Measuring environmental sustainability: The use of LCA based building performance indicators

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Abstract

Today's common praxis of architects and engineers to create sustainable buildings is often dominated by optimizing and focusing on single aspects such as energy efficiency, water efficiency or "grey energy". Even today, in the age of information, tradition, conviction or experiences are very often more important in decision-making processes of planners of sustainable buildings than scientifically-based and quantified results of assessments.

In 2009, the European DGNB System for sustainability assessment of buildings was introduced to this group of decision makers. It contains a new way of quantifying a building's environmental performance: Benchmarks for total building LCA results, using building performance indicators. The starting point of setting the benchmarks used and introducing the quantification method was based on data received from a defined quantity of building LCA results. The successful introduction of this methodology represents a unique way of life cycle management in practice and can serve as an example for other sectors and applications others than the building sector: During the short time-span since its introduction more than 150 buildings already went through the certification process, containing total building LCA calculation.

But how will the benchmarks and the performance indicators be developed in future? Several methods are possible; each standing for different aspired development pathways.

1 Introduction

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But how can the benchmarks and the performance indicators be developed in future? Several methods are possible; each standing for different aspired development pathways.

2 Building-LCA: The DGNB methodology of environmental profile calculation of buildings

In general the building LCA methodology follows a performance measurement method. Cause and effect relations can be derived between inputs, outputs and results: How and to what extend do key inputs enable progress towards outputs and outcomes. If performance measurement systems are used in business, usually the following stepwise approach is applied: 1. Set strategic goals, 2. Define strategic metrics, 3. Define performance benchmarks, 4. Measure and control continuously performance. In general, DGNB's building LCA methodology follows this approach.

2.1 Development and status for LCA data for building products

The methodology of Life Cycle Assessment (LCA) is known, discussed and improved for decades now. But only during the last few years it became a prominent tool for environmental performance identification and improvement in the building and construction (B&C) sector not only used arbitrarily by some building products manufacturers, by few architects in few real buildings or by scientific institutions. Especially in Germany the tendence of rising prominence of LCA in building and construction can be observed. Main reason for this trend is today's availability of consistent LCA datasets. Defining a strict framework and calculation rules for LCA data for the product stage and other life cycle stage modules approximately five years ago was the most important milestone towards achieving consistent LCA datasets. This steps was performed and launched on the one hand side by the German Environmental Product Declaration (EPD) for building products program holder Institute Construction and Environment (IBU), on the other hand side by the German Ministry of Building and Transport, supporting the development of a methodology report for the first issue of the German building products LCA database "Oekobau.dat" [1] [2]. The format of the database (xml-files) was mainly derived from the ELCD format definitions provided by the European Commission, main difference is the provision of LCIA results instead of LCI results (as the ELCD does). The database is publicly available and contains today more than 850 LCA datasets. It also includes numerous associations and producer specific third party verified IBU Environmental Product Declarations and serves as one communication path of selected EPD content. The database contains datasets for most of the commonly used building products and is continuously expanded.
With regards to a European perspective, the German Sustainable Building Council (DGNB) initiated the development of a corresponding European LCA database, containing datasets with a European geographical scope. This database "ESUCO" (European SUstainable COnstruction Database) is available for all DGNB International auditors.
This German pathway was at the same time accompagnied by CEN and ISO standardization activities in the context of sustainable construction (e.g. CEN TC 350 work). The latest corresponding result of these activities is the development of the EN 15804 and the EN 15978 [6]. The first defines rules for the provision of building life cycle elements environmental profile information, the latter defines rules for building LCAs.
The product or building environmental profiles contain (amongst others) the following LCI and LCIA indicators:

- Global warming potential (GWP) in kg CO2 equivalents

- Depletion potential of the stratospheric ozone layer (ODP) in kg CFC 11 equivalents
- Acidification potential of land and water sources (AP) in kg SO2 equivalents
- Eutrophication potential (EP) in kg (PO4)3- equivalents
- Formation potential of tropospheric ozone photochemical oxidants (POCP) in kg Ethene equivalents
- Input of non-renewable primary energy in MJ, net calorific value
- Input of renewable primary energy in MJ, net calorific value

This set of indicators is complemented in the Oekobau.dat or ESUCO database and in the IBU declarations by additional indicators such as abiotic depletion potential for non fossil and fossil resources ADP, waste indicators, total water consumption, etc.

2.2 Definition of building-LCA according to DGNB

In 2008, DGNB and the German Ministry of Building and Transport (BMVBS) developed together the first version of the German Sustainable Building Certificate. This development enclosed the definition of building-LCA methodology. It was seen indispensable and the most forward oriented way to evaluate environmental building performance and so this methodology was integrated into the building certification scheme. Within the DGNB scheme, the building LCA results make up more than 13 % of the total building rating, which reflects the importance the actors give to the methodology. [5]

2.2.1 Description of the life cycle modeling rules

The Goal of the assessment is to quantify and document the environmental performance of the building under consideration and to compare the results with benchmarks per environmental indicator (as stated above), defined by DGNB. The comparison with the benchmarks results in points (for each indicator x out of 10 points are calculated). If the methodology is used during the planning stage of a building, the assessment can also be used for assisting decision making processes, comparing the environmental performance between different design options or identify environmental improvement potentials and comparing options between different life cycle stages.

The scope of the building assessment is a life cycle assessment, calculating environmental impacts of the production, use and end-of life stages.
The functional equivalent is the entire building for a defined time-span (reference study period). Core indicators of the building which are to be documented include a clear description of the technical characteristics and functionalities of the building, the building type and pattern of use (e.g. number of occupants). This complements the functional equivalent of the assessment.
For office buildings, 50 years are defined as reference study period, industrial buildings are regarded for 20 years. Defined scenarios for the operational energy use have to be calculated for the respective period and additionally, a scenario for replacements of building elements have to be calculated for the same period. The system boundaries include:

- the product stage (raw material supply, transport and manufacture of products used in the building)
- a use stage scenario (operational energy use and replacement including transport and end-of-life)
- an end-of-life stage scenario (waste processing and disposal)
- and a scenario for potential benefits and loads beyond the system boundaries (re-use / recycling / re-covery potentials in next product system)

Not included are the construction stage (including transport to site and construction installation process), the energy use scenario for user equipment, operational water use, maintenance, repair, refurbishment, deconstruction, demolition, transport to recycling / re-use or disposal.
The assessment method is carried out with two main methods:

- Life Cycle Assessment of the buildings’ elements (product, use and EoL stage)
- Life Cycle Energy Modeling of the energy demand during the operation of the building (in-use stage)

Calculation of the first is carried out by defined scenarios (e.g. using reference service life spans) and system boundaries, calculation of the latter is carried out by a whole building energy analysis using local climate data.

2.2.2 Description of the LCA indicator calculations

The results of the LCA are used as follows: A reference-building method is used to evaluate the building’s environmental performance. If the building’s environmental profile is equal to the reference building's profile, 5 points (reference value) out of a maximum of 10 points (target value) are given. If the

value of the designed building is lower than the value of the reference building, more points will be awarded (except for the indicator for renewable primary energy). For minimum of 1 point, minimum requirements need to be fulfilled in any case as a prerequisite (limit value).
The environmental profile is given as LCA indicator result (total building life cycle) per area and year, e.g. in kg CO_2 equivalents / m² net usable floor space * year. Only for industrial buildings such as logistic centers, the value is given per volume of the building in m³, reflecting the commonly used metrics for this kind of buildings. Deriving these kinds of metrics allows comparison of building performance and benchmark setting. [7]
DGNB provides three types of benchmarks: "reference value" R, "limit value" L and "target value" T for each of the LCA indicators. The values for L and T are set as follows: L = 1.4 * R and T = 0.7 * R.

3 Using building-LCA methodology

3.1 The use of building-LCA for architects and planners

With regards to the databases, average indicator results are available for numerous building products. Company and product specific LCA results are provided in EPD, such as the IBU scheme. On building product level, architects and planners can use these results for assessing alternatives. Today, more than 150 IBU EPDs are available.
Building LCA is far more complex than the assessment of single products due to the large amount of products and systems being generally part of a building. Secondly, the complexity is high because of applying the defined scenarios for the use and EoL stage. To cope with the complexity, specifically designed building LCA tools are applied more frequently.
Architects and planners use building LCA for the following purposes: Identification of environmental highlights, comparing alternatives, deriving performance oriented results on building level for benchmarking, and, when applied simultaneously with LCC having the same system boundaries, identifying eco-efficiency metrics.

3.2 The use of building-LCA for producers

That product LCA is best qualified to serve as environmental analysis tool and to support the identification of environmental optimization potential is no new message. Eco-design with LCA provides a big picture view on the product life cycle and its alternatives. The environmental optimization of an insulation material can include the assessment of bio-based alternative materials, the switch to renewable on-site energy generation, an assessment of the suppliers' performance or evaluating alternative end-of-life pathways.
The assessment of a product's environmental profile e.g. during an EPD project allows producers to understand own impacts and when integrated into an exemplarily building LCA, to gain orientation how relevant a product performs in a building's life cycle context. Sustainability certification scheme frameworks such as the DGNB scheme also allows to identify and assess additional performance criteria and to better understand and strategize product development.

4 Building LCA benchmark definition methodologies and their implications

Different building LCA benchmark definition pathways are feasible. The following three groups were identified by the author: Technically defined benchmarks, statistically defined benchmarks, and benchmarks that are motivated externally.

4.1 Technically defined benchmarks

These benchmarks are derived from technical aspects throughout the buildings' life cycles. Whether certain minimum requirements regarding structural safety, noise or fire protection, or other functionalities have to be met, or efficiency rates of power and heat generation appliances, thermal loss rates or minimum fresh air rates: The technical feasibility affects minimum environmental impacts.
Examples how to derive benchmarks from the technical performance include percentage reduction compared to state of the art performance, best in class or toprunner benchmarks.
Due to uncertainties of technology jumps, these types of benchmarks have a rather short term perspective. They have a restricted use for setting strategic benchmarks

and bear the risk of driving the sector into too narrow solutions instead of supporting innovations.

4.2 Statistically derived benchmarks

These types of benchmarks are derived from statistical analyses. A set of results is analysed and statistically identified values are used for benchmark setting. The most commonly used benchmarks are averages e.g. for building types. Starting from these averages, reduction goals can be set, as it is common practice in environmental management systems e.g. 5 % less impacts each measurement period. The so-called "yardstick competition" is also a statistical method, using e.g. the best 10 % best performing buildings as benchmarks.

These types of benchmarks can only be derived from "looking backwards". The amount of buildings that are setting these benchmarks should be large enough to derive robust numbers. The benchmarks are restricted to maximum mid-term goal setting, due to the intrinsic need of getting new statistics. If these benchmarks are used, the achievement of "realistic" goals can be supported.

4.3 Externally motivated benchmarks

These types of benchmarks are derived from societal, political or other external drivers. Quantified benchmarks can be derived e.g. by applying an "equal share" cap derived from a defined maximum of total impacts. An example for this is the "2000 W Society" movement or the striving towards not to exceed the "2 degree target" for climate change. "Efficient share" benchmarks are a further way of deriving benchmarks, e.g. the share of a sector for total "allowed" emissions, allocated to specific building types with high efficiency rates. A third way of setting externally motivated benchmarks can be caps derived through applying cultural-political developments e.g. zero net impacts, or maximized renewable materials use.

Externally motivated benchmarks are well suited to support long term strategic goals without predefining technical means to achieve the goals or taking "technical barriers" into account when setting the goals. On the other hand, these goals bear the risk of under- or overrun the target values due to their long-term perspective.

5 Summary

The building LCA methodology is suited to assess relevant aspects of the environmental performance of buildings. It is not only suited to support planners and architects, but also to give orientation to producers and other stakeholders throughout the value chain of a building's life cycle. Data availability and being essential part of the DGNB certification scheme gave a boost of applying the methodology in Germany. The methodology as it is used there provides whole building LCA benchmarks. The future development of these benchmarks can substantially impact Germany's environmental development path by intelligent combining short- and long-term benchmarks in a benchmark controlling system: Short-term benchmarks derived from technical and statistical assessments, long-term benchmarks from externally motivated tagets.

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