Implications of the building system boundary definition to conduct an LCA. A case study comparison of two frameworks for assessing building sustainability: DGNB and Level(s)

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Abstract. The embodied impacts calculation is increasing attention in research, and the use of Life Cycle Assessment (LCA) is the most widely recognised method for that purpose. To support architects and engineers in the use of LCA and to overcome the complexity of calculations in design stage practice, different frameworks for assessing building sustainability propose to conduct simplified LCA methods. Nevertheless, LCA implementation in these frameworks is not completely harmonised, causing problems of inaccuracy and incomplete assessments that generate incomparability among case studies and even possible deviations to achieve carbon- neutral scenarios. There, the system boundary definition is a key step. The present paper aimed to illustrate its implications, analysing the implementation of the LCA in a building envelope of a certified passive house located in Italy. Two building sustainability frameworks, DGNB and Level(s), are used to identify how the system boundary definition influences the impact assessment results. The study keeps LCA methodological assumptions (data sources, impact categories, characterisation methods, and indicators) constant to allow a comparison focused on the system boundary implications (such as the modularity principle of LCA). The results show the margins and reduction percentages that can be achieved by the two different assessment frameworks. Finally, limitations and challenges related to methodological aspects in the use of simplified LCA to calculate the impacts of a Passive House building are addressed.

1 Introduction

Current decarbonization and climate change mitigation scenarios are moving us toward implementing strategies to reduce the environmental impacts produced by the built environment. The literature [1] shows that the different strategies focused on the reduction of operational impacts can also increase the embodied impacts related to the building

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materials, resulting in no overall environmental performance improvement. Thus, the balance between embodied and operational impacts is increasing research attention [2]. There, the Life Cycle Assessment (LCA) is the most widely recognised method for embodied impacts. To support architects and engineers in the use of LCA and overcome the complexity of calculations in design stage practice, different building sustainability assessment frameworks propose to implement simplified LCA methods. In this vein, there are (among others) two widely recognised frameworks, the German DGNB [3] and the European Level(s) [4], a certification scheme and framework, respectively, that integrate the LCA application in the assessment process.

The present study aimed to compare the two LCA methods and identify the implications and consequences of using different LCA methods, derived from two assessment schemes, to assess the sustainability of the building.

2 Materials and method

To illustrate the differences between the two schemes Level(s) vs. DGNB we first conducted a comparison of the two methods. Secondly, we conducted an LCA according to the two methods, using an Italian passive house 'CASAUNICA' [5] as a case study. Finally, we compared and discussed the results obtained.

2.1 Comparison of the Schemes

Despite being conceived for a similar purpose, building sustainability assessment, several differences are detected when implementing the LCA technique on the two schemes. First and foremost, the LCA system boundaries are considered differently (see Table 1). Level(s) propose including different LCA phases depending on the LCA type, simplified (Option 1 and Option 2) or complete. On the other hand, DGNB proposes including several LCA phases (see Table 1) for all LCA types. Regarding the building elements system boundaries, Level(s) propose a fixed list of building elements including shell, core, and external works (complete list of elements in Table 2). However, the DGNB LCA method considers different building elements system boundaries depending on the LCA model, which can be a partial, simplified, and complete calculation models (complete list of elements in Table 2).

Table 1. LCA modules included in each method.

	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
LEVEL(S)																	
Complete LCA Cradle-to-Grave	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Simplified OP1. Product stage, calculated energy performance, and projected service life	X	X	X						X	X	X						
Simplified OP2. Product stage, calculated energy performance, and building material bank	X	X	X								X				X	X	X
DGNB																	
Declared modules Depending on the building element.	X	X	X				(X)		(X)		X	(X)			X	X	X

Table 2. Comparison of the frameworks.

	DGNB		**Level(s)**
Building elements included in the LCA	**Partial calculation model**	• Only structural elements • Exterior and basement walls – only concrete • Roofs – only perimeter insulation and concrete components • Internal floors and ceilings – only concrete structures and elements • Ground-level floor – only floor concrete construction and perimeter insulation boards • Foundations - only concrete incl. reinforcement • Internal walls – only concrete blocks, bricks • Load bearing structure – all concrete and metal components	Shell: • Foundations • Load bearing structural frame • Non-load bearing elements • Facades • Roof • Parking facilities Core: • Fittings and furnishings • In-built lighting system • Energy, ventilation, sanitary systems Lifts, escalators, communication and security installations, telecoms, and data installations External Works
	Simplified Calculation Model	• Exterior walls, doors and windows, and basement walls • Roofs • Internal floors and ceilings • Ground-level floor • Foundations • Internal walls and doors • Heating and cooling systems and air conditioning systems • Other building installations • In individual cases: User equipment with considerable energy consumption in the use phase	
	Complete Calculation Model	Cut-off criteria: Materials that make up more than 1% of the total mass of the building. In total, the ignored Materials/material groups must not make up more than 5% of the mass of the entire building.	

2.2 Description of the case study

The case study is a single-family house located in Biella (Italy), climate zone E. The two-story building 'CASAUNICA' has a total floor area of 190 square meters. The energy demand classification is an A+ (<15 kWh/m^2 year). The building's energy requirement (including the main end uses of heat /m^2, including, domestic hot water, cooling, ventilation, and lighting) amounts to 13 kWh per year calculated according to EPBD (Annex A) [5,6]. The main materials included in the envelope are described in Table 3.

Table 3. Complete list of building elements.

Building element	Material	Thickness (cm)
Roof	Roof Tiles	
	Polyurethane with graphite addition	10
	Polyurethane	10
	Bitumen sheeting G 200	4
	Wooden planking	2
	Laminated timber beams filled with rockwool	20
	Plasterboard	1.8
External Walls	Plasterboard	1
	EPS thermal insulation	25
	RC panels and interposed steel HEA profiles	16
	EPS thermal insulation	10
	Air Gap	10
	Rockwool	5
	Plasterboard	1.8
External windows	Wooden Frame	
	Low-emissive Argon filled triple glazing	0.6-1.2-0.6-1.2-0.6
Slab-on-grade	Wood flooring	4.5
	Double EPS board	12
	Sand	2.5
	RC Slab and welded mesh	5
	EPS shuttering for concrete	25

Figure 1. Casaunica House (Source: [5])

2.3 Description of the LCA implementation

The LCA method was implemented following the guidelines and specifications of the sustainability frameworks. The LCA complied with EN 15978 [7] and EN 15804 [8]. The scope of the building elements included in the assessment is described in Table 3. The LCA application was focused on the building envelope, including the roof, external walls, external windows, and slab on grade (Table 4). The environmental data have been manually extracted from the ÖKOBAUDAT [9], selecting the GWP impact category. The total energy consumption (primary energy and energy demands for heating and cooling) included in the calculation was 51.84 kWh/m^2 year [6].

Table 4. List of building elements included in LCA application.

	DGNB	Level(s)
Case study application	PCM included (A1-A3): • Roof (only perimeter insulation and concrete or main material) • External walls (only concrete) • Slab on a level (only concrete)	The same applies for the early and details stages. The shell, including: • Non-load bearing elements • Load bearing structural frame • Facades
	SCM included (A1-A3): • Roof • External walls, windows, and doors • Slab-on-grade	
	CCM included (A1-A3, B2; B4, B6; C1-C4; D): Material Cutoff Rules	

3 Results and Discussion

Table 5 shows that the highest values for GWP are obtained using the Level(s) simplified method OP1, and the lowest using the DGNB Partial Method, the difference between the two is almost two times. It means that the results can be affected depending on the method and the type of LCA. It is also demonstrated that the system boundaries definition, related to the building elements involved can affect the LCA. For example, the main building elements can be relevant at the early decision stages, but the sum of the other elements can influence the total results. The DGNB results for the A1-A3 modules varied almost 50% from the initial design to SCM and CM. The results also provide evidence that the operational energy demand impacts are the highest impacts (included in both schemes), followed by the product stage impacts.

Table 5. LCA results for the case study application considering a building service life of 60 years.

	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**	**Total**
LEVEL(s)																		
SR OP1	X	X	X						X	X	X							
GWP (kgCO2eq./m^2)	**308.42**								77.48		**1527**							**1913.62**
SR OP2	X	X	X								X				X	X	X	
GWP (SR OP2) (kgCO2eq./m^2)	**308.41**										**1527**				48.93	2.40	-89.59	**1799.88**
DGNB																		
LCA	X	X	X				(X)		(X)		X				X	X	X	
GWP (PCM) (kg CO2eq./m^2)	**159.65**						0*		77.48		**1527**				24.96	0***	-2.58	**1709.76**
GWP (SCM and CM) (kgCO2eq./m^2)	**308.41**						0.005		77.48		**1527**				48.93	2.40	-89.59	**1875.38**

4 Conclusions

The present study demonstrates the scope and implications of using different LCA methods for sustainability assessment frameworks. It also concludes that when conducting LCA system boundaries are mostly affected by data availability. For example, EPDs or ÖKOBAUDAT, include limited data about the building products, material life cycle stages. The study demonstrates the need for harmonizing the LCA application, which affects the carbon metrics (especially needed for the decarbonization path) and other environmental impacts calculation. Thus, aspects such as LCA stages, and information modules need to be reconsidered, for example, establishing mandatory phases for all the GBRS. Also, the building systems, elements, and components boundaries can be established by a common list of elements, and it can evolute depending on the building design stages. The environmental impact categories, indicators and categorization method should be harmonised for all the GBRS. The service life, maintenance, and replacement should be also harmonised due to their great influence in the LCA results.

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References

[1] A. Hollberg, J. Ruth, LCA in architectural design—a parametric approach, Int J Life Cycle Assess. 21 (2016) 943–960. doi:10.1007/s11367-016-1065-1.
[2] L.F. Cabeza, L. Boquera, M. Chàfer, D. Vérez, Embodied energy and embodied carbon of structural building materials: Worldwide progress and barriers through literature map analysis, Energy Build. (2021). doi:10.1016/j.enbuild.2020.110612.
[3] D. System, Certificate for Sustainable and Green Building; DGNB GmbH: Stuttgart, Germany, 2019, (2019).
[4] European Commission, Level(s), (n.d.). https://ec.europa.eu/environment/topics/circular-economy/levels_en.
[5] la casa passiva in ogni condizione climatica, (n.d.). www.casaunica.it.
[6] E. Palumbo, Effect of LCA Data Sources on GBRS Reference Values: The Envelope of an Italian Passive House, Energies 2021, Vol. 14, Page 1883. 14 (2021) 1883. doi:10.3390/EN14071883.
[7] EN, EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method, Int. Stand. (2011).
[8] EN, EN 15804:2012 + A2:2019 - Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products, Int. Stand. (2012) 70.
[9] ÖKOBAUDAT, (n.d.). https://www.oekobaudat.de/en.html.