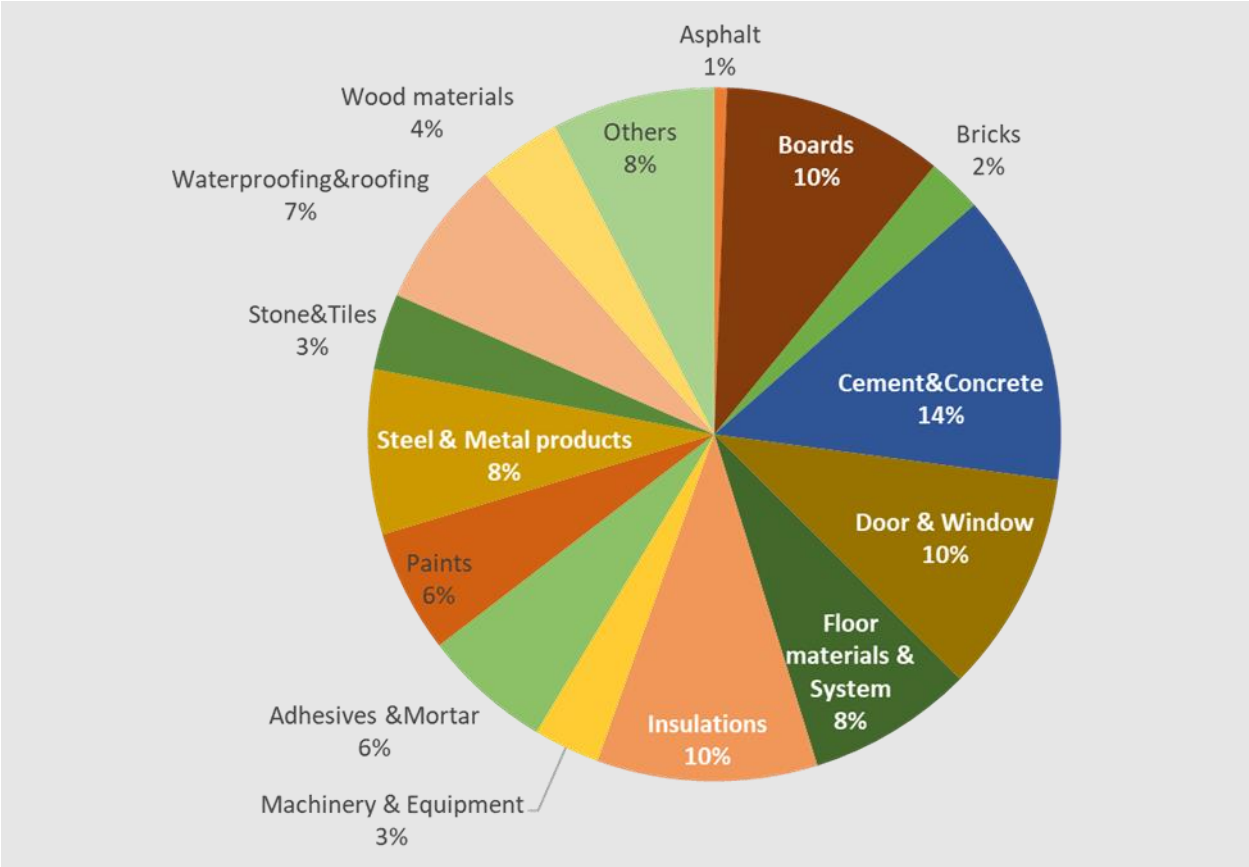


Figure 23 Categories of building and construction products registered to national EPD programs

4.2 Comparison of EPD Results in building-related products by countries

ISO 21930, one of the primary international standards on which to operate the EPD program in the construction sector, does not clearly limit the system boundary for building products. Rather, it proposes to determine the detailed LCA implementation methods such as life cycle stage, parameters or criteria for the inclusion of inputs and outputs with an open consultation process. As a result, even the same building products may have different environmental impacts depending on the EPD operating country. Considering this trend, it is possible to compare in detail how countries differ in the process of implementing LCA of building products through EPD certified products.

Comparative analyzes were conducted at the building product level, building element level, and the building level. For the analysis, the most registered categories of products were searched in the countries with the highest number of registered EPDs. Subjects were mainly found in products registered in IBU (Germany), Norge EPD (Norway), NSF (USA), ASTM (USA), Australasian EPD and International EPD system (see Figure 24). It was not easy to find exactly the same product in different EPD programs because each country has different level of technologies or degree of maturity in construction industry. However, it was compared similar products as possible, so that it was analysed which factors caused differences in the LCA assessment.

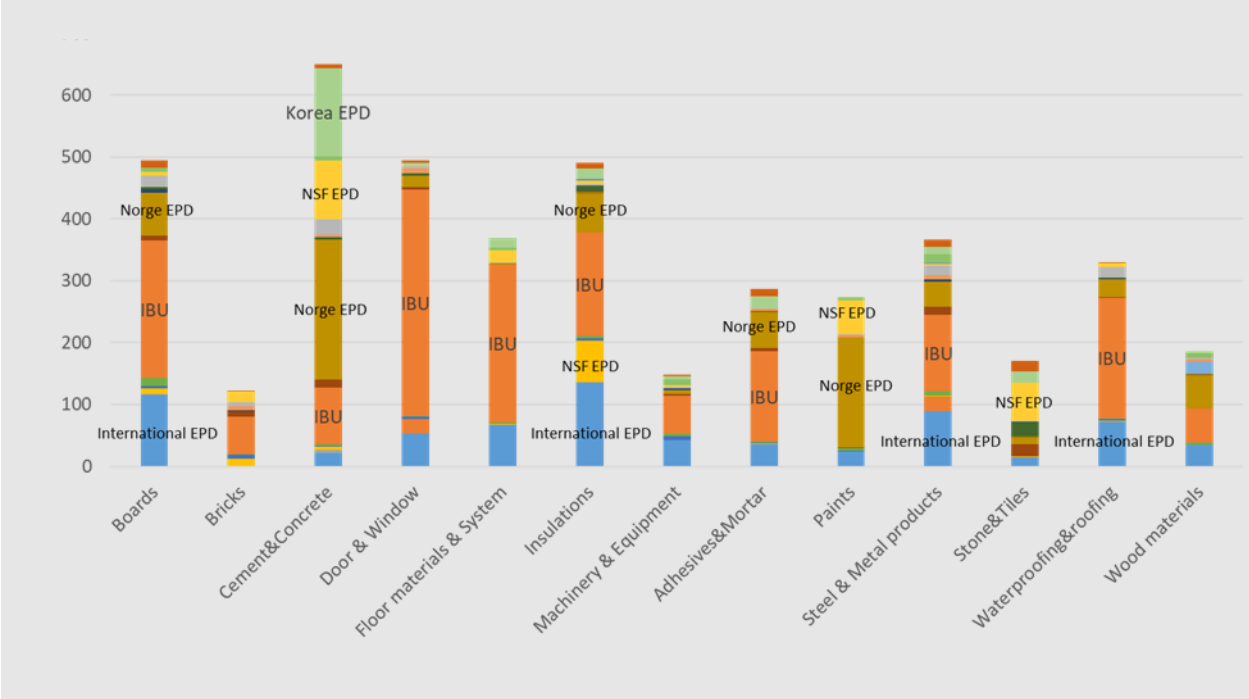


Figure 24 Number of registered EPD by product categories and countries

4.2.1 In building product level

Cement and Concrete products

In the cement and concrete product family, the system boundaries tend to be limited to the production stage. Exceptionally, the Norwegian EPD program included transportation stage into the life cycle of ready-mixed concrete (see Table 32). The same declared unit tends to be used in the similar products in same categories. However, the environmental load of Portland cement products in the view of global warming potential does not vary significantly between countries, but slag cement and ready-mixed concrete are up to two times higher.

Portland cement

First, the causes of the difference in environmental load values of Portland cement shown in Table 29 and Table 30 can be found in the following factors.

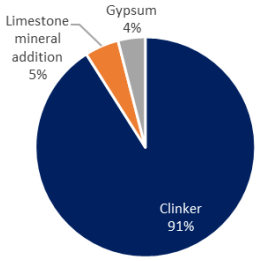
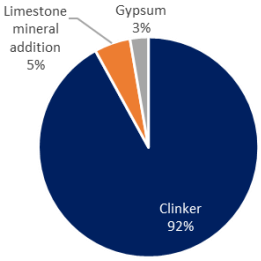
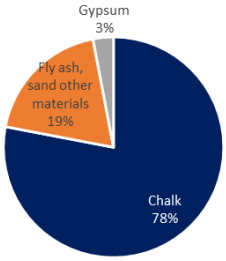
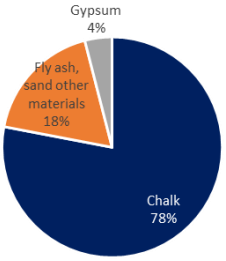
– Korea's Portland Cement, which has the highest GWP per ton, does not publicly open the details of the EPD
– For EverSure GP cement with the lowest GWP value among the list (table 4.3), data on production and specific upstream activities was collected from the factory in New Zealand, while background data was taken from GaBi database which its datasets are representative of Europe, particularly Germany. In addition, all primary data was collected within the last five years, while background data within the last 10 years. Cut-off criteria is that less than 1% of total mass or energy inputs to any unit process are excluded and less than 5% of the total energy or mass flows are excluded.
– Another product manufactured in New Zealand and registered with the Australasian EPD is Holcim Portland Cement. This product has a higher GWP value of 165kgCO2 eq. than EverSure GP cement. Although there are no mentions about cut-off criteria or temporal boundary in the EPD document, the composition of raw materials is similar to the previous New Zealand product. Perhaps the difference in environmental load may be due to the background data source. In addition, it can be due to the fact that some of the raw materials are imported from Japan.

– LAVALKALI SULFATBESTANDIG cement registered in the Norwegian EPD, the next highest GWP per ton, is manufactured in Denmark. Data on production and specific upstream activities was collected from the factory in Denmark, and background data was taken from statistics published by the Danish government and scientific literature published within 5 years. Additional background processes have been modeled with the use of Ecoinvent v.3.2 LCI database. Cut-off criteria is that less than 1% of total mass or energy inputs to any unit process are excluded.

Table 29 EPD comparisons of Portland cement

EPD Program	Country of declaration owner	Product Name	Life Cycle Stages																Environmental impact	
			Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
			A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Environmental Product Declarations	Italy	cemento grigio medio Italia (CEMENTO MEDIO)	○	○	○															777	per 1 ton
Australasian EPD	New Zealand	Bulk type cement, EverSure™ General Purpose (GP) Cement	○	○	○															732	per 1 ton
Australasian EPD	New Zealand	Holcim Ultracem-NZS 3122:2009 General Purpose Portland Cement	○	○	○															897	per 1 ton
EPD Norge	Denmark	LAVALKALI SULFATBESTANDIG cement CEM I 42,5 N - SR5 (EA)	○	○	○															925	per 1 ton
EPD Norge	Denmark	BASIS® cement CEM II/A-LL 52,5 R (LA)	○	○	○															745	per 1 ton
IBU	Latvija	Portland cement CEM I 42,5 R	○	○	○															755	per 1 ton
Korea LCI DB	Korea	Portland Cement	○	○	○															944	per 1 ton

Table 30Comparisons of data quality and environmental result

EPD Program	Australasian EPD	Australasian EPD	EPD Norge	EPD Norge
Product Name	Bulk type cement, EverSure™ General Purpose (GP) Cement	Holcim Ultracem-NZS 3122:2009 General Purpose Portland Cement	LAVALKALI SULFATBESTANDIG cement CEM I 42,5 N - SR5 (EA)	BASIS® cement CEM II/A-LL 52,5 R (LA)
Country of declaration owner	New Zealand	New Zealand	Denmark	Denmark
Composition				
Upstream data	factory data in New Zealand	factory data in New Zealand	factory data in Denmark	factory data in Denmark
Background data	GaBi database	Japanese statistics, New Zealand statistics, IEA, Ecoinvent database	Danish statistics for energy data, scientific literature, Ecoinvent database	Danish statistics for energy data, scientific literature, Ecoinvent database
Cut-off criteria	less than 1% of total mass or energy inputs to any unit process are excluded.	Unknown	less than 1% of total mass or energy inputs to any unit process are excluded.	less than 1% of total mass or energy inputs to any unit process are excluded.
Temporal boundary	primary data: within the last 5 years background data : within the last 10 yrs	Unknown	within the last 5 years	within the last 5 years
GWP (kgCO2 eq.)	732	897	925	745

– Another Danish Portland cement, BASIS® cement emitted 180kgCO2 eq. less than LAVALKALI SULFATBESTANDIG cement. Again, this product has a similar raw material composition and data quality

as the previous Danish product. Both products are manufactured by Aalborg Portland A / S., so it can be considered that the technical level of the two products is the same. However, BASIS® cement and LAVALKALI SULFATBESTANDIG cements differ in strength and therefore in fly ash content. This seems to have caused the difference in environmental load between the two products.

Slag cement

The data quality between EPD of slag cements was limitedly compared in Table 31. because EPD documents were not publicly released. In Korea, blast furnace slag cement differs by nearly 300 kgCO2 eq. between the national LCI database and the EPD. Slag is regarded as waste from other system boundary, so that the environmental load from the slag was excluded from the calculation. Nevertheless, it is interesting that the entire environmental load from Blast furnace slag cement by Koryo company was calculated as 2.4 times higher than national average data.

Table 31 EPD comparisons of Slag cement

EPD Program	Country of declaration owner	Product Name	Life Cycle Stages																Environmental impact	
			Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
			A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Environmental Product Declarations	India	Average Portland Slag Cement	○	○	○															325	per 1 ton
Korea LCI DB	Korea	Average Blast furnace slag Cement	○	○	○															208	per 1 ton
Korea EPD	Korea	Blast furnace slag cement by Koryo slag cement Co.LTD	○	○	○															501	per 1 ton

Ready-mixed concrete

As it can be seen in the Australasian EPD case (see Table 32), even though it was manufactured by the same company, the environmental load of ready-mixed concrete can be calculated differently depending on the strength of the product or the conditions of batching plants.

– In case of B45 MF49 SV40 manufactured by a Norway company, the environmental load is relatively low compared to other products, even though the transportation (A4) is included in the life cycle stage. Since much contents were not disclosed in the EPD document, the details were unknown. Regarding data quality, the followings were identified: the sources of unit process data were factory data, Ecoinvent database and the other EPD. Cut-off criteria is that less than 1% of total mass or energy inputs to any unit process are excluded.
– Both ASTM and NSF are EPD programs operating in the United States. ASTM International is one of the world's largest international standards developing organizations. NSF EPD is managed by The Public Health and Safety Organization. Although both EPD schemes are operated in the United States, the difference of 2 products were more than 2.4 time higher as shown in environmental load values in the case of Table 33. In both cases, products with concrete strength of 50 MPa were compared. The difference might be caused by that the products registered in ASTM EPD were manufactured in the United Arab Emirates. Since NSF EPD follows the PCR developed by ASTM, the data quality of the two products is similar. The other ready-mixed concrete manufactured in the UAE and registered to International EPD system also have a similar GWP value as the product registered in the ASTM EPD.

Table 32 EPD comparisons of ready mixed concrete

EPD Program	Product Name	Life Cycle Stages																	Environmental impact	
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Environmental Product Declarations	Ready Mixed Concrete from Quick Mix Beton LLC - Dubai Branch	○	○	○															315.5	per 1 m3
IBU	DiamondcreteTM R-Ready-mixed Concrete	○	○	○															466.0	per 1 m3
EPD Norge	B45 MF49 SV40 Standard	○	○	○	○														278.9	per 1 m3
ASTM EPD	Ready-mixed Concrete as Manufactured by Emirate Beton	○	○	○															254.0	per 1 m3
NSF EPD	Environemental Product Declaration Ready-Mix Concrete	○	○	○															611.9	per 1 m3
Australasian EPD	Ready-mixed Concrete using Holcim supplied cement (40MPa Normal Grade)	○	○	○															336-445 (depending on batching plant)	per 1 m3
Korea EPD	Korea EPD	○	○	○															392	per 1 m3

Steel bar

The EPD evaluations of the steel bar (see Table 33 and Table 34) tend to include different life cycle stage according to each national EPD program, therefore the environmental impact is also very different. In most cases, the life cycle stage included the production stage (A1 to A3) or transportation (A1-A4). Exceptionally among the list, the Australasian EPD program follows the “cradle-to-gate with options” which includes production stages (A1-A3) and some ranges of end-of-life stage (C3-C4) and environmental benefits (D) due to recycling of waste. Nevertheless, the environmental load from Seismic branded bar registered to Australasian EPD is calculated to be 2.3 times higher than the average value (1.7 kgCO2 eq.) of other products. To find out the cause, it is compared the hot-rolled reinforcing steel (IBU) which has the lowest emissions and the prestressed steel (EPD Norge) which has same value of emissions as the Australasian EPD case.

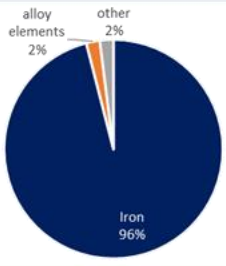
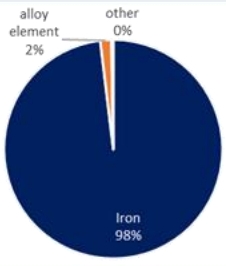
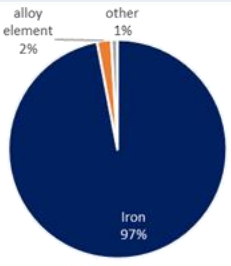
– The Hot-rolled reinforcing steel product was manufactured in Italy and registered in IBU, German EPD program. More than 99% of the raw materials of this product consisted of by-products produced as waste from other product’s system boundaries. The cut-off criterion is 1% mass and energy flows according to EN:15804. Data was collected from manufacturing facility (Catania, Italy) during year 2018. The factory has been making efforts to improve the environmental performance of its production process since 2010. It is installed a new gas filtering system, impulse cleaning system, or radiometric monitoring instruments in order to enhance the manufacturing environment. It is understood that this case produced very little environmental impact due to the use of recycled materials (environmental benefit) generated within the production area (short distance of raw material transportation) and the improvement of the manufacturing environment.
– The prestressed steel, which manufactured in China and registered in Norway EPD program, has same system boundary(A1-A4) and cut-off criterion as the hot-rolled reinforcing steel. Data for module A1 was specifically collected from Worldsteel data for represents of rest-of-world (ROW), and Chinese suppliers for steel wire stranding. For LCA calculation, GaBi 6.4 database was used. It is estimated that the environmental load of this product is greater than the average value of other surveyed products on the list due to the transportation of goods from China to Norway and the environmental condition of factories in China.
– The seismic branded bar was manufactured in New Zealand using steel billets supplied by New Zealand Steel. All primary data came from New Zealand Steel company. The background data were from GaBi Databases 2018. The temporal boundary is within the last 10 years as specified in EN 15804.

Cut-off rule is also that less than 1% of total mass or energy inputs to any unit process are excluded. Although the environmental benefits beyond the system boundary have also been considered, the entire CO2 emissions is still high due to the environmental load from the production stage A1-A3. Looking at the detail of manufacturing process, firstly iron billets are made at New Zealand Steel, and then those billets are reheated in a furnace at Pacific Steel. As the complex process is added to meet the required performance, accordingly the resulting environmental load has also increased.

Table 33 EPD comparisons of steel bar

EPD Program	Product Name	Life Cycle Stages																Environmental impact	
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Environmental Product Declarations	Steel reinforcing bar manufactured from iron ore	○	○	○															1.1	per 1 kg
IBU	Hot-rolled reinforcing steel for concrete in bars and colls	○	○	○	○														0.70	per 1 kg
EPD Norge	Prestressed steel for reinforcement of concrete, PC Strand	○	○	○	○														2.69	per 1 kg
NSF EPD	NSF EPD	○	○	○															2.39	per 1 kg
Australasian EPD	Seismic branded bar by Pacific Steel	○	○	○												○	○	○	2.69	per 1 kg
Australasian EPD	Seismic branded bar by Pacific Steel	3.97														7.77 E-03	5.26 E-03	-1.29	2.69	per 1 kg

Table 34 Comparisons of data quality and environmental result of steel bar EPDs

EPD Program	IBU	EPD Norge	Australasian EPD
Product Name	Hot-rolled reinforcing steel for concrete in bars and coils	Prestressed steel for reinforcement of concrete, PC Strand	Seismic branded bar by Pacific Steel
Country of declaration owner	Italy	Norway	New Zealand
Composition			
Upstream data	factory data in Italy	factory data in China	factory data in New Zealand
Background data	factory data in Italy	Worldsteel statistics, GaBi database	New Zealand statistics, GaBi database
Cut-off criteria	less than 1% of total mass or energy inputs to any unit process are excluded.	less than 1% of total mass or energy inputs to any unit process are excluded.	less than 1% of total mass or energy inputs to any unit process are excluded.
Temporal boundary	Year 2018	within the last 10 years	within the last 10 years
GWP (kgCO2 eq.)	0.70	2.69	2.69

Insulation

The environmental load of insulation products registered in the national EPD was also compared based on global warming perspective (see Table 35). It was not possible to compare the cases because each EPD presents in different declared units. The declared units were various in volume (m^3), area (m^2) and weight (kg). In some cases, the life cycle includes only the production stage(A1-A3), while others include more life cycle stages such as construction (A4-A5), Use stage (B1-B2, B6-B7), end-of life stage(C1-C4) and environmental benefits (D).

Interestingly, the stone wool thermal insulation product registered in EPD Norge generated relatively low carbon emissions, even though it included the most life cycle stages among the investigated cases. This product generated less than half of the carbon emissions compared to the Ravaber Stone Wool Boards registered in Turkey EPD.

On the other hand, the glass wool insulation 32K[11] registered in Korea EPD includes only the production stage (A1-A3), but the GWP was calculated almost 50 times higher than EPD Norge case. This difference may also come from various factors such as raw materials between rockwool and glass wool. Since the EPD document of this product has not been open to public, the details could not be confirmed.

Table 35 EPD comparisons of insulation

EPD Program	Product Name	Life Cycle Stages																	Environmental impact	
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Czech EPD	Clima Glass-W	○	○	○	○										○	○	○		0.33	per 1 kg
IBU	Deutsche Rockwool Gmb H	○	○	○	○									○	○	○	○	○	1.38	per 1 m3
EPD Norge	ROCKWOOL stone wool thermal insulation	○	○	○	○	○	○	○				○	○	○	○	○	○	○	1.32	per 1 m2
NSF EPD	Polyiso Wall Insulation Boards	○	○	○	○	○								○	○	○	○		various depending on the thickness	per 1 m2
Australasian EPD	Pink Batts glass wool insulation	○	○	○															0.96	per 1 m2
Korea EPD	Glass wool insulation 32K	○	○	○															67.40	per 1 m2
Turkey EPD	Ravaber Stone Wool Boards	○	○	○															3.23	per 1 m2

Gypsum board

For the gypsum board category registered in the national EPD systems, single or multi-combined declared units were used such as both area (m^2) and thickness (mm) together, or area(m^2) and weight (kg) together (see Table 36). Due to this difference in declared units, it was impossible to compare the results of GWP in depth. The system boundary also tends to vary from the production stage to the entire life cycle. However, the environmental load did not show a significant difference among gypsum boards compared to other product categories.

[11] The product was manufactured by the French company Saint-Gobain Isover.

Table 36 EPD comparisons of gypsum board

EPD Program	Product Name	Life Cycle Stages																	Environmental impact	
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP	Declared unit
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	(kgCO2 eq.)	
Environmental Product Declarations	**12.5mm Gyproc Habito**	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	3.90	per 1 m2 (12.5mm)
IBU	**Gypsum plasterboard**	○	○	○															2.09	per 1 m2 (10kg)
EPD Norge	**Gyproc Normal**	○	○	○	○	○	○	○	○	○	○			○	○	○	○		2.32	per 1 m2
ASTM EPD	**North American Glass Mat Gypsum Panels**	○	○	○															Various	92.9m2 with stated thickness
Australasian EPD	**GIB Plasterboard**	○	○	○	○	○									○		○		3.68	per 1 m2 (10mm thick)

Tile

Since the life cycle of tile products tends to include the whole life cycle stages with options, it was possible to compare the serviced life span between the products (see Table 37 and Table 38). Serviced life span varied from 50 to 75 years depending on the national EPD program. The life cycles of all surveyed products included production stage (A1-A3), construction stage (A4-A5), maintenance (B2) in use stage and end-of life stage (C2-C4) in common. Assumptions for maintenance scenario are mentioned in each EPD document. In general, all energy and mass flows were considered in the environmental impact assessment of tiles. The effect of reducing environmental loads due to considerate the environmental benefits is significant as shown in table 4. 10, the comparison between IBU case and NSF EPD case.

Table 37 EPD comparisons of tile

EPD Program	Product Name	Life Cycle Stages																	Environmental impact		
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP (kgCO2 eq.)	Declared Unit	Service Life (year)
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D			
Environmental Product Declarations	**Ceramic Floor Tiles from Kaleseramik**	○	○	○	○	○		○	○	○	○			○	○	○	○		13.50	per 1 m2	50
IBU	**Ceramic tiles Bundesverband Keramische Fliesen e. V.**	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	13.54	per 1 m2	50
EPD Norge	**Ceramic tiles via Regina Pacis**	○	○	○	○	○		○							○	○	○	○	18.86	per 1 m2	50
NSF EPD	**Floor Tile manufactured at Dickson, TN**	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		23.44	per 1 m2	75
EPD Italy	**Piastrelle di ceramica italiane**	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	13.79	per 1 m2	50-60

Table 38 Comparisons of data quality and environmental result of tile EPDs

EPD Program	Environmental Product Declarations	IBU	EPD Norge	NSF EPD
Product Name	Ceramic Floor Tiles from Kaleseramik	Ceramic tiles Bundesverband Keramsche Fliesen e. V.	Ceramic tiles via Regina Pacis	Floor Tile manufactured at Dickson, TN
Country of declaration owner	Turkey	Germany	Italy	USA
Composition	Unknown	Clay 45-60% Sand 3% Feldspar 25% Others 12-27%	Clay 26-28% Sand 16-37% Feldspar 23-26% Others 8-32%	Clay 36.3% Sand 4% Feldspar 24.7% Others 35%
Upstream data	factory data in Turkey	factory data in Germany	factory data in Italy	factory data in USA
Background data	TLCID (Turkish LCI database), Ecoinvent database	GaBi / GaBi ts database	GaBi database, Italian IPPC document called AIA	GaBi database
Cut-off criteria	Include all the flows	less than 1% of total mass or energy inputs to any unit process are excluded.	Include all the flows	Include all the flows
Temporal boundary	2016	2009-2014	within the last 3 years	2018
Serviced life span	50 years	50 years (80-150 years possible)	50 years	75 years
GWP ($kgCO_2$ eq.)	13.50	13.54	18.86	23.44

4.2.2 Comparison of EPDs in building element level

There are no many cases that have obtained EPD certification among building element category. Some examples of precast concrete beams used as structures, and system walls used as bearing or non-bearing walls were investigated and analyzed. It was not possible to find valid cases for comparison between floor elements.

Precast concrete beam

In the precast concrete beam, the declared units were used in length (m) or weight (ton). The serviced life span varied greatly from 50 to 100 years. However, there is no environmental load occurred during use stage. Precast concrete T-Beam was manufactured in the United Kingdom and registered in the IBU, German EPD. The product was assumed to be 90% recycled and 10% landfilled, so that the environmental benefits by recycling was calculated as negative values. All the mass and energy flows were included. Background data is based primarily on a generic dataset from GaBi ts 2014.

Comparing two cases (EPD Norge and International EPD) with the same declared unit, there is no big difference in GWP values whether use or end-of life stages are included (see Table 39). Rather, it can be seen that the proportion of the environmental load by the production stage is more significant. Detailed LCA information of each product is as follows:

– Precast concrete beams (EPD Norge): Product specific data was collected from factory in 2014. Generic data is from SimaPro v.8.05.13 with Ecoinvent 3.1. All major materials and energy were included with the exception of materials less than 1%.
– Solid precast concrete beams (International EPD): Temporal boundary was within the last 10 years. Its background data came from Ecoinvent 3.4 and SimaPro 8.4. All major materials, production energy usage and waste were included. It was excluded materials less than 1% weight in the concrete product.

Table 39 EPD comparisons of concrete beam

EPD Program	Product Name	Life Cycle Stages																	Environmental impact		
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP (kgCO2 eq.)	Declared Unit	Service Life (year)
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D			
IBU	UK Manufactured Precast Concrete T-Beam	6.68			0.31	0.00	-0.37	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.12	-0.64	0.00		6.08	1m length of generic precast concrete T-Beam	100
EPD Norge	Precast concrete beams	241.0			32.8	3.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.03	2.53	0.00	2.55		288.87	1 tonne Precast concrete beams	60
International EPD	Solid precast concrete beams	251.0			15.5														266.50	1 tonne Precast concrete beams	50-100

System walls

The declared unit utilized in the system wall category was the area (m2) or weight (ton). In this wall element category, it was mentioned the serviced life span although use and end-of life stages were not included in the LCA evaluations. Detailed LCA information of three products registered to International EPD is described in Table 40 and Table 41.

Table 40 EPD comparisons of system walls

EPD Program	Product Name	Life Cycle Stages																	Environmental impact		
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP (kgCO2 eq.)	Declared Unit	Service Life (year)
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D			
International EPD	Sandwich Wall elements	211.00			4.60														215.60	1 ton of sandwich wall elements	100
International EPD	Insulated Precast Concrete Wall	237.00			12.10														249.10	1 ton of insulated precast concrete wall	50-100
International EPD	Composite walls	163.80			16.60														180.40	1 ton of composite wall	100
IBU	wedi building board made of XPS, coated with cement mortar and fibre glass fabric	4.63				0.02													4.65	1 m2	Unknown

Table 41 Comparisons of data quality and environmental result of system walls EPDs

EPD Program	International Environmental Product Declarations	International Environmental Product Declarations	International Environmental Product Declarations
Product Name	Sandwich Wall elements	Insulated Precast Concrete Wall	Composite walls
Geographical scope	Nordic contries	Nordic contries	Nordic contries
Upstream data	factory data in Sweden	factory data in Sweden	factory data in Sweden
Background data	Ecoinvent database	Ecoinvent 3.3, SimaPro 8.3	Ecoinvent 3.4, Thinkstep's own database from 2017
Cut-off criteria	less than 1% of total mass or energy inputs to any unit process are excluded.	less than 1% of total mass or energy inputs to any unit process are excluded.	less than 1% of total mass or energy inputs to any unit process are excluded.
Temporal boundary	2017-2018	2017	within the last 10 years
Serviced life span	100	50-100	100
GWP (kgCO2 eq.)	215.60	249.10	180.40

4.2.3 Comparison of EPDs in building level

Two cases of EPDs at the building level were identified (see Table 42). The results and characteristics are discussed in this section to show that EPDs are elaborated for buildings too although not so often. A

comparison of the performance of the two buildings is duscouraged because they are very different in terms of purpose and location (to name just two): One is an apartment building in Sweden and the other one is a hotel building in Australia. The production and construction process stages contribute 44 % (apartment, SE) and 21 % (hotel, AU) to the life cycle related greenhouse gas emissions. Both cases follow the PCR for building provided by International EPD system, thus both have same assumption in cut-off rule, serviced life span and temporal boundary. Since the buildings were evaluated in conceptual design stage, the data were based on literature and design document. Secondary data were from EPD systems, national LCI database and commercial LCA software. More detailed information of LCA study is described in Table 43.

Table 42 Two EPDs at building level

Country (purpose of building)	Product Name	Life Cycle Stages																Environmental impact		
		Product stage			Construction process		Use stage							End of Life stage				benefits beyond the system boundary	GWP (kgCO2 eq.)	Declared Unit	Service Life (year)
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D			
Sweden (Apartment)	Folkhem's concept Building	210			48		0.00	5.2	2.6	54	5.9	250	0.00	0.72	1.8	0.62	2.1		580.94	1 m2 temperature controlled space of apartment block	50
Australia (Hotel)	NXTTM Concept Building Wyndham LUX Perth Hotel	774			213		168	50.9		0	244	2,960	137	85.2	38.8	0.8	27	-97.6	4601.10	1m2	50

Table 43 Description of data quality and greenhouse gas emissions of the two buildings

EPD Program		Australasian EPD
Product Name	Folkhem's concept Building	NXTTM Concept Building Wyndham LUX Perth Hotel
Geographical scope	Sweden	Perth, Australia
PCR	PCR 2014:02 Buildings, version 1.0	PCR 2014:02 Buildings, version 2.0 (2018-01-24)
Upstream data	Literature	Design documents (plans, schedules, digital building models and specifications)
Background data	EPD programs, SimaPro version 8.0.5.13, EcoInvent Database 3.1	ELCD, AusLCI database, Ecoinvent 3.0 database
Cut-off criteria	Include 99% of material flows	Include 99% of material flows
Temporal boundary	within the last 10 years	within the last 10 years
Serviced life span	50 years	50 years
GWP (kgCO2 eq.)	580.94 per 1m2	4601.10 per 1m2

5. Conclusion

5.1 Limitations and Weakness

5.1.1 Applied standards

Life Cycle assessment methods have long been evolved with International Standards and European Standards and guidance developed by various international organizations. Regardless of specialty in industrial sectors, most LCI databases follow the ISO standards, and most of the 14020 series and 14040 series, but in rare cases, ISO 14067 was applied. When developing a database in each country, the International Standards were used as the basis, but they were indigenously revised to the own circumstance in leading countries such as France, Germany, and UK. Most of the databases developed in Europe conformed to EN 15804, but the RICS data in the UK, interestingly, conformed to the EN 15978 standard.

Because these standards offer only minimum level to be followed in evaluation process, system boundary and data quality checklist in LCA study, there are no more detailed explanation on unit process aggregation, data modelling process or raw data collection methods. Therefore, even a database that conforms to International or European standards may differ in compatibility of results of environmental performance, or usage with LCA software. This trend was also revealed in a study comparing the operational status of EPD programs. When comparing the certified EPD results within the same product category, there were various differences in topics determined at the goal and scope stages, such as life cycle and declared unit. This suggests that in order to perform LCA of a building with databases developed by different organizations, it is required a database manual in which all details are described.

5.1.2 Unit process modelling

Roughly 75% of the databases surveyed follow the process-based LCA. However, it was observed that IO LCA and hybrid LCA are also partially used depending on the purpose of database. Looking at the databases that can be used in the construction sectors, all databases are based on process-based LCA primarily using field data or statistical data. Even when developing a unit process, data was collected mainly from field data, and national statistics was used for insufficient data. Secondary data were mainly used from simaPro, Ecoinvent, and Gabi database. In addition, the EPD values were actively utilized for LCA databases in building level, for example BEDEC, Spanish LCA database. However, the problem was confirmed in some databases by using literature data developed through private studies, not by coefficients that are officially and widely applied, such as IPCC or PAS2050, to fill the data gap. In this case, it is difficult to confirm the validity of these coefficients, as it is not disclosed the purpose of original research. In order to lower the uncertainty of the dataset according to these problems, it is also recommended that a list of data sources for building specific datasets is offered to database developers.

The majority of investigated databases follows Cradle-to-Grave. In some cases, it follows a more specific life cycle than the life cycle that is generally presented, such as to Cradle-to-Factory gate or Cradle-to-Site. This is also related to the purpose of each database. Depending on the developer of database, impacts by material transportation can be considered as important factor. However, when performing LCA at a building level, this construction product becomes a unit process. If a dataset containing transportation effects to the site is utilized, the environmental load caused by transportation can be double calculated. Therefore, LCA accuracy at the building level can be improved only by using a database that utilizes a unified life cycle.

5.1.3 Cut-off criteria

The cut-off criteria were mostly followed by excluding less than 1% flow based on mass balance. In some cases, however, cut-off criteria were proposed based on energy, and rarely cost was suggested in one database, RICS Building Carbon Database. Cut-off criteria enable LCA practitioners to conduct LCA without having to model 100% of the product system in order to save time and effort in relatively trivial LCA activities. But, in the LCA study at the building level, since the construction material or product is not always proportional to the input quantity and its price, setting a cut-off rule based on the cost can be an obstacle to calculating an accurate environmental impact.

5.1.4 EPD values in LCA database

EPD is an approach that helps to quantify the environmental performance of a product according to ISO standards. However, the results of the survey showed that even in the case of EPD programs using the same standard, the evaluation contents differed depending on the country in which it was operated.

First of all, the PCR at International level that can be commonly used in the construction sectors is under development as of March 2020. There is no uniformity of PCR in each country, and it is difficult to find the uniformity in life cycle stage, or declared unit in product level. As previously discussed in chapter 4, various units such as length, weight, volume and area are used in building product EPD. Even in the same product category, it is found cases that length, area, and weight units are applied simultaneously. Different units make it impossible or very difficult to compare the environmental impacts between alternative products.

Regarding the system boundary for EPD, the life cycle of products applied to structures of buildings, such as concrete and steel, was generally limited to the production stage. On the other hand, products with thermal performance, such as insulation, or finishing materials that are related maintenance activities during use stages, such as gypsum boards and tiles, showed many differences in their system boundary. It means that various scenarios were applied to unit process modeling. Therefore, it is difficult to fairly compare environmental loads between similar products if only EPD results are offered in EPD repositories without considering these different assumption and unit process modelling.

5.1.5 LCA results

Life cycle inventory is a compilation of resource inputs (such as energy, water, land, etc.) and waste outputs (such as atmospheric emissions, waterborne emissions, solid wastes, etc.) associated with entire life cycle. The LCI results are the input to Life cycle impact assessment (LCIA) phase addressing environmental impacts such as climate change, human health, and biodiversity. Several impact assessment models have been developed in the LCIA. LCA software is equipped with various LCIA models to conveniently compare LCI results.

Most of the investigated databases and repositories provided the environmental impact assessment results of the dataset through websites or documents. The environmental impact category is represented by at least 2 indicators of which are greenhouse gas emissions and primary energy consumption, or as many as 17 indicators. The purpose of the LCA study is to determine which option is the best in environmental perspective. Although it is possible to quickly compare results when providing only one or two environmental impact indicator results, it might lead to a biased judgment on the environmental performance of a product or building. Because there are many factors that affect the environment, a fair number of indicators or a comprehensive single score indicator should be used based on international trend to compare environmental performance.

5.1.6 Data format

As a result of investigating nearly 100 databases, it was very rare to follow internationally common LCI data formats such as ILCD or EcoSpold. In some cases, specific results were provided in pdf, excel for product level comparison only, or to check only the values through the web. This shows that they were

developed without sufficient interest in interoperability between other databases. This implies that data format is structured according to industry perception or national program operation characteristics.

On the other hand, some databases have been developed with compatibility with various LCA tools to allow LCA studies at the building level. In this case, it is easy to use the database for various LCA studies, because the environmental performance of the building product can be checked to select the best option in the building. Therefore, to make the database compatible with multiple software, it is also necessary or at least helpful to unify the database format.

5.1.7 Documentation

Most LCI and LCA databases reflect the market conditions of their own country and target the domestic market. However, due to the difficulty of data collection, old data sources may be used to evaluate the latest technology, or domestic industry data can be used together with overseas statistics. In these cases, the data quality may become deteriorated. Even if all evaluation processes are transparent, some unit process data can be hidden due to confidentiality issues. Some databases developed by universities are not publicly available for judging the data quality, and some have not been developed according to international standards. In addition, it should be paid attention to using a database with special purpose such as database of embodied energy or embodied carbon, which has a different system boundary for unit process data collection.

Dataset with low data quality does not always mean that there is a large error. But an LCA study will be more accurate if the user can identify the most appropriate datasets. All contents related to data quality should be documented and disclosed so that the user can select a database suitable for his or her purpose.

5.2 Suggestions for the further works

The life cycle inventory data required to evaluate the life cycle related environmental impacts of buildings are being developed more and more. The total number of databases currently available is over a few hundred, and the total number of datasets counted for this report is over 682,000 covering all kinds of categories. The number of datasets available for building and construction sectors is more than 24,000, and this number is on the rise. In addition, the number of EPDs registered for the construction product and element is also increasing significantly, and the product categories are getting more and more diverse. A total of 4,773 EPDs related to construction products have been surveyed for this report. Among them, there are cases in which companies have EPD approval of the same product in several countries, but it is considered to be a very meaningful number regarding the categories of products used in buildings. Although various materials are included in the building, depending on how to set the cut-off category, and based on mass flow, the building material evaluated in the LCA stage of the building can be limited to 20 or less. Therefore, even with the currently established LCI database, it is possible to accurately predict the environmental load during the entire life cycle of the building, reflecting our realistic situation.

Not all evaluators of building's environmental performance may have a sufficient understanding of LCA. They might only have more architectural engineering knowledge. However, eventually users are those who have responsibility to make the best choice after performing LCA study. In a product level, difference between databases may be little significant per same declared unit. On the other hand, since the difference can cause a major exaggerated evaluation in a building scale during a whole life cycle stage, the evaluator needs to check and utilize how the product data was developed.

Therefore, in order for such users to use the database correctly, it is very important to unify the LCA methodology in detail, and to improve the data quality. With regard to the methodology, clear guidance is required for all factors affecting data quality. It is necessary to describe available data sources which the

help of database developers to apply similar data collection method. In addition, database developers should disclose data quality information so that the users can improve the accuracy of evaluation results. In order to compare between similar products, the results of LCA study should be expressed with a sufficient number of environmental indicators according to international trends. When these guidelines are supported, individual researchers and database developers can improve the quality of LCA research results, facilitate comparative research between data, and maximize the use of the LCA database in the building and construction sector.

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7. Appendix

No.	Country	Name of Database	Types of database	Organization	Website
1	Global	IISI Life Cycle Inventory Study for Steel Industry Products	LCI database	International Iron and Steel Institute (IISI)	www.worldsteel.org/?action=programs&id=62
2	Global	Life Cycle Inventory / Analysis of Stainless Steel	LCI database	International Stainless Steel Federation (ISSF)	http://www.worldstainless.org/
3	Global	Zinc Environmental Profile	Environmental Profile	International Zinc Association (IZA)	http://www.zincforlife.org/life_cycle_publications.html
4	Europe	Eco-Profiles of the European Plastics Industry	Environmental Profile	PlasticsEurope (Association of Plastics Manufacturers in Europe)	https://www.plasticseurope.org/en/resources/eco-profiles life-cycle-thinking.aspx
5	Europe	Environmental Footprint (EF)	Environmental Footprint	European commission	https://eplca.jrc.ec.europa.eu/EF-node/
6	Europe	Environmental Profile Report for the European Aluminum Industry	Environmental Profile	European Aluminum Association	http://www.european-aluminium.eu/media/1329/environmental-profile-report-for-the-european-aluminium-industry.pdf
7	Europe	European Database for Corrugated Board	LCI database	European Federation of Corrugated Board Manufacturers	www.cepi-containerbord.org
8	Europe	European Reference Life Cycle Database 2.0(ELCD)	LCI database	European Commission – Joint Research Centre	http://eplca.jrc.ec.europa.eu/ELCD3/index.xhtml?stock=default
9	Europe	Life Cycle Assessment of Container Glass in Europe	LCI database	European Container Glass Association	www.feve.org/index.php?option=com_content&view=article&id=16&Itemid=18
10	Europe	Life Cycle Analysis for	LCI database	European Copper Institute	www.kupfer-institut.de/lifecycle/

		Copper Products			
11	Europe	NEEDS LCI database	LCI database	NEEDS(New Energy Externalities Developments for Sustainability)	http://www.isistest.com/needswebdb/
12	UK	Carbon Calculations over the Life Cycle of Industrial Activities (CCaLC)	LCI database	The University of Manchester	www.ccalc.org.uk
13	UK	EuGeos' 15804-IA Database Version 3.0	LCI database	EuGeos	http://www.eugeos.co.uk/lifecycle_assessment/epd.html
14	UK	Green Book Live	Environmental Profile	Building Research Establishment	www.greenbooklive.com/search/productsearch_env_profiles.jsp?partid=10000
15	UK	ICE database	LCI database	Circular Ecology, Sustainable Energy Research Team (SERT) at University of Bath	http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html#.XlHv0igzZEY
16	UK	RICS Building Carbon Database	Embodied carbon database	UK Green Building Council	https://wlcarbon.rics.org/About.aspx
17	Germany	EstiMol	LCI database	ifu Hamburg	https://www.ifu.com/en/umberto/estimol/
18	Germany	GaBi Databases	LCI database	Thinkstep	http://www.gabi-software.com/international/support/latestupdate/gabi-database-upgrade-2020/
19	Germany	ÖKO-BAUDAT platform	EPD database	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)	www.oekobaudat.de.
20	Germany	ProBas	LCI database	Federal Environment Agency - Germany	www.probas.umweltbundesamt.de/php/index.php
21	Switzerland	BUWAL 250 LibraryTM	LCI database	Swiss Packaging Institute	http://svi-verpackung.ch/de/Services/Publikationen
22	Switzerland	Ecoinvent Database v2.2	LCI database	Swiss Centre for Life Cycle Inventories	http://www.ecoinvent.org/home/

23	Switzer-land	ESU-ETH 96	LCA data-base	ETH Zürich	www.pre.nl/download/manuals/DatabaseManualETH-ESU96.pdf
24	Switzer-land	ESU-services data-on-de-mand LCIA	LCIA data-base	ESU-services Ltd.	http://www.esu-services.ch/data/data-on-demand/
25	Switzer-land	iLCA2010+ LCI Data Base System	LCI data-base	Gruner-Team Sustainability	http://grauner.blogspot.com/
26	Switzer-land	LC-Invento-ries.ch	LCI data-base	Swiss Federal Office of the Environ-ment, (SFOE)	http://www.lc-inventories.ch/
27	Switzer-land	UVEK LCI data DQRv2 : 2018	LCI data-base	Platform Life Cy-cle Assessment in the construction sector	http://www.lc-inventories.ch/
28	Switzer-land	KBOB rec-ommendation 2009/1:2016	LCA data-base	KBOB	https://treeze.ch/projects/case-studies/building-and-construction/kbob
29	France	DEAM	LCI data-base	Ecobilane (PwC)	www.ecobilan.com/uk_deam01_02.php
30	France	EIME	LCA data-base, EPD database	Bureau Veritas - CODDE	http://codde.fr/en/our-software/eime-en/eime-presentation
31	France	INIES	LCI database, LCA database, EPD database	ADEME	http://www.inies.fr/home/
32	France	DIOGEN da-tabase	LCA data-base	AFGC	http://www.diogen.fr/
33	Nether-lands	CML-IA	LCIA data-base	Institute of Envi-ronmental Sci-ences at Leiden University	http://www.cmlca.eu/
34	Nether-lands	IVAM LCA DATA 4	LCI data-base	Universiteit van Amsterdam	https://ghgprotocol.org/Third-Party-Data-bases/IVAM
35	Nether-lands	Nationale Mi-lieudatabase 3.0	LCA data-base	STICHTING BOUWK-WALITEIT	https://milieudatabase.nl/
36	Czech	Envimat	LCA data-base, EPD database	Faculty of Civil Engineering CTU Prague	http://www.envimat.cz/
37	Denmark	EDIP method and tools	LCI data-base	FORCE Tech-nology, IPU(In-stitute for	https://lca-center.dk/

				Product Development at Technical University of Denmark)	
38	Finland	ARVI database	LCI database	CLIC Innovation LTD	http://arvifinalreport.fi/
39	Spain	BEDEC - Banco BEDEC 2019	LCA database	ITeC	https://metabase.itec.cat/vide/es/bedec
40	Sweden	CPM LCA Database	LCI database	Centre For Environmental Assessment of Product and Material Systems Chalmers University of Technology	http://cpmdatabase.cpm.chalmers.se/Start.asp
41	America	Athena Life Cycle Inventory Product Databases	LCI database	Athena Institute	http://www.athenasmi.org/our-software-data/lca-databases/
42	America	Canadian Raw Materials	LCI database	University of Waterloo, Environment Canada, Environment and Plastics Industry Council	http://crmd.uwaterloo.ca/eng.html
43	America	Quebec LCI Database	LCI database	CIRAIG	http://www.ciraig.org/en/bd-icv_qc.php
44	America	Franklin US LCI Database	LCI database	Franklin Associates, published by PRé Consultants	www.fal.com/projects.html
45	America	Minnesota Building Materials	LCA database	College of Architecture and Landscape Architecture · University of Minnesota	http://www.buildingmaterials.umn.edu/materials.html
46	America	Federal LCA Commons	LCI database	USDA, EPA, DOE	https://www.lcacommons.gov/lca-collaboration/search
47	America	U.S. Life-Cycle Inventory Database V1.6.0	LCI database	National Renewable Energy Laboratory	http://www.nrel.gov/lci/
48	Australia	Australian National Life Cycle	LCI database	Australian Life Cycle	http://auslci.com.au

		Inventory Database (AusLCI)		Assessment Society (ALCAS)	
49	Australia	Evah OzLCI2019 Free Database	LCI database	Evah Institute	http://www.evah.com.au.
50	China	Chinese Life Cycle Database	LCI database	Sichuan University, China; IKE Environmental Technology CO., Ltd, China	http://www.itke.com.
51	China	eFootprint	LCA database	IKE Environmental Technology CO., Ltd	http://www.efootprint.net/#/home
52	Japan	IDEA v2	LCI database	AIST/JEMAI	http://www.milca-milca.net/download-files/MiLCAguidebook_En.pdf
53	Japan	JLCA-LCA database	LCI database	Life cycle assessment society of Japan	http://lca-forum.org/
54	Korea	Korea LCI database	LCI database	Korea Environmental Industry & Technology Institute	www.keiti.re.kr
55	Malaysia	The Malaysia Life Cycle Inventory Database (MYLCID)	LCI database	SIRIM	https://mylcid.sirim.my/static/jumppage.xhtml
56	New Zealand	BRANZ CO 2 NSTRUCT	Embodied energy/carbon database	BRANZ	https://www.branz.co.nz/co2nstruct
57	New Zealand	LIFE CYCLE INVENTORY DATASETS	LCI database	New Zealand Life Cycle Management Centre	http://lcm.org.nz/data-sets
58	Thailand	Thai National Life Cycle Inventory Database	LCI database	MTEC (National Metal and Materials Technology Center)	http://www.thailcidatabase.net/

ANNEX 72

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