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LCA BENCHMARKS
IN BUILDING'S ENVIRONMENTAL CERTIFICATION SYSTEMS

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Abstract *The paper deals with the definition of reference values (benchmarks) referred to the Life Cycle Assessment (LCA) indicators used in the environmental certification systems of buildings (Green Building Rating Systems, energy-environmental certifications and environmental labels) highlighting their potentiality and criticality.*

The environmental certification systems more and more often consider the use of indicators based on LCA methodology which allow to draw attention to environmental performances of building in terms of impacts during the whole life cycle, from the raw materials extraction to the disposal. Today, the environmental impact measure obtained, could be interpreted through the comparison between similar solutions, due to the absence of thresholds which indicate the eco-efficiency of buildings: the benchmark applied to the LCA indicators becomes the threshold value through which measure the real environmental performance of the object analysed. It is a variable value because it depends on the evolution of technologies and construction practices.

The environmental certification systems are the first ones which develop a process to define benchmarks because they have to assign a rating score to the indicators in order to obtain the certification. Through the analysis of principal certification systems, characterized by the use of LCA methodology within the score criteria, the different benchmarks methodologies (related to the LCA indicators) are identified and explained. Benchmarks are typically developed through linear interpolation systems, statistical analysis or the modelling of a reference building. In particular the analysis refers to the Green Building Rating Systems (GBRSs), such as DGNB, LEED, and BREEAM, and the energy-environmental certifications (Minergie-Eco). It is showed how the benchmark, into the certification systems, assumes different meanings: it could be the starting standard value (reference value), or the improvement value (target value) or the minimum value to obtain the certification.

Starting from these differences and peculiarities, the paper demonstrates potentiality and criticality of the methodological approaches used, in order to understand the role of benchmark in the development of new policies and environmental strategies.

1. INTRODUCTION

In this text are reported the different calculation methodologies of benchmarks related to environmental impacts calculated with the Life Cycle Assessment (LCA) methodology to define an environmental sustainability level. They are used in the Green Building Rating Systems (i.e. Deutsches Gutesiegel Nachaltiges Bauen-DGNB, Leadership Energy and Environmental Design-LEED, British Research Establishment Environment Assessment Methodology-BREEAM), in the energy certifications (i.e. Minergie-ECO) and in the environmental labels of products (EU Ecolabels).

The GBRSs are evaluation tools to assess environmental sustainability of buildings. They derive from a voluntary path of research institutions and environmental organizations that want to create at national level a tool to evaluate sustainability with requirements and criteria which allow a rewarding score, if respected. To each criterion is assigned a performance indicator and a threshold value (benchmark) which represents the current building practice; the criterion's rewarding score is calibrated on the achievement of best performance compared with the benchmark. Then, all the scores obtained from different criteria are summed and the building is puts in a ranking of sustainability defined by the environmental certification. The final result represents the environmental sustainability level of the building. In this way the project's system is verified by parts, but the final score can hide distortions, because the sustainability level is represented by scores related to quantitative aspects (i.e. consumption of materials and water, GHG emission, waste production) and qualitative aspects of the project (i.e. space for socialization, flexible use, comfort indoor), which are verified separately and then summed together.

Today, in some GBRSs is inserted the LCA evaluation to guarantee a more objective calculation of the environmental sustainability of the project under certification. The benchmark used is the *reference value* and its achievement is associated to different scores based on the environmental certification considered. It can be a value with a rewarding score equals to 0 points (i.e. LEED) or a score equals to the average points of the criterion, because it represents the construction standards (i.e. DGNB). Consequently, it is set a *limit value*, a value associated to a score equals to 0 (i.e. BREEAM) or negative (i.e. Minergie-ECO), and a *target value*, a value associated to a highest score. In different GBRSs the benchmarks are calculated with different methodologies.

Benchmark's classification developed in the economic field, *external* and *internal* benchmarks, is applied in this text to the construction sector, where it is find the same differentiation on the basis of different benchmarking processes. In the economic-managerial sphere a benchmark is external if the benchmarking process is performed versus competitors and the data analysis is done to improve own performances through an external comparison. A benchmark is internal if the benchmarking is performed within its own processes to improve the best practice. In construction sector, benchmarks can be also external, if they are obtained from the analysis of threshold values already used in construction field, or internal, if they are set through the analysis of data obtained from the modelling of building, in order to improve the performance. The first ones are established from values provided by national standards (such as primary energy consumption) or from studies of national building stock; in this case they correspond to the average values of the statistical analysis, such as the procedure adopted by DGNB and BREEAM. The second ones derive from modelling a reference building with geometrical and context features equal to the project and conventional construction characteristics; this reference-model is the benchmark against to which the project must demonstrates the improvement to acquire scores (LEED).

Even in the energy certifications and in the environmental labels are used external threshold values to measure environmental sustainability. In the energy certification, benchmarks are set on data obtained from statistical researches on building stock (Minergie-ECO), while in the type I labels the benchmarks are based on the European eco-efficient products' analysis (EU Ecolabel). In these certification's types, the benchmarks are *target values*, because their achievement is mandatory and the criterion's fulfilment does not give a score, but it allows the access to the certification.

2. EXTERNAL BENCHMARKS

The environmental impacts' benchmarks related to the LCA analysis, can be defined external if the threshold values are obtained through the comparison of project's data with an external "competitor's" data, in order to improve building's performance. Data used for a comparison can derive from an environmental performance analysis of reference building stock. This is the method used in the DGNB and in the energy certification Minergie-ECO. The external data may be also referred to different construction typologies typically used in a specific State. This is the method used by the Green Building Rating System BREEAM, in which the LCA analysis is applied only within construction technologies' evaluation.

2.1. External Benchmarks from statistical analysis of the national building stock

External benchmarks used in the DGNB and in the energy certification Minergie-ECO are analysed in this section. They derived from the statistical analysis of a representative part of the national building stock, characterized by the choice of buildings with energy and environmental certifications. They are investigated according to typological, constructive and technological characteristics [1] .

The DGNB was founded in Germany and was the first GBRS to adopt the LCA evaluation since its first articulation. The certification is divided into six categories (ecological quality, economic quality, socio-cultural quality, technical quality, process quality and site quality) and the LCA analysis is divided between the criterion Environment 1.1 (Life Cycle Impact Assessment) and the criterion Envronment 2.1 (Life Cycle Impact Assessment – Primary Energy). In the first one [2] are reported the indication for five environmental impacts' calculation (Global Warming Potential-GWP, Ozone Depletion Potential-ODP, Photochemical Ozone Creation Potential-POCP, Acidification Potential-AP, Eutrophication Potential-EP), while in the second one [3] are reported the indication for the Non-renewable Primary Energy demand calculation (PEInrn). The renewable primary energy demand it is not reported in the text because it is calculated with a different method. The LCA methodology is related to the whole building and the whole life cycle stages and is based on the indications given by standard EN 15978 (production phase A1-3, construction phase A4-5, use phase B1-7, end-of-life phase C1-4), while the software used for the outputs calculation is LEGEP, with the Ökobau.dat database. The calculations of electric energy and heating energy are based on DIN V 18599 and on EnEV 2014 requirements. Each environmental impact indicator has a threshold value related to the environmental impact produced in the production phase (A1-3) and in the use phase (B1-6) by a building with construction characteristics in accordance with national construction standards and with a lifespan of 50 years. The values are expressed with a reference unit equals to one kilogram of equivalent pollution element ($kgCO_2eq$) for a square meter of net floor area (NFA) in a year (a): i.e. GWP = $kgCO_2/m^2NFA*a$.

Table 1. Reference values of LCA environmental impacts' indicators for production phase of building. For the use phase are described below the calculation procedures to obtain the reference values. Legend: OEI = the environmental impact of electricity demand in use (calculated in compliance with Life Cycle Energy Modelling, LCEM and ESUCO database); OH = the environmental impact of heating demand in use (according to LCEM and ESUCO database); EI = electricity demand H = annual heating demand; G = weighting key. Reference: DGNB Core and Scheme Sheet, Env 1.1[2] for GWP, ODP POCP,AP, EP and Env 2.1[3] for PEInrn.

GWP	**ODP**	**POCP**
[$kgCO_2eq/m^2NFA*a$]	[$kgR11eq/m^2NFA*a$]	[kgC_2H_4eq/m^2NFA*a]
G = 40%	G = 15%	G = 15%
Construction	**Construction**	**Construction**
9.4	$5.3*10^{-7}$	0.0042
Use	**Use**	**Use**
$GWP_{OEIref} + GWP_{OHref}$	$ODP_{OEiref} + ODP_{OHref}$	$POCP_{OEIref} + POCP_{OHref}$
$GWP_{OEIref} = 0.62*EI_{ref}$	$ODP_{OEIref} = 3.07*10^{-9*}EI_{ref}$	$POCP_{OEIref} = 7.62*10^{-5}\ EI_{ref}$
$GWP_{OHref} = 0.29*H_{ref}$	$ODP_{OHref} = 3.08*10^{-11}*H_{ref}$	$POCP_{OHref} = 3.95*10^{-4}*H_{ref}$

AP	**EP**	**PEInrn**
[$kgSO_2eq/m^2NFA*a$]	[$kgPO_4eq/m^2NFA*a$]	[kWh/m^2NFA*a]
G = 15%	G = 15%	G = 60%
Construction	**Construction**	**Construction**
0.037	0.0047	34.167
Use	**Use**	**Use**
$AP_{OEIref} + AP_{OHref}$	$EP_{OEiref} + EP_{OHref}$	$PEInrn_{OEiref} + PEInrn_{OHref}$
$AP_{OEIref} = 1.03*10^{-5}*EI_{ref}$	$EP_{OEIref} = 9.92*10^{-5*}EI_{ref}$	$PEInrn_{OEIref} = 3.07*10^{-9*}EI_{ref}$
$AP_{OHref} = 3.92*10^{-4}*H_{ref}$	$EP_{OHref} = 2.43*10^{-5}*H_{ref}$	$PEInrn_{Href} = 3.08*10^{-11}*H_{ref}$

The benchmarks used by DGNB derived from an independent research modelled on the basis of a national research on German building stock and promoted by the Federal Ministry of Transport, Building and Urban Development (BMVBS) [4]. The research investigates, with a statistical analysis, a sample of buildings with an environmental certification and contained in the BKI Building Catalogue and in WEKA Catalogue. The buildings' choice is based on representative typology, construction techniques and energy performances. For the typology the observed features are: building type (single-family house/multi-family house), typology (detached house/central/head house), basement (with basement or without it), attic (expanded attic or not expanded), floors number: (from 1 to 10), roof type (pitched roof/plan roof) and equipment (standard). The constructive techniques are in accordance with the DIN 277 and the analysed types are sandstone with thermal insulation, bricks and timber frame. The energy performance is in accordance with the EnEV 2009 and derived from different heating systems: fossil, gas, wood, district heating, heat pump. The reference sample's for the LCA analysis is performed with LEGEP software using Ökobau.dat database. The LCA system boundaries include the production phase (A1-3), the construction phase (A4-5), part of the use phase (B2-4) and the end-of-life phase (C1-4). The results of each building are statistically analysed with the creation of a corridor, from which derives a reference value, a limit value and a target value. The benchmarks obtained were tested on five buildings with an LCA evaluation and they confirmed the statistical corridor's reliability. Through a own research, the DGNB Rating System define its reference values, which assign a criterion score of 5 points (Table 1).To assign the right score is necessary to establish the limit value (L_{EIP}) and the target value (T_{EIP}), which are related to the reference values provided. The building's environmental impacts must be arranged in the numerical interval defined by the three benchmarks (Table 2).

Table 2. Target and Limit values of environmental impatcs indicators. Legend: EIP = environmental impact potential; X_{EIP} = associated X size to each environmental impact; Y_{EIP} = Y size to each environmental impact; R_{EIP} = Total sum of environmental fo construction and operation (use) in kg-impact-equiv./m^{2}NFA*a. Reference: DGNB Core and Scheme Sheet, Env 1.1[2] e Env 2.1[3]

Limit value: $L_{EIP} = X_{EIP} * R_{EIP}$
Target value: $T_{EIP} = Y_{EIP} * R_{EIP}$

	GWP	ODP	POCP	AP	EP	PEInrn
X_{EIP}	1.4	10.0	2.0	1.7	2.0	1.4
Y_{EIP}	0.7	0.7	0.7	0.7	0.7	0.7

Then, with a linear interpolation, for each indicator is assigned a sub-point on a scale from 0 to 100. With a percentage weighting of each indicator (weighting key G in table 1) is possible to assign the evaluation score (limit value = 1 point; reference value = 5 points; target value = 10 points).

The study of the building stock in Switzerland brought to the definition of benchmark values for the Swiss certification Minergie-ECO. It is an energy certification in which energy performance's evaluation is not limited to the use phase, but it includes in the system boundaries the production phase (A1-3), the construction phase (A4-5), the use phase (B1-7) and the end-of-life phase (C1-4). The certification is divided into two categories: health (with the natural illumination, sound insulation and the indoor air quality criteria) and construction ecology (with grey energy, materials and building concept criteria). The LCA evaluation is within the Grey Energy criterion [5], that is the total amount of building's energy used in lifespan of 60 years for the production phase (A1-3), construction phase (A4-5) and end-of-life phase (C1-4). The building system analysed includes building parts and technologies, according to the Swiss standard SIA 380/1: building envelope, unheated parts outside the building's perimeter, interior constructive parts, excavations and plants (electrical, heating, ventilation and plumbing systems) [6]. The environmental impact is expressed in MJ for a square meter surface per year (MJ/m^2*a) and it is calculated with software in compliance with the certification (Bauteilkatalog, Enerweb 380/1, Lesonsai, THERMO and GREG).The analysis of the Swiss building stock is differentiated by types, materials and energy performances. It brings to the definition of benchmarks related to the grey energy consumption (Table 3). The threshold values indicate the limit value (GW2) and the target value (GW1) in order to define an energy consumption interval in which the building must fall inside to obtain the certification. Benchmarks refer to the new buildings with office, school and residential (single or multi-family) functions and they are different according to the building's parts with heated surface or unheated surface.

Table 3. GW1 and GW2 values for new buildings. (Minergie-ECO). Reference: "Calcolo dell'energia grigia per gli edifici Minergie-A, Minergie-ECO, Minergie-P-ECO, Minergie A-ECO"[6]

Use	**GW1** [MJ/m^2*a] Heated surface	**GW2** [MJ/m^2*a] Heated surface	**GW1** [MJ/m^2*a] Unheated surface	**GW2** [MJ/m^2*a] Unheated surface
Office	110	150	30	50
School	90	130	30	50
Residential	90	130	30	50

If a new residential building has a grey energy consumption equal or lower than 50 MJ/m^2*a (for "GW1 Heated Surface") is assigned to the building a best energy certification, the Minergie-A. In this case the reference value is mandatory, because the criteria have not a rewarding score, but they must be achieved in order to obtain the energy certification.

2.2. External Benchmarks from environmental impacts rating

The certification BREEAM provides the LCA analysis only for construction solutions. The GBRS is divided into ten categories: management, water, health and wellness, materials, energy, waste, transport, land use and ecology, innovation, pollution. The LCA approach is in the category "Materials" in "Mat01 – Life Cycle Impacts" criterion. The different environmental impact indicators are calculated for a square meter of the construction sub-system and they have a different percentage weight in the criterion: climate change (21.6%), water extraction (11.7%), mineral resource extraction (9.8%), stratospheric ozone depletion-ODP (9.1%), human toxicity (8.6%), eco-toxicity to freshwater (8.6%), nuclear waste (8.2%), eco-toxicity to land (8%), waste disposal (7.7%), fossil fuel depletion (3.3%), eutrophication (3%), photochemical ozone creation-POCP (0.20%), acidification (0.05%). The embodied carbon ($kgCO_2eq$) and the kilograms of recycled materials used (Table 4) are also calculated. The building parts considered are the building envelop, the horizontal and the vertical internal partitions and the roof, with a lifespan of 60 years. The LCA system boundaries include the production phase (A1-3), the construction phase (A4-5) and the end-of-life phase (C1-4) [7].

Table 4. Evaluation scheme of BREEAM criterion Mat01 "Life Cycle Impacts". Reference: The Green Guide to specification, 4th edition, 2009 [8]

Solid concrete ground floors Plywood decking on vapour control layer, on timber battens and insulation on in situ concrete floor on polyethylene DPM on blinded recycled aggregate sub-based	**Summary Rating**	Climate change	Water extraction	Miner resources extraction	ODP	Human toxicity	Ecotoxicity to freshwater	Nuclear waste (higher level)	Ecotoxicity to land	Waste disposal	Fossil fuel depletion	Eutrophication	POCP	Acidification	Embodied CO_2 ($kgCO_2eq$)	Recycled content (kg)	Recycled content (%)	Recycled currently at EOL (%)
	D	A	E	B	D	E	E	D	C	E	D	D	D	C	65	332	38	89

The environmental impacts of building's sub-systems must be calculated with the BREEM International Calculator Mat01 software, which puts the sub-systems within a sustainable ranking from A+ (3 points) to E (0 points). The rating is made with the environmental impacts' comparison of project's sub-systems with the "Green Building Specification Rating" database's results [8]. This database is built through the sub-systems' LCA analysis, which are considered the most representative in UK and Wales (1200 technological sub-systems). The *element* considered are ten and the relative *sub-section* (within parenthesis) are sixteen: ground floor (solid; suspended), upper floors, separating floors (in situ concrete; precast concrete; timber; composite), roofs (flat; low pitched; pitched), external walls, windows and curtain walls, internal walls (framed; masonry; demountable and proprietary), separating walls (masonry; steel; timber), insulation and landscaping (pedestrian only; lightly trafficked areas; heavily trafficked areas). According to the LCA evaluations of the 1200 subsections, for each environmental impact is defined a maximum value (limit value), indicated with the letter E which represents the highest environmental impact, and a minimum value (target value), indicated with the letter A+ which represents the lowest environmental impact. Then, the rating is divided into six equal parts and the sub-system's impacts are placed inside the sustainable rating sections.

3. INTERNAL BENCHMARKS

The environmental impacts' benchmarks related to the LCA analysis may be defined as "internal", if the reference values are obtained through the creation of a single model in accordance with the construction standards. The reference building allows a comparison to demonstrate the possible impact's reduction of the building. The rewarding scores are obtained with the achievement of improve threshold (target value) than the reference building's value, which is expressed in terms of percentage impacts' reduction. This is the methodology used by LEED.

The new version 4 of LEED v.4 introduces in the score-criteria the LCA analysis. The certification is divided in eight categories: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, regional priority. The LCA analysis is in the "Materials and resources" category, in "Building Life Cycle Impact Reduction" criterion. The environmental impacts calculated are the Global Warming Potential (GWP), the Ozone Depletion Potential (ODP), the Photochemical Ozone Creation Potential (POCP), the Acidification Potential (AP) and the Eutrophication Potential (EP). The indications to calculate the building life cycle are the standards ISO 14044, ISO 14025, ISO 14040, ISO 21930, EN 15804 and the instructions given by the US Green Building Council. The system boundaries include the production phase of materials (A1-3), the transportation to the site (A4), the use phase for a lifespan of 60 years (B1-7) and the end-of-life phase (C1-4) [9]. For the achievement of the criterion is necessary to model a reference building with a main structure, floors, walls and roof based on the standard ASHRAE 90.1-2010, appendix G "Opaque assemblies, vertical fenestration, skylights, roof-solar reflectance and thermal emittance section". The *baseline-building* (reference building modelled for the definition of the reference values) and the *propose-building* (project) must be similar and comparable in shape, size, function, site orientation and energy performance. The two buildings can have different characteristics, but they must be minimized. The baseline-building becomes the internal benchmark: it is the project under certification built in compliance with the American construction standards, in order to elaborate a comparison between the improvements obtained. The LCA analysis is performed using the ATHENA database, but other databases can be used for the assessment. Software and tools recommended are SimaPro and GaBi. The baseline-building's environmental impacts values are reference values which allow a comparison in which the propose-building must demonstrates a minimum reduction of 10% at least of three environmental impact indicators to satisfy the criterion requests and to obtain the score. Furthermore, the propose-building's environmental impacts values, must not exceed more than 5% if compared to baseline-building's impacts.

4. CONCLUSIONS

From the GBRSs analysis, different methods for calculating the environmental benchmarks emerges. External benchmarks are established through a national analysis of the building stock. The first difference in methodologies analysed is the use of different buildings sample: DGNB and Minergie-ECO include in the research only buildings with energy-environmental certification, while BREEAM includes in the analysis all the buildings (with energy-environmental certification, or not) which represent the UK construction techniques. This difference in the reference sample brings to different reference values, because in the first case the buildings have higher environmental performances than in the second case; consequently the threshold value of the first method has an lower impact than in the second method. The second difference is the definition of the LCA system boundaries: in DGNB the evaluation is extended to the whole building's parts and it considers all the phases, while in BREEAM it is only applied to building materials. The DGNB certification allows to implement the overall environmental building's performance (materials and energy consumption), while BREEAM only allows an improvement of materials' choice. Even in Minergie-ECO the system boundaries are applied to materials, but it is an energy certification and the energy consumption theme is separately treated.

External benchmarking operations bring to a reference value characterised by a variable magnitude, because it is linked to the improvement of built environment and it must be continuously updated. The three benchmark's types (limit, reference and target value) allow to understand the environmental sustainability levels and the project can use them to improve its performance. The visualization and the understanding of benchmarks is fundamental for a correct evaluation of preliminary design choices. In DGNB and in Minergie-ECO the values are expressed through numbers, while in BREEAM the rating division is in six sections and each of them is signed by a letter. This does not allow to understand the LCA results in a transparent manner. Furthermore the allocation of a letter, and not of a number, does not allow to understand the exact result's location in the sustainable rating (near or far from the limit value and the target value), preventing the orientation of possible improvements.

The internal benchmark derives from the comparison of the project with itself during its environmental performance's improvement process. The building does not have a reference value, but is itself the benchmark to beat. The baseline building is modelled in accordance to the national construction standards, but in this way it has not a comparison with the building stock in which it is located. In LEED, the LCA analysis is used as support design tool; however the LCA evaluation is used only for the material's impacts evaluation and it is not applied to the energy consumption (calculated with the same baseline building).

The LCA analysis and the related benchmarks are used to measure the environmental sustainability of products. An example is the ecological labels type I (ISO 14024), the European Ecolabel, an example of low environmental products' eco-certification (non-construction products included) during the whole life cycle. The Ecolabel's criteria derived from the scientific studies and collaboration of the European Eco-labelling Committee, environmental organizations, consumers organizations and industries (SMEs). The criteria are valid for three/five years, because they are related to the technology advances and market's development, in order to improve the environmental performance of the European products. Benchmarks of criteria analysed are restrictive and mandatory values, which must be respected for obtains the labelling. In Europe, other environmental certifications for products are developed, such as the Product Environmental Footprint (PEF) which is linked to the products' LCA and to the definition of a new benchmarks: the environmental impacts are measured through a benchmark which represents the average performance level of 51% of the European products belonging to a specific category product.

Today, the methodological differences between external and internal benchmarks bring to the choice of one of them to understand the environmental impacts. The internal benchmark could not be a significant comparison values, because it does not compare itself with the whole built environment. It can be used when there is a lack of information about the reference buildings stock and market. The real comparison between the new building and the buildings stock is done with the external benchmark, which gives a meaning to the result's. It verifies how the environmental evaluation's result is placed than the construction standards (constantly updated). This should be the LCA's benchmarking goal, with the improvement of lower impacts choices.

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