Spread of Innovative Solutions for Sustainable Construction

Handbook

2 Life Cycle Assessment

IS-SusCon

Co-funded by the Erasmus+ Programme of the European Union

2 Life Cycle Assessment

2.1 What is life cycle assessment (LCA)?

Life cycle approach and LCA

Our everyday life has direct and indirect impacts on the environment. **Direct impacts** are quite clear and evident: whenever we directly take a raw material from our surrounding environment, or something gets directly into the soil, surface waters or burns into the air, have a direct impact. For example, when one has a garden and that person takes ground water from an own well or puts fertilizers into the soil or pesticides on the plants. Or when someone burns gas in their boiler or wood in their stove, smoke appears in the chimney representing their direct air emissions.

It is more difficult to understand our **indirect impacts** as they do not happen in front of our eyes. These impacts are "hidden" and so they can be even more dangerous if we are not aware of them.

Where are these indirect impacts? They are related to the many products we use during our life, meaning food, clothing, building materials, electricity, transport etc. All these products have been produced somewhere in the world and then transported to us. These production and transport processes have their own direct impacts: on a larger scale, resource extraction activities can lead to serious resource depletion, water scarcity or deforestation; emissions of greenhouse gases leads to climate change, while emission of other substances may cause acid rains, smog or eutrophication. When we use these products, we are indirectly responsible for these damages to the environment.

After the usage of the products, there can be different types of wastes: transport and treatment of these waste – such as landfill disposal, incineration, recycling or reuse - have also their direct impacts, which are also unseen from our homes.

If we call this long chain and network of processes – production, transport, usage, end of life – as "life cycle" of a product then we can understand all impacts with "**life cycle approach**".

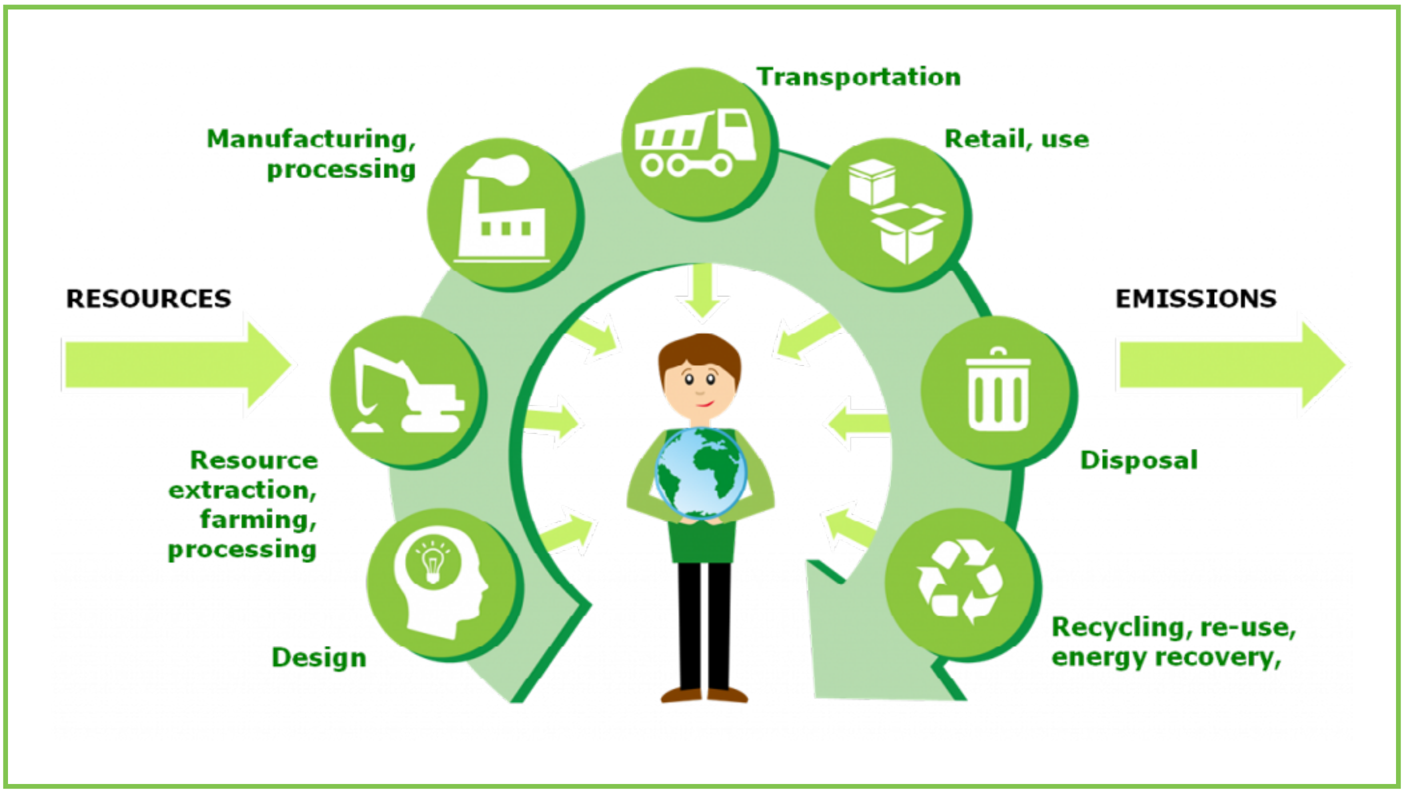


Figure 6: Life cycle approach[8]

Life Cycle Assessment (LCA) is a standard method to quantify potential impacts applying such a life cycle approach. LCA gives us numbers that help to manage our environmental impacts: we can identify the so called "hot spots" where our impact is the highest, and so it spots where and how can we achieve the highest possible reduction of our direct or indirect impacts.

8 Source: https://areeweb.polito.it/ricerca/LCA/ (last access in April 2021)

If we understand our impacts in depth with a life cycle approach, and we can quantify them through LCA, then we realize our decision-power to reduce these impacts. The kind of products we purchase and use and the amount may significantly influence our environmental impacts. Think of all the materials, energy sources, transporting services that we use during our everyday life! We can make plenty of decisions to decrease our direct, but mainly our indirect impact by using a life cycle approach.

The phases of LCA

LCA is called also as a “from cradle to grave” analysis, but according to the concept of circularity “from cradle to cradle” would be more appropriate. LCA is a special science where experts can work on LCA with software and database with huge number of processes.

According to the ISO 14040 and ISO 14044[9] standards an LCA shall include the following phases:

- **goal and scope definition,**
- **inventory analysis**, when resources consumptions and emissions of the life cycle are quantified,
- **impact assessment**, when potential environmental impacts due to resource consumptions and emissions are assessed,
- **interpretation** of results.

The connection of these phases can be seen in the following figure of the ISO 14040 standard:

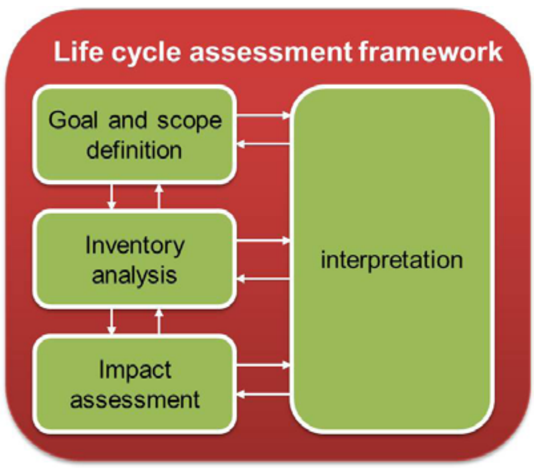


Figure 7: Methodological steps according to ISO 14040[10]

9 ISO 14040/14044 (2006): Environmental management — Life cycle assessment — Principles and framework / Requirements and guidelines
10 Source: ISO 14040

The process of preparing an LCA is perfectly covered in keywords by the ISO 14040 standard. Based on this, we need to clarify the goal of the analysis at the beginning of the work, namely why the analysis is performed (for example, we wish to make our operations more sustainable and therefore we wish to reduce our environmental impact; we wish to communicate to our customers our commitment to the environment by declaring the environmental performance values of our activities etc.) The answer to this first question influences also the definition of the additional initial aspect, i.e., what is the scope of the analysis:

- **functional unit:** e.g.: one piece of product, 1m^2 surface of product; 1-year production, etc. for which we calculate the results expressing the environmental impact,
- **system boundaries:** considering only our own activity (from gate to gate) or including the previous phases (from cradle to gate), or the whole life cycle (from cradle to grave), etc.

In practice, the **data collection** represents the most important part in the preparation of an analysis - it determines the data quality - and it is also the most time-demanding step. The best and most recommended approach is to collect the data related to the activity directly: that is to collect the manufacturing data of the product under investigation. It is also possible to work with secondary data for other life cycle processes: calculated and estimated data, industry data, databases, literature data, etc.

The analyst is taking then the further steps in the LCA: inventory analysis, impact assessment, and interpretation of the results. As a matter of course, these steps are also strongly influenced by the goals defined in the first step, as it determines for example, the applied impact assessment method or impact category (e.g. carbon footprint), and the interpretation of the results and possible definition of recommendations as well.

An environmental life cycle assessment most often considers the following impact categories:

- **climate change:**

The impact category is known by different names: global warming impact, climate change, carbon footprint depending on the chosen impact assessment method and the targeted audience. Our everyday speech uses most often the carbon footprint value, but also the name "climate change" is frequently applied. How should we interpret the results of this category? In each case, the quantities of greenhouse gases released into the atmosphere are aggregated and assessed in kg CO_2 equivalent. This simply means that 1 kg of carbon dioxide emission is considered as 1 kg of CO_2 equivalent in this category. Any other greenhouse gases are weighted differently. For example, the value of methane is currently (in 2021) 36.8 kg of CO_2 equivalent. The time of the data / analysis is also important as 15 years ago, this value was only 21 kg CO_2 equivalent in the same category. It also shows that the effects of climate change has become more serious; they are present in our daily lives and are strongly influencing our future. Different multipliers are applied also to the other greenhouse gases, for example the potential release of 1 kg of freon-12 (difluorodichloromethane) into the atmosphere would mean a 11500 kg CO_2 equivalent. (In fact, this material was removed due to this reason from the refrigerant in old refrigerators.)

The results of the other **impact categories** are calculated in a similar way. An equivalent has been determined for each one, to which the weights of the other relevant elements were compared and then summed, so that the impact category can be characterized by one number:

- acidification (e.g. SO_2 kg or mol H + equivalent),
- eutrophication (e.g. PO_4, P or N kg equivalent),
- ozone depletion (e.g. CFC-11 equivalent),
- resource depletion (e.g. kg Sb equivalent),
- photochemical ozone formation (e.g. ethylene or NMVOC " non-methane volatile organic compounds equivalent),
- human, aquatic, terrestrial, marine ecotoxicity (complex equivalent types exist).

IMPACT CATEGORIES 1(*)

Climate Change

Covered environmental issue: All inputs or outputs that result in greenhouse gas emissions. The greatest contributor is generally combustion of fossil fuels such as coal, oil and natural gas. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

This impact category can be further subdivided in:
• Climate change fossil that covers greenhouse gas emissions originated from the transformation or degradation of fossil fuels (i.e. combustion)
• Climate change biogenic that covers greenhouse gas emissions originated from the transformation or degradation of biomass
• Climate change land use change that covers carbon uptakes by the soil or the biomass and emissions originating from carbon stock changes caused by land use change and land use, such as deforestation, road construction or other soil activities
Unit of measurement: Kilogram of Carbon Dioxide equivalent (kg CO_2 eq).

Ozone Depletion

Covered environmental issue: The stratospheric Ozone (O_3) layer protects us from hazardous ultraviolet radiation (UV-B). Its depletion can have dangerous consequences in the form of increased skin cancer cases in humans and damage to plants. The stratospheric ozone depletion is an impact which affects the environment on a global scale. Unit of measurement: kilogram of CFC-11 equivalent (kg CFC-11 eq).

Acidification

Covered environmental issue Acidification has contributed to a decline of coniferous forests and an increase in fish mortality. Acidification can be caused by emissions getting into the air, water and soil. The most significant sources are combustion processes in electricity, heating production and transport. The contribution to acidification is greatest when the fuels contain a high level of Sulphur. Acidification is an impact which mainly affects the environment on a regional scale.
Unit of measurement: Mole of Hydron equivalent (mol H+ eq).

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

IMPACT CATEGORIES 2(*)

Eutrophication freshwater

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). If algae grow too rapidly, it can leave water without enough oxygen for fish to survive. Nitrogen emissions into the aquatic environment are caused largely by fertilisers used in agriculture, but also by combustion processes. The most significant sources of Phosphorus emissions are sewage treatment plants for urban and industrial effluents and leaching from agricultural land. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilograms of Phosphorus equivalent (kg P eq).

Eutrophication -marine

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). As a rule, the availability of one of these nutrients will be a limiting factor for growth in the ecosystem, and if this nutrient is added, the growth of algae or specific plants will be increased. For the marine environment this will be mainly due to an increase of nitrogen (N). Nitrogen emissions are caused largely by the agricultural use of fertilisers, but also by combustion processes. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Nitrogen equivalent (kg N eq).

Eutrophication - terrestrial

Covered environmental issue: Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and therefore, limit the growth in the original ecosystem. Eutrophication is an impact which affects the environment at local and regional scale.

Unit of measurement: Mole of Nitrogen equivalent (mol N eq).

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

IMPACT CATEGORIES 3(*)

Photochemical ozone formation - human health

Covered environmental issue: While stratospheric ozone protects us, ozone on the ground (in the troposphere) is harmful: it attacks organic compounds in animals and plants, it increases the frequency of respiratory problems when photochemical smog ("summer smog") is present in cities. Photochemical ozone formation is an impact which affects the environment at local and regional scale.

Unit of measurement: kilogram of Non-Methane Volatile Organic Compound equivalent (kg NMVOC eq).

Resource use, mineral and metals and energy carries

Covered environmental issue: The Earth contains a finite amount of non-renewable resources, such as metals, minerals and fossil fuels like coal, oil and gas. So, extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. For example, the depletion of fossil fuels may lead to the non-availability of fossil fuels for future generations.

The impact categories that analyse this phenomenon are:

• Resource use, mineral and metals that covers the depletion of metal and minerals

Unit of measurement: kilogram of Antimony equivalent (kg Sb eq)

• Resource use, energy carriers that covers the depletion of fossils fuels

Unit of measurement: MJ of energy.

Water scarcity

Covered environmental issue: The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers the availability or scarcity of water in the regions where the activity takes place.

Unit of measurement: cubic metres (m3) of water use related to the local scarcity of water.

(*)https://ec.europa.eu/environment/eussd/smgp/communication/impact.htm (last assess: April 2021)

So in the LCA practise we should answer the following three questions at the beginning of the analysis:

Questions	Example answer
What is the goal?	I would like to know the carbon footprint of my insulation product
What is the functional unit?	1m^2 insulation (100mm thickness) with 0,0389 W/m°K thermal conductivity
What are the system boundaries?	From cradle to gate – from the production of base materials to the end of the manufacturing process

If an LCA expert can get the important information for the assessment from the owner, following that the real impacts can be defined. In this example, the most important result is the carbon footprint, but an LCA also can determine many other potential impacts on the ecosystems, humans and natural resources.

Returning to the example: the carbon footprint of the examined insulation can be 6 kg CO_2eqv. divided in 3 parts: the pre-manufacturing of the base materials (5 kg CO_2eqv.), the transport of the base materials to the factory (0,5 kg CO_2eqv.) and the manufacturing of the insulation product (0,5 kg CO_2eqv.). As a comparison: manufacturing one loaf of bread has about 1,5kg CO_2 equivalent.

All of these data and results are summarized in an LCA study, which finally contains also the interpretation of the results.

The life cycle approach and assessment provide the basis of other evaluation methods, e.g.: EPD – Environmental Product Declaration (see details in Ch.2.3a), PEF – Product Environmental Footprint or LCC – Life Cycle Costing, etc. Which one we use depends on the goal of the LCA.

2.2 The role of LCA in the construction industry

LCA is one of the most effective methods for assessing the environmental impact of building products and constructions. Application of LCA has two primary benefits:

- It helps the consumer and construction professionals in their decisions from design through the construction process by objective information.
- It encourages manufacturers to improve the environmental performance and quality of their product through the innovation.

An LCA shows the amount of energy necessary to a building or the amount material saving possible over the life of the building, as well as how they have a positive impact on environment during investment and maintenance.

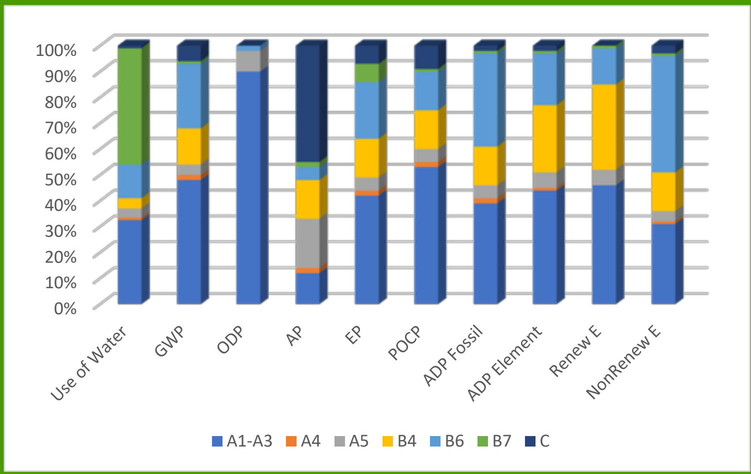
The role of LCA has increased in the construction industry in recent years, given that the **construction sector is one of the most burdensome sectors** in terms of both resource use and environmental impact. 36% of the global energy consumption and 39% of emissions are related to the construction sector and buildings (IEA & UN 2019[11]). Construction accounts for 11% of global CO_2 emissions (WGBC, 2019[12]). Reducing loads requires a more in-depth, life-cycle approach to material flows. It is no coincidence that in the construction sector, in addition to energy efficiency, the goal has been to build near-zero or zero-energy buildings. This is true for both newly built and renovated buildings.

11 IEA & UN (2019): 2019 Global Status Report for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector https://www.unenvironment.org/resources/publication/2019-global-status-report-buildings-and-construction-sector (las access in April 2021)
12 World Green Building Council (2019): Bringing Embodied Carbon Upfront https://www.worldgbc.org/bringing-embodied-carbon-upfront-report-webform (last access in April 2021)

Impact of building life cycle:

The examination of the environmental performance of buildings over their entire life cycle can be applied to the following stages (ISO EN 15643): from the extraction of building materials and raw materials to their production and transport, the installation phase "A1-A5", the use phase "B1-7" and the end of life after the demolition of the building "C1-C4".

*Relative contribution of building life cycle stages to environmental impacts **



Nearly half of the environmental impacts are related to the A1-A5 modules, the other half derives from the use phase. The end of life impacts constitutes to 5%.

A representative survey was also carried out in the EU about sustainable consumption and production, and a part of it assessed the environmental impact of the building stock (EU 27). As 60% of the building stock is residential, the environmental impacts per capita and per year was examined, as well as the impacts of the average European dwelling were examined and compared with the impact on an average European citizen. The age and type of the housing stock, the size of the living space and climatic conditions were assessed per capita and the load on the life cycle stages of the building stock were examined through 24 models. Taking into account the average greenhouse gas emissions of the life cycle of buildings were 6.36 tonne CO_2 eq. per dwell per year, compared to the average 2.62 tonne CO_2 eq. per capita. The use phase (energy and water consumption) was the most important aspect, followed by the production and maintenance of building materials. It was found that single-storey houses are responsible for the greatest impact. The same building has different effects in different climatic zones, especially due to differences in heating needs. In general, electricity consumption and space heating contribute the most to the environmental impact. **

Concerning average impact of building is Europe the value is 6.78 t CO_2 equivalent per capita, while this value is 8.8 t in Finland; 5.8 t in Italy and 5.4 t in Hungary ***.

(*) Source: Delem, L. Wastiels, and J. Van Dessel (2013): Assessing The Construction Phase In Building Life Cycle Assessment, Delemetal_avniRConference

(**) Source: Lavagna, M., Baldassarri, C., Campioli, A., Giorgi, S., Dalla Valle, A., Castellani, V., & Sala, S. (2018). Benchmarks for environmental impact of housing in Europe: Definition of archetypes and LCA of the residential building stock. Building and Environment, 145, 260–275. doi:10.1016/j.buildenv.2018.09.008

(***) Source: EU publications: Fossil CO_2 and GHG emissions of all world countries, 2019 report Study

Driving forces of LCA application in the industry: Why companies apply LCA?

The application of LCA provides important information in the **design** process – that can be based on BIM-method (Building Information Modelling) digital solution to model the design and construction - and in the maintenance and demolition phase. In addition to measuring the environmental performance of the materials used in a building, LCA can be used at an early stage in the design in order to identify aspects of the building that are important for the environmental impact regarding the impact categories considered. For materials which have a higher environmental impact, a life cycle assessment of sustainable building materials can help in finding alternative materials with lower impacts. In this way, environmental impacts can be reduced, less waste would be generated, buildings would have a more efficient use of energy and water, and costs can be optimised as well.

The main users of LCA are manufacturers of construction products, as they may have a legal obligation or **market pressure** to submit an LCA-based Environmental Product Declaration (EPD) (see Ch.2.3a) for their products. Architects use their monetised LCA data during design to compare different product types. In addition to energy efficiency aspects, eco-design and circular solutions also strengthen the role of LCA in the construction sector. When reusing materials, their impact should be assessed in a life-cycle approach.

For certification schemes of newly built buildings, such as BREEAM, LEED, DGBN, LCA is used as an objective method to quantify the environmental impacts of the selected building elements. (see Ch.2.3b) The requirement of these schemes present one of the main drivers to perform the LCA for entire buildings. Additionally, there are existing regulatory requirements in some countries (e.g. the Netherlands), while similar regulations are on the way to be implemented in countries, such as France, Denmark, Finland, Sweden.

Databases

LCA in the construction sector is supported by a number of databases. Databases to perform products LCA include manufacturing processes in different territorial coverage (Switzerland, Europe, USA, North America, France) and various material categories (e.g., metals, plastics, wood and cement, as well as concrete). A European database is the Swiss-developed Ecoinvent, which is also used by many LCA software solutions, such as One Click LCA, SimaPro, GaBi, openLCA and Umberto due to its consistency and transparency. The ELCD, created with the support of the European Commission, contains hundreds of processes, including some key materials, transport and waste management systems, but other parts need to be complemented to the building materials sections. The GaBi database is one of the largest databases on the market with thousands of processes, including building materials as well. Data for some substances are from Plastics Europe, ELCD or Eurofer. Manufacturers usually perform a building product LCA in order to publish an Environmental Product Declaration (EPD). For building LCA, the calculations for most commercial applications are typically based on manufacturer-specific or industry average EPD, and further generic data that are published by national authorities or other parties. These data contain information for building materials and products, such as use of resources, as well as impacts causing climate change, acid rain, smog, eutrophication etc. A well-known example of EPD database is the German online database ÖKOBAUDAT, and there are many other EPD databases such as NMD in the Netherlands and Inies in France. Finland and Sweden also recently published official generic LCA data that is mandatory to be used - along with EPDs - for building LCAs that are in accordance with the upcoming national regulations. In U.S., the database Athena contains a range of data on building materials, energy, transportation, construction and demolition processes, maintenance, repair, and waste management processes, some of which are derived from the U.S.LCI database.

a. The EU policies for the sustainability of the construction sector

In the European Commission's **Integrated Product Policy (IPP)**[13], Life Cycle Assessment (LCA) has emerged as the best framework for assessing the potential environmental impact of products. The Integrated Product Policy (IPP) defines tools and measures to reduce the environmental impact of products, taking into account their entire life cycle. With this, the impact of products and services on the environment has become a key element in decision-making processes, and LCA has become increasingly important in supporting community policies and businesses. "Life cycle thinking" has become a central pillar of environmental policies and sustainable business decision-making. The creation of EPLCA has been defined within the framework of the IPP.

The **European Platform for Life Cycle Assessment (EPLCA)**[14] provides assistance in the availability, coherence and quality assurance of data and information, as well as mainstreaming of LCA and related environmental footprint methods in business and policy. It supports the methodological development of LCA, the analysis of supply chains and end-of-life waste management. The efficient and effective operation of the platform and its action programs contribute to the progress of environmental sustainability.

The review of the **European Commission's strategy for the construction sector**[15], which also includes circular principles, also aims to promote the realisation of a sustainable built environment, taking into account the whole life cycle of buildings. It covers among others, the recycled product content and the requirements of construction products, the design of buildings, the promotion of the circularity, the improvement of durability and adaptability, the development of digital logs for buildings and the integration of life-cycle assessment into public procurement and into the EU sustainable financing framework.

13 COM (2003) 302 Integrated Product Policy Building on Environmental Life-Cycle Thinking
14 https://ec.europa.eu/jrc/en (last access in April 2021)
15 COM (2012) 433 final: Strategy for the sustainable competitiveness of the construction sector and its enterprises

Within the framework of the "**Single Market for Green Products Initiative**[16]", the EU developed the **Environmental Footprint** methodology including the assessment of the environmental performances for products (PEF-product environmental footprint) and organisations (OEF-organization environmental footprint). **PEF** is also based on LCA, and aims to provide a uniform method for measuring environmental performance for those companies that wish to market their products within the EU. It contributes to the achievement of sustainability goals, as does the Environmental Product Declaration (EPD). A product assessment performed with the PEF methodology covers numerous impact categories (see details in Chapter in 2.2b).

A European initiate for the building sector is the COM (2014)445 "**Resources Efficiency Opportunities in the Building Sector**", which recognizes the relevance of addressing impacts all over the building's life cycle through better design and planning, promoting resource efficient manufacturing of construction products as well as more efficient construction and renovation works.

The importance of LCA is mentioned also in the EU **Circular Economy Action Plan**[17] aiming the development of sustainable product policy. The new Action Plan identifies the key value chains of the transition towards circular economy. Construction is among these key sectors as the built environment has a significant impact on different aspects of the economy (e.g. local jobs, quality of life etc.)

The **EU Green Deal**[18] is related to the goal of the EU concerning carbon neutrality for 2050. A key element of the action plan of the Green Deal is the EU Renovation Wave initiative aiming for making more environmentally friendly buildings, job creation, increasing life quality, reaching carbon neutrality. Environmental assessment of the new, planned technologies and solutions (carbon footprint) is based on LCA.

16 https:// ec.europa.eu/environment/eussd/smgp/ (last access in April 2021)
17 https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf (last assess in April 2021)
18 https://ec.europa.eu/clima/policies/eu-climate-action_en (last assess in April 2021)

b. LCA standards in the construction sector

Construction product scale

The main reference for the assessment of environmental footprints of construction products is the European Standard **EN 15804**[19]. Its first version was published in 2012 and last version in 2019. The standard is the main reference for the LCA studies in the construction sectors as well as for the Environmental Product Declarations (EPD) of construction products and services. EPD is such a voluntary declaration that can be used by companies to communicate towards the market the environmental performance of their construction products and services (see Ch.2.3a).

The standard EN 15804, on the one hand while keeps consistency with the general intersectoral standard ISO 14040 and 14044 on the Life Cycle Assessment (LCA) methodology, on the other hand it establishes specific rules concerning the 5 main methodological aspects of the LCA, namely the functional unit, the system boundaries, the allocation, the Life Cycle Impact Assessment (LCIA) methods, and the requirements of data quality.

As described in chapter 2.1, the **functional unit** in LCA identifies the function of the studied system (e.g. the product) and provides a reference to which the impacts are referred. For example, the function of a thermal insulation panel is to avoid heat loss and therefore, the value of the insulation power is presented through a specific parameter (i.e. the thermal conductivity, measured in W/mk).

However, the impacts due to the use stage of the building products and components are often strongly related to the specific application. For example, a specific thermal insulation panel will allow higher or lower energy consumption for heating, based on the specific wall system in which it is integrated and the context (including climatic conditions) in which the building is located.

19 EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

Due to the utilisation of each single building product or component, the EN 15804 allows that environmental impacts to be quantified excluding the use stage and using what is called a "**declared unit**", instead of a functional unit. The declared unit uses the quantity of product/component (e.g. m^2 or kg) as a reference unit for expressing the environmental impacts. Thus, if we consider the thermal insulation panel, the impacts on Climate Change, for example, will be expressed as follow:

- greenhouse gas emissions per 1 W/mk achieved by the panel, in case of functional unit
- greenhouse gas emissions per kg of panel, in case of declared unit.

The decision to use a functional or declared unit as reference to express the environmental impacts of a product is linked and affects the **system boundary**. The system boundary identifies which life cycle stages are going to be included in the study and to be represented in the resulting impacts. The EN 15804 adopts a modular structure for the definition of the system boundary, which is represented in the following figure.

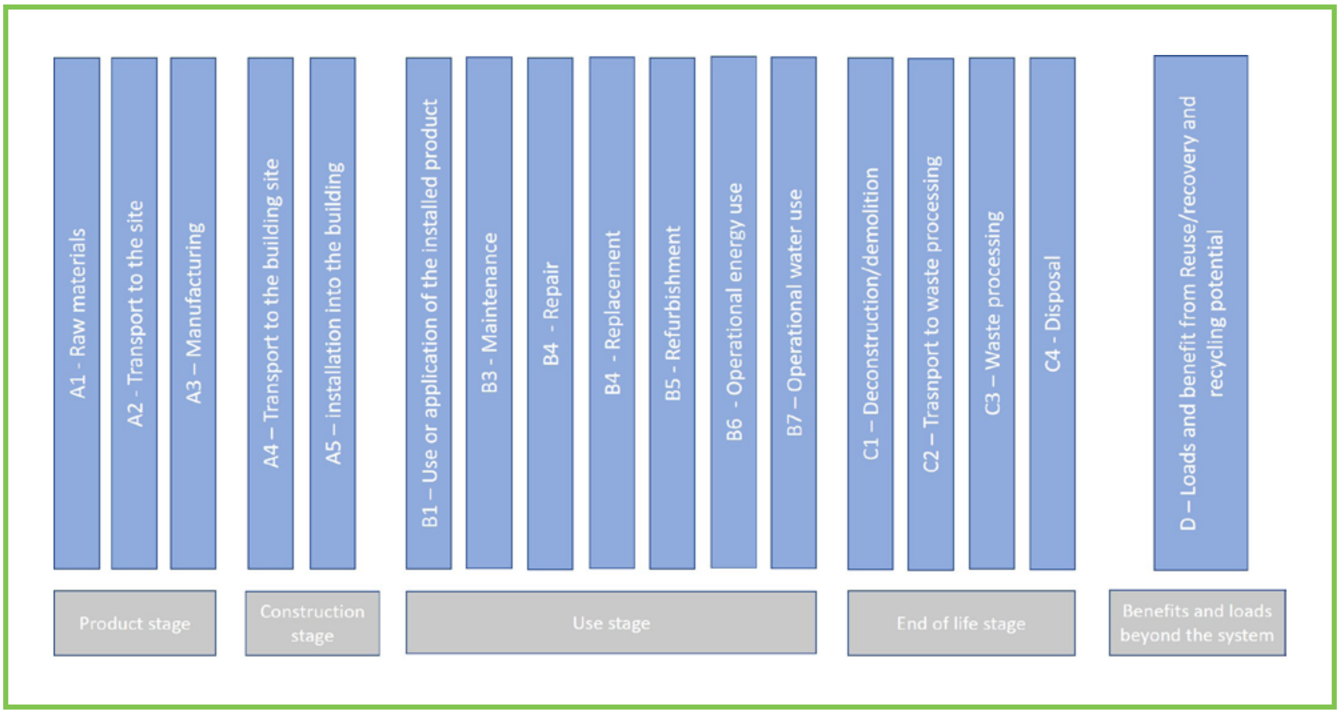


Figure 8: Modules used by EN 15804 for the definition of the system boundary[20]

20 Source: EN 15804

Allocation

A key aspect of the LCA methodology is allocation. The allocation is defined by the ISO 14040 as the procedure for the division the input or output flows of a process or a product system between the product system under study and one or more other product systems. In other words, the purpose of the allocation is to present such a procedure that allows that the impacts of a multifunctional process are properly allocated among the functions of the examined system/process. For better understanding, the example of energy recovery process from waste incineration can be considered. The waste incineration is a disposal method (first function), however, the process also produces energy (second function). Allocation is the procedure, the specific approach, applied to calculate the share of impacts to be allocated to one function and the share to be allocated to the other. The EN 15804 provides a set of methodological approaches which can be applied. Among the possible criteria there is allocation based on a physical reference (e.g. impacts allocated proportionally to the mass of each main product/output from a multifunctional process) or on an economic reference (impacts allocated proportionally to the economic value of the output). The decision of use depends on the specific case (not all approaches can be applicable in all cases) and affects the final impact of the involved products. For this reason, the standard specifies the order of priority in the approach selection. Such priority order is in line with the order specified by ISO 14044.

Concerning the life cycle impact assessment – **LCIA** – several methods exist, all of them allowing to report impacts on different number of environmental aspects, calculated according to specific scientific environment models. The earlier version of **EN 15804 (2012)** requires the use of a specific LCIA method, which is CML 2001. Impacts assessed according to this version of EN cover the following impacts categories:

- Abiotic Depletion (ADP fossil) [MJ]
- Abiotic Depletion (ADP elements) [kg Sb-Equiv.]
- Acidification Potential (AP) [kg SO_2-Equiv.]
- Eutrophication Potential (EP) [kg Phosphate-Equiv.]
- Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]
- Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]
- Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]

In the new version of **EN 15804 (2019)**, the LCIA method is different. It is the latest adopted one within the EF methodology and the minimum environmental aspects to be covered by the study includes an extended set of impact categories. In addition, for some elements already covered by the old standard, the scientific model has been slightly updated. The minimum list is reported below:

- Climate Change – total (GWP total) [kg CO_2 eq];
- Climate Change - fossil (GWP fossil) [kg CO_2 eq];
- Climate Change - biogenic (GWP biogenic) [kg CO_2 eq];
- Climate Change - land use change (GWP luc) [kg CO_2 eq];
- Ozone Depletion (ODP) [kg CFC11 eq];
- Acidification terrestrial and freshwater – AP [Mole of H+ eq.]
- Eutrophication freshwater (Epfr) [kg P eq.]
- Eutrophication marine (Epmar) [kg N eq.]
- Eutrophication terrestrial (Ep ter) [Mole of N eq.]
- Photochemical ozone formation - human health – (POCP) [kg NMVOC eq.]
- Resource use, mineral and metals (ADP elements) [kg Sb eq.]
- Resource use, energy carriers (ADP fossil) [MJ]
- Water scarcity (WS) [m^3 world equiv.]

Other additional impact categories can be introduced as well, which however are optional.

Data quality

In line with ISO standard for LCA, the quality of data must be documented. The quality of data used for the assessment, significantly affects the results on one hand. On the other hand, the data quality description provides a better understanding and interpretation of the information for the results of the assessment. Two main types of data are used in the LCA studies:

- generic data (also called secondary data) Generic data are not available/ accessible directly from the manufacturer. These can typically be data from database, literature and other selected sources.
- specific data (also called primary data). Specific data are those collected at the specific manufacturing site where products are manufactured (for example, the electricity consumption of the manufacturing plant).

EN 15804 essentially refers to ISO, according to which the data quality description should address:

- representativeness (temporal, geographical, technological)
- precision
- completeness
- consistency
- reproducibility
- source of data
- uncertainty

Further specifications could be, for example, the data used cannot be older than 10 years in case of generic data or 5 years in case of specific data.

Building scale

As far as a whole building is concerned, two main tools can be used to evaluate environmental aspects of building. The first one is the standard for the environmental footprint of building, i.e. the **EN 15978[21]** , which is the standard to quantify the performance of buildings in the environmental pillar of the three main (environmental, social and economic) pillars identified by the ISO 15643[22] and which basically extends to the level of buildings, the methodology and reporting rules established at product level by the EN 15804.
The second type of tool is the rating scheme, which addresses the environmental quality of buildings through the use of qualitative criteria and requirements (see Ch.2.3b), including, for example the use of construction products with EPD declaration.
Standard EN 15978 relies on EN 15804, which remains the key reference for the methodological aspects. EN 15978 is intended for the quantification of the environmental performance of buildings, both in case of renovation and new constructions, with the following main aims:

- to support decision process, for example the comparison between diferent design options or scenarios and the definition of strategies for improvement,
- to help prepare the declaration of the environmental performance against specific requirements,
- to document the environmental performance of buildings, for the aim of labelling, declarations and marketing,
- to support the environmental policies of the building sector.

However, in standard EN 15978, key methodological aspects are partly adapted to the characteristic of the whole building. Two aspects to be highlighted concern the **functional unit and the system boundary**.

While EN 15804 has been revised and its latest version was published in 2019, this is not valid for EN 15978, for which one single version exists.

21 EN 15978 (2012): Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method
22 EN 15643 (2011): Sustainability of construction works - Assessment of buildings

EN 15978: functional unit and system boundaries

The concept of functional unit is substituted by the "functional equivalent" which is the set of quantified functional requirements or technical requirement of a building (or of a part of building) to be used as a reference for comparison. In the definition of the functional equivalent, it is needed to consider at least the intended use of the building (e.g. school, office, etc), the technical and functional requirements as for example defined by the legislative and by the client, the use model and the service life.
The identification of the system boundary basically follows the modular structure defined in EN 15804. Thus, all impacts have to reported in the modules exactly where they are generated. For example, if during the service life of the building a window is broken and repaired, the impacts associated with the repair activity is reported in the related module (module B3 "Repair"), including the production of the needed materials and the disposal of waste generated by the activity. In addition, the standard specifies that for a new construction the whole building in the whole service life has to be fundamentally considered, whereas for refurbishments, only the added parts and/or related works in the remaining building service life shall be included in the assessment.

Sustainability performance of buildings can be evaluated also according to **ISO 15643**-2; 15643-3 and 15643-4[23] . These standards help to perform assessment from an environmental, economic and social perspective.

Building energy certification can be carried out according to **ISO 52000[24]**.

23 EN 15643 (2011): Sustainability of construction works. Assessment of buildings.
24 ISO 52000 (2017): Energy performance of buildings. Overarching EPB assessment.

2.3 Market tools for the environmental sustainability

a. Environmental product declaration (EPD) for the construction sector

EPDs are so called **type III. environmental labels and declarations** regulated by **ISO 14025[25]**, which establishes general rules for EPDs development and management. Basically, EPDs are declarations which have to be verified by a third-party body and registered within a specific EPD program, which establishes its own (additional) rules for the EPD development, validity and communication format (Product/sub-product Category rules – PCR/Sub-PCR) and which is in charge of make EPD publicly accessible within its own website. EPD should not be confused with Declaration of Performance (DoP). Indeed, while DoP addresses the technical performance of interest for a specific product category and is a mandatory declaration required by the Construction Product Regulation, EPD is a voluntary declaration which addresses environmental potential impacts arising from the production process and the use of a product.

Several EPD programs currently exist compliant to ISO 14025 and covering one or more economic sectors. With reference to the construction sector, **EPD programs** existing at European level are for example the International EPD System (Sweden), the IBU (Germany), Inies (France), EPDItaly (Italy). EN 15804 always represents the basis of the product/sub-product categories rules (PCRs/sub-PCRs) defined by the mentioned programs and thus of the EPD issued within the programs.

The mentioned EPD programs have all been developed within the frameworks of national initiatives. Some have highest number of registered EPDs, for example the International EPD System, as it covers several other sectors beyond construction and it has been the first EPD program put in place, and IBU, as it is focused only on the construction sector and is supported by industrial associations. Although EPD programs can set additional requirements for developing and achieving EPD compared to those ones defined by EN 15804, this one remains the common basis.

25 ISO 14025 (2010): Environmental labels and declarations - Type III environmental declarations - Principles and procedures

For this reason:

- several program operators have decided to put in place a **mutual recognition**, which allows the EPD issued with a program to be promoted also within a different program, with the consequent advantage of a higher visibility for the products and the manufacturer.
- a platform, called **Eco-platform**, has been created to promote EPD har monization of compliant to EN 15804 and issued within the different programs. When companies develop the EPD for their products in com pliance to EN 15804, they can decide to have the EPD registered and pro moted within the Eco-platform, again with the consequence of higher visibility.

It has to be underlined that EPDs compliant to EN 15804 can be essentially used in the same way and for the same aims, disregarding the specific EPD programs within which specific EPD programme they have been issued[26]. The basic content of an EPD includes:

- The name and address of the manufacturer, and the production site
- The description of the products, its simple visual representation such as a picture, and the description of main product components and/or materials
- Declaration regarding content, including at least those substances listed in the "Candidate list of substances of very high concern for authorization" (SVHC list, published by the European Chemical Agency) in case the content exceeds the limit for registration.
- The reference to the EPD program used
- The publication data and the validity period
- Information on which life cycle stages are excluded, if any
- The intended use of the product and the functional or declared unit to which environmental impacts data refer to
- Environmental impacts indicators, reported by module, although impacts in modules from A1 to A3 can be presented aggregated
- Life cycle inventory indicators, which provides additional information on resource use (e.g. use of secondary materials), on output flows (e.g. quantity of materials sent to recycling or reuse) and on waste (e.g. amount of hazardous waste produced).

26 It has to be underlined that national regulations, for the aims of specific applications, can officially require for EPD registered in a national program, if any. Thus, a check on national regulations is always suggested to support the selection of the EPD program operator.

As mentioned in the previous chapter, the EPDs and/or information included in the EPDs are becoming more and more used in the context of building rating schemes or in the context of green public procurement. For example, the LEED Scheme for "Building Design and Construction", in the section "Materials and Resources – Building Product Disclosure and Optimization", awards credits for the use of secondary materials (recycled content). There, EPD is mentioned as one of the means to demonstrate the recycled content.

b. Building rating schemes

The building rating schemes are tools developed to evaluate the building from the aspect of its environmental **sustainability**. The evaluation is based on a multi-criteria method. Criteria considered in the method can address different aspects of sustainability, affecting both the environment, such as the energy consumption or use of material resources, or the users, such as the indoor air quality and thermal comfort. **Several rating schemes** currently exist. Mentioning a few of them follows:

- LEED, developed U.S. Green Building Council
- BREEAM, developed by the U.K. Building Research Establishment
- DGNB, the German scheme promoted by the Deutsche Gesellschaft für Nachhaltiges Bauen
- ITACA, the Italian scheme promoted by the Istituto per la trasparenza, l'aggiornamento e la certificazione degli appalti
- Level(s), the scheme developed by the European Commission

Criteria can be organized by main sections, e.g. Management, Materials, Health and Wellbeing, Energy etc. **Credits** are achieved in each criterion, based on qualitative requirements or quantitative assessment of the performance, contributes to the definition of the overall score of the building and its final classification. Different scales can be adopted for classification, e.g. based on colour (silver, gold) or qualitative statement (good, very good).
All mentioned schemes were recognized to a different extent on considering the materials included in the buildings to evaluate the environmental sustainability of the buildings and/or its potential impacts resource consumption. Most of them evaluates by achieving credits if parts of products used in the building are covered by EPD and/or include recycled content.