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Next generation of life cycle related benchmarks for low carbon residential buildings in Germany

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Abstract. Germany's national climate targets are in line with the Paris Climate Agreement and set the ambitious goal of becoming net zero emissions by 2045. The construction and real estate sector play an important role for sustainable development. In a cross-sectoral approach operational and embodied emissions of buildings account for 40% of GHG emissions in Germany. In order to contribute to climate protection, it is necessary to both pursue a strategy for decarbonizing the national building stock and to develop benchmarks for assessing greenhouse gas emissions in the life cycle of individual buildings. In Germany, benchmarks are used in sustainability assessment systems for more than 10 years to assess primary energy non-renewable (PENRT) and global warming potential (GWP) in the life cycle of buildings. Therefore, these need to be regularly reviewed and further developed in order to (1) adapt them to more ambitious reduction targets, (2) consider the current database, (3) include the state of standardization, and (4) follow the state of scientific discussion on methodological issues. This paper identifies new benchmarks for PENRT and GWP and shows the scale of current levels of performance. These can form the basis for funding programs and contribute to the discussion on the introduction of binding legal requirements.

Keywords: Residential buildings, LCA, benchmarks, GWP, PENRT

1. Introduction

Buildings are essential to social and economic development and, as part of the built environment, influence the quality of life of their occupants and users. The construction product industry, the construction industry and the housing and real estate industry can be assigned to the "industry" sector. The field of action "buildings", which includes the construction, maintenance and operation of buildings, causes 39% of all greenhouse gas emissions in Germany, following an cross-sectoral approach [1]. At the same time "housing" is an area of need. Thus, the further development of the building stock has a major impact on sustainable development and the achievement of resource efficiency and climate protection targets, while at the same time meeting technical and functional requirements.

The goal of achieving a net zero greenhouse gas (GHG) emissions building stock in Germany by 2045 has consequences for the design of new construction and refurbishment measures. The traditional requirements for limiting the demand of primary energy, non-renewable (PENRT) in the use phase must be expanded, on the one hand, in the direction of including the entire life cycle (embodied energy) and, on the other hand, supplemented by requirements for limiting GHG emissions. The PENRT input in the life cycle represents the use of primary raw materials (in this case energy sources), the global warming potential (GWP) shows the impact on the global environment. PENRT and GWP become the target-, calculation-, and verification-variables. In addition to methods, data and calculation tools, assessment standards and performance levels in form of benchmarks and target values are also needed.

Benchmarks for the assessment of PENRT and GWP were developed in Germany over 10 years ago and used in sustainability assessment systems such as BNB and DGNB and later NaWoh and BNK. They are mandatory for federal construction projects. In this context, the creation of benchmarks followed a systematic structure of limit, reference and target values from the very beginning, which can be found today in ISO 21678: 2020 [2], among others.

In the meantime, the need for an update arises. This results from (1) a tightening of political targets for climate protection and with that the need of more ambitious target values, (2) more up-to-date databases in the form of Ökobau.dat [3], (3) the further development of European standards like EN 15643 [4], and (4) the state of scientific discussion on selected issues [5, 6]. Using the example of the current benchmarks for new residential buildings, the consequences of (1) and (2) are shown in the first part of this paper. The values are comparable with commonly known benchmarks. In addition, policy guidelines for such requirements are discussed here. The consequences of (3) and (4) are discussed then in a special section. These values are not comparable with values from literature they have extended system boundaries.

As in other countries, the introduction of mandatory requirements for PENRT and GWP in the life cycle is currently being discussed in Germany. This contribution is part of the discussion.

2. Methodological Approach for Study Frameworks

The study boundaries and the included buildings are determined according to the following definitions.

2.1 Building Typology

The methodological approach for buildings typology follows König (2011) [7], in which a system was developed for the use category "residential buildings". This system was supplemented by following typologies: single-family (SFH) (one- and two-storey single-family houses, two-storey semi-detached and terraced houses, 3-storey and multi-storey apartment houses) and multi-family house (MFH) (with various entrance situations and number of flats per floor. The number of stories ranges between 3 up to 8).

2.2 Construction method

In König (2017) [8] a single-family house was modelled in six different construction methods. The calculation results showed a differentiation of the LCA values in the group “mineral construction”, here named conventional, and the group “renewable materials”. In Hafner and Schäfer (2017) [9] and Hafner et al (2017) [10] the same differentiation was used to compare MFH over the entire life cycle. Constructions that are predominantly made of renewable materials are referred to as future-oriented construction in this paper.

Therefore, all buildings in this study are modelled in two construction methods.

The designation of the construction methods is:

- (A) “conventional” and
- (B) “future-oriented” (biobased materials / recycling products / in future low carbon products)

2.3 Energy performance standards

The German building energy law (GEG 2020) also introduced new energy performance standards that are intended to reduce energy consumption without drastically increasing construction costs. In addition to the legal binding requirements of GEG standard, there are other accepted sub-standards for better energy performance of buildings in Germany in place in relation to funding programs. They are referred to in this study as "energy performance level 55" (45 % below legal requirements) and "energy performance level 40" (60% below legal requirements) for buildings.

The additional financial expenditure for insulation and building services differs by a maximum of 10 % between the GEG and level-55 energy performance [8]. The potential subsidy increases by attainment of higher energy standards, so the economic feasibility has to be examined. In the context of this study, only the energy performance standard level-55 and level-40 defined by KfW are taken into account for the buildings under consideration.

This results in the following energy performance alternatives:

- "Level 55"
- "Level 40"

2.4 Representativ buildings

Based on the determinations, a data pool of buildings was compiled, which is listed in Table 1. In addition, a further subdivision of the MFH building type was made on the basis of the building classes (GK) relevant for the fire protection requirements. "MFH small" corresponds to GK 3, while the "MFH large" are classified in GK 4 and 5.

From GK4, the use of renewable materials as insulation or in the construction is not possible without compensatory measures such as plasterboard cladding or sprinkler systems, which then lead to an increased use of materials, relevant for the LCA calculations.

Table 1: Building types, material type, gross floor area, energy standard, building class

Number	**Building design**	**Abbreviation**	**Construction**	**GEA [m²]**	**energy performance standard**	**Building class**
1	SFH/ZFH	**1-A-55**	mineral - sand-lime brick	184	level 55	GK1/2
		1-B-55	timber-construction / timber frame			
		1-A-40	mineral - sand-lime brick		level 40	
		1-B-40	timber-construction / timber frame			
2	MFH small	**2-A-55**	mineral - sand-lime brick	560	level 55	GK3
		2-B-55	timber-construction			
		2-A-40	mineral construction	572	level 40	
		2-B-40	timber-construction			
3		**3-A-40**	porous concrete	1773	level 40 Passive house	GK3
		3-B-40	timber-construction			
4	MFH large	**4-A-55**	reinforced concrete	2108	level 55	GK 4
		4-B-55	timber-construction			
5		**5-A-40**	porous concrete and reinforced concrete	2.717	level 40 Passive House	GK4
		5-B-40	timber-construction			
6		**6-A-55**	sand-lime brick	9115	level 55	GK4
		6-B-55	timber-construction			
7		**7-A-55**	porous concrete	1280	level 55	GK4
		7-B-55	timber-construction			
8		**8-A-40**	porous concrete	2.033	level 40 Passive House	GK5
		8-B-40	timber-construction			

3. Methodical approach for LCA Framework

Specifications for the calculation method for the benchmark development are:

3.1 Life Cycle Assessment of Buildings

Life cycle assessment (LCA) is a method to analyze the potential environmental impacts of a product system or service throughout its life cycle holistically. The generally applicable standards are specified by the principles and framework in ISO 14040 [11] and the requirements and guidance in ISO 14044 [12]. Applied LCA for the building and real estate sector is specified by EN 15804 [13], in which the framework is related to the building product level, and by EN 15978 [14], in which the framework conditions for assessing the environmental performance of buildings is defined.

Figure 1 shows the modular structure of the entire life cycle according to EN 15643: 2021 [4], which includes the production and construction phase (module A), the use phase (module B) and the end-of-life phase (module C). As supplementary information and outside the system boundary, module D, covers benefits and loads beyond the building life cycle. Same classification is used for the LCA calculations according to EN 15978 [14].

The calculation method and the considered life cycle stages follows the German "Assessment System for Sustainable Building" (BNB) [15], "Sustainable Housing Construction" [16] and "Sustainable Small Housing Construction Assessment System".

Thus the modules A1-A3 (production), module B2 (maintenance) and B4 (replacement) and modules C3-C4 (waste processing, disposal), module B6 (operational energy use) are taken into account within the system boundary. Module D (benefits and loads) is shown separately as an information module. The modules that are considered in this study are outlined red in Figure 1.

Module B6 is divided into B6.1 (energy consumption of buildings, regulated), B6.2 (energy consumption of buildings, non-regulated, e.g. elevators) and B6.3 (user and use related energy consumption, see chapter 3.3). The operational energy use (Module B6.1) is included in the calculation according to the GEG. The final energy demand values are used in the LCA calculations. The future inclusion of energy use for energy consumers that cause building-related energy use but are not included in the GEG, including lifts (B6.2 - currently not included), is under discussion. International standards for the determination of energy expenditure as well as for the recording of greenhouse gas emissions in the use phase allow the inclusion of e.g. lifts see ISO 16745-1: 2017.

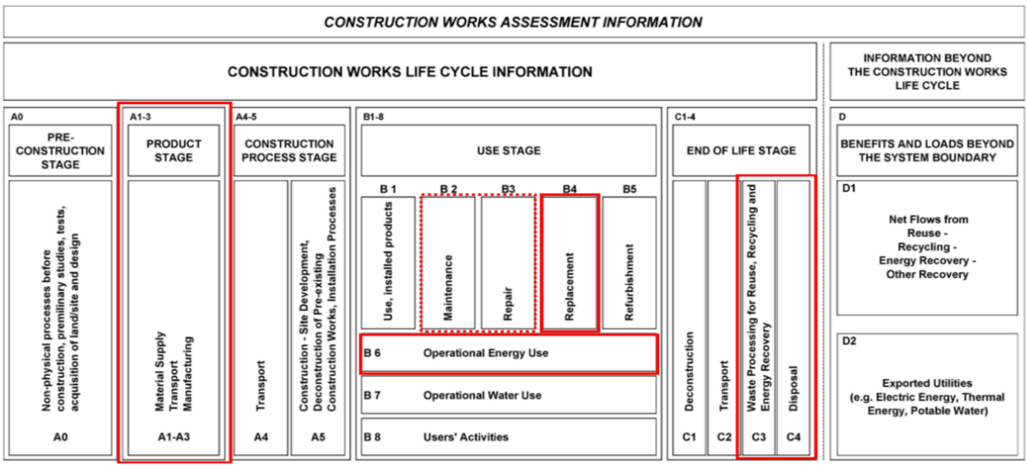

Figure 1. Life cycle stages for buildings according to new EN 15643: 2021 [4]

The reference study period is set at 50 years, following the BNB [15] and NaWoh [16] certification systems.

The database "Oekobau.dat" is an online database, which contains Environmental Product Declarations (EPDs) on building materials, building components and technical systems. Oekobau.dat [3] is provided by Germany's Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) since 2013 and offers a uniform database fulfilling the requirements of EN 15978 [14] (under redevelopment) and EN 15804: 2012 [13]. For this research the Oekobau.dat Version 2020-II was used.

3.2 Reference unit

The used reference unit is defined by m² gross external area (GEA). For the calculations, also the net floor area could be used. It is recommended to refer the results to various reference units.

3.3 Module B6.3

The requirement to increasingly meet the energy needs of buildings with renewable energy tends to result in buildings that not only demand energy, but also generate or produce energy themselves in or on the building or on the site. In some cases, an obligation to install photovoltaic systems (BIPV) is being discussed. Therefore, the question must be answered how the generated energy can be included in the LCA and how the maximum self-consumption can be mapped. Methodological approaches can be found in EN 15643: 2021 and in the scientific literature [5, 17–19]. The benchmarks of a new generation that already respond to this are presented below. They are based on the principles shown in Table 2. These were developed in 2021 and now form the basic concept for the calculation rules in a new label QNG [20].

Table 2: Calculation rules and system boundaries in QNG

• Extension of the system boundaries of module B6 by B6.2 and B6.3 with a flat rate of 20 kWh/m²a for the electricity demand of the users • Dimensioning and yield determination for BIPV under site-specific conditions. • Determination of the self-consumption share in relation to B6.1, B6.2 and B6.3 • B6.2 (elevators) not considered in this specific case	• Indication of the impact of exported energy as additional information not included in the balance sheet • Attribution of embodied impacts of BIPV to the building in the order of the self-used portion of the energy generated.

In a special evaluation, the influence of module 6.3 in B6 was carried out in various scenarios for "Building 2" (see Table 1) with the energy performance level 40. The building construction and building services have been fully considered in the scenarios.
The scenarios are structured as shown in Table 3.

Table 3: Scenarios 1 to 5: Fully considered construction and building services and differentiated consideration of operation B6 differentiated in B6.1 and B6.3

	Embodied		BIPV		Operational B6	
	Construction and building service	BIPV technical systems	user consumption	export		
	Module A-C				B6.1	B6.3
Scenario 1	x				x	
Scenario 2	x				x	x
Scenario 3	x	0%	0%	100%	x	x
Scenario 4	x	25%	25 %	75%	x	x
Scenario 5	x	50%	50 % (+Battery)	50%	x	x

4. Results

The assessment results for 8 buildings of table 1 are shown for GWP and PENRT and divided in construction method A (conventional construction method) and B (future-oriented construction method with predominant use of wood and renewable materials). The dashed lines indicate the minimum and maximum values as a basis for benchmarking and target setting. Reference unit is the GEA.

4.1 LCA results GWP

Figure 2 shows the LCA results for the building variant A Figure 3 shows the LCA results building variant B. The maximum and minimum values for variant A are between 12 and 18 kg CO2-eq. m² GEA and year, resulting in a value corridor of 6 kg CO2-eq. / m² GEA and year;

For variant B the maximum and minimum values are between 10 and 14 kg CO2-eq. m² GEA and year, thus the value corridor is 4 kg CO2-eq./ m² GEA and year.

On the one hand, the corridor of values is affected by the size of the buildings; on the other hand, a possibly wide range of different MFHs in terms of the number of apartments and building height were modeled in the selection of representative buildings for MFHs. The variations also highlight the manifold construction possibilities in alternative A and B as well as the effort made by the architects to create buildings with low embodied emissions.

The global warming potential is highest in production (A1-A3) and in operation (B6.1) over the entire life cycle for variant A. In variant B, on the other hand, the GWP in production stage is very low or possibly even negative. This is due to the biogenic carbon stored in the building products made from wood, expressed GWP biogenic. This advantage is completely offset at the end of the life cycle by higher values in module C ("-1 / +1" approach). Nevertheless, in variant B the GWP of all buildings are lower over the entire life cycle. The differences between the two alternatives can be explained by the choice of construction method ("embodied emissions") for variant A - conventional and B - future-oriented building. Here, for every building the identical functionally equivalent is calculated. Therefore, the emissions from module B6.1 are the same for both variants. The differences result reclusively from the choice of material/construction method.

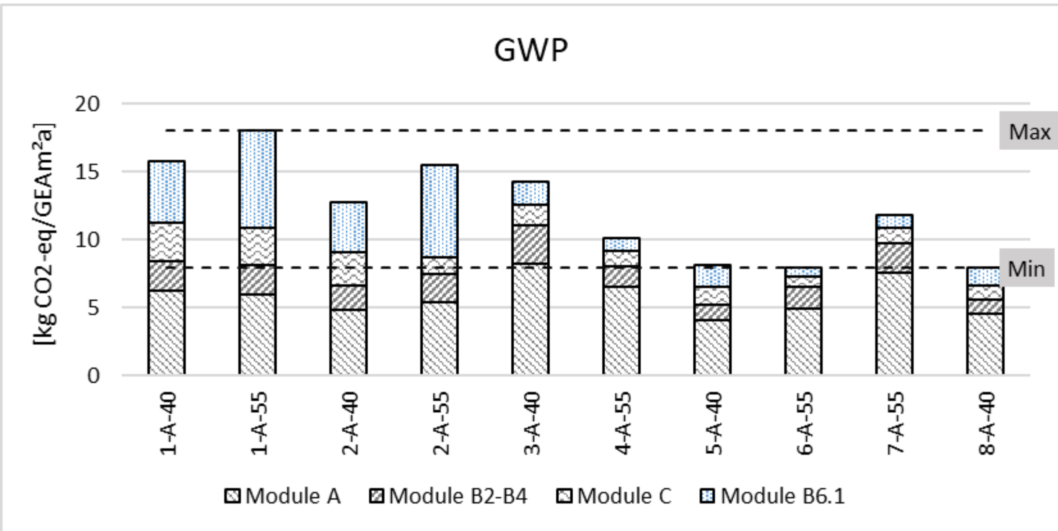

Figure 2: LCA results for the GWP indicator for all buildings in variant A

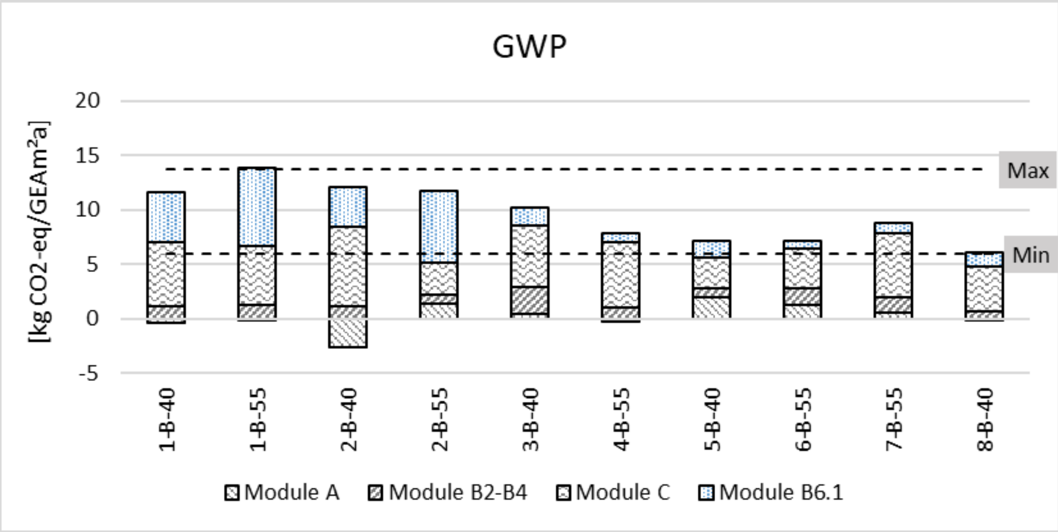

Figure 3: LCA results for the GWP indicator for all buildings in variant B

4.2 LCA results PENRT

Figure 4 shows the LCA results for the building variant A Figure 5 shows the LCA results building variant B. The maximum and minimum values for variant A are between 165 and 255 MJ/ m² GFA and year or 45,8 and 70,8 kWh/ m² GFA and year, thus the value corridor is 90 MJ/m² GFA and year or 25 kWh/m² GFA and year. For variant B, the minimum and maximum values are between 140 MJ/m² GFA and year and 220 MJ/m² GFA and year, or 38.9 kWh/m² GFA and year 61.1 kWh/m² GFA and year.

Here too, the LCA results for the indicator PENRT for Variant B tend to be lower.

It has been shown that embodied emissions can no longer be neglected over the life cycle of buildings in the level-55 and level-40. They represent an adjustment screw that needs to be further optimized. The highest emissions were found in module A1-3, which is not surprising, since the difference in construction methods is expressed most strongly in this module. Emissions caused by replacement of components in the life cycle (module B4) offer a further opportunity for optimization. The following applies: the fewer replacements, the more durable the construction, the lower the values. The disposal phase (module C3-C4) has a minor influence on the overall result.

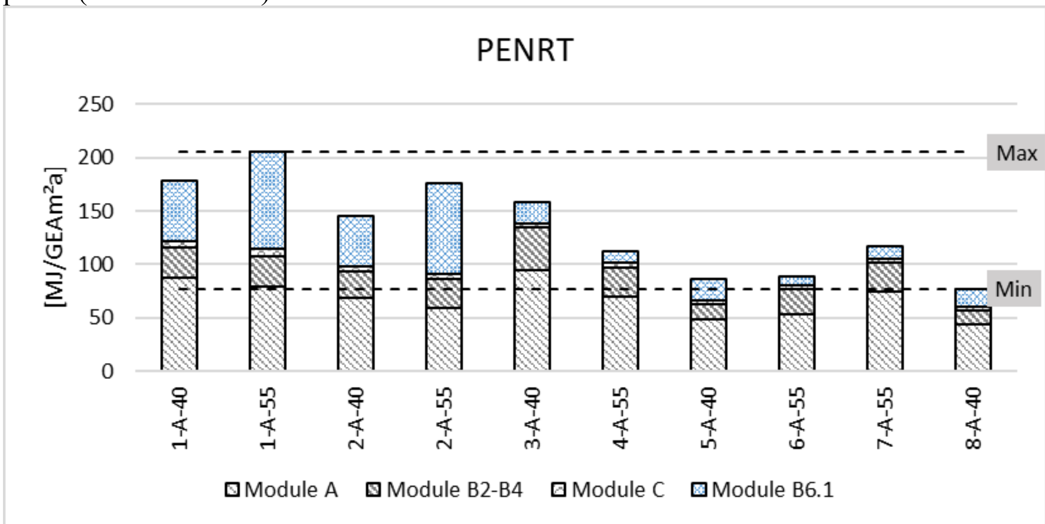

Figure 4: LCA results for the PENRT indicator for all buildings in variant A

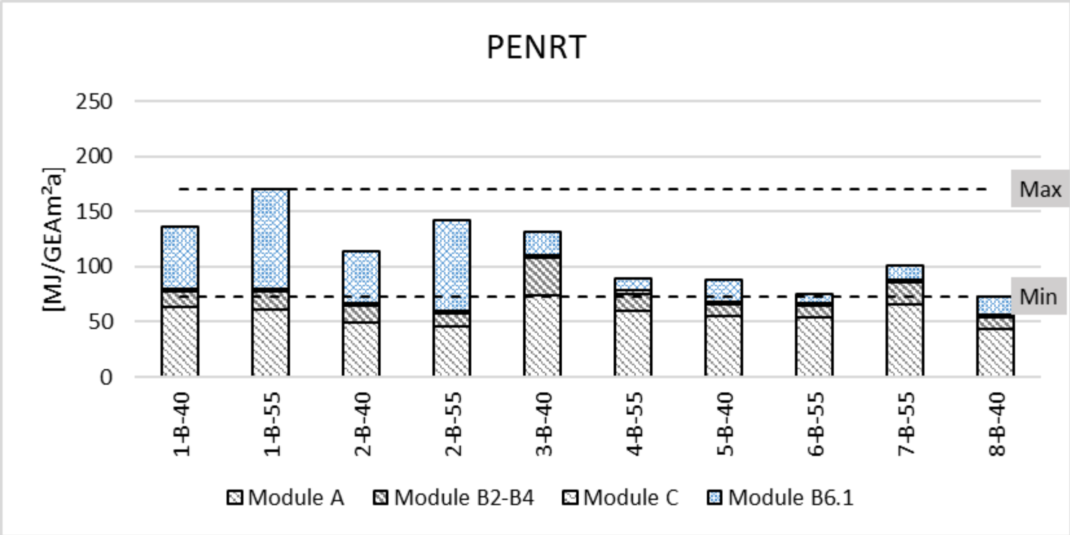

Figure 5: LCA results for the PENRT indicator for all buildings in variant B

4.3 Sensitivity analysis on operating energy use including Module B6.3

In the following, the scale of the influence of B6.1 and B6.3 on total B6 for each scenario was analysed. The LCA results are presented for the GWP indicator in differentiated into construction variants A (Figure 6) and B (Figure 7). Results on PENRT are in their effect similar to the results on GWP, therefore only GWP results are shown. The different scenarios are described in Table 3. In Table 4 only the conclusions are displayed.

Table 4: Conclusions of the scenario 1 - 5

Scenario	Effects
1	B6 does not vary for variants A and B, while the difference for modules A-C is due to the design differences of the buildings.
2	With the addition of module B 6.3, the total module B6 is increased equally in variants A and B. The difference that already occurred in scenario 1 remains identical.
3	The energy generated by BIPV is exported at 100 %. As the BIPV has no impact on module B6, the BIPV system is not included to the building, so the LCA is unaffected.
4	The influence of construction (Module A-C) changes due to the proportionally chargeable BIPV system. For the own utilization of the energy generated by BIPV (here 25%), 25% of the embodied emissions are attributed to the building and the other 75% to the exported energy (D2). * The influence of operation in B6 is lower, as the BIPV system is credited by 25% to own consumption and thus reduces the amount of operational GHG emissions by this amount. ** The potentially avoided emissions elsewhere as a result of exported energy are reported in Module D2.
5	The influence of the design changes due to the proportionally credited BIPV system and the total life cycle energy demand and GHG-emissions of the battery. The influence of operation is lower (6.1 + 6.3), because the BIPV system B 6.3 is credited at 50% for self-consumption and thus reduces the amount of energy consumption and GHG-emission in operation. The separately reported effect of potentially avoided emissions at third parties is reduced by 50%. The effect of exported electricity nearly equals the embodied emissions in variant B, but not in variant A.

* The exported energy therefore is not free of emissions.
** The own utilization of energy is accounted for in B6 with an emission factor of 0.

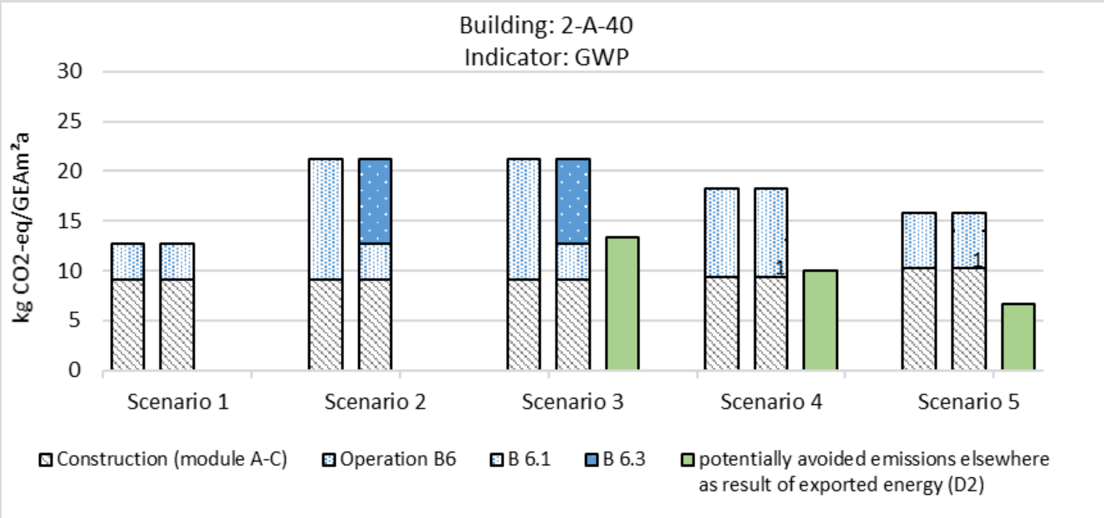

Figure 6: LCA results for the 5 scenarios for indicator GWP for Variant A.

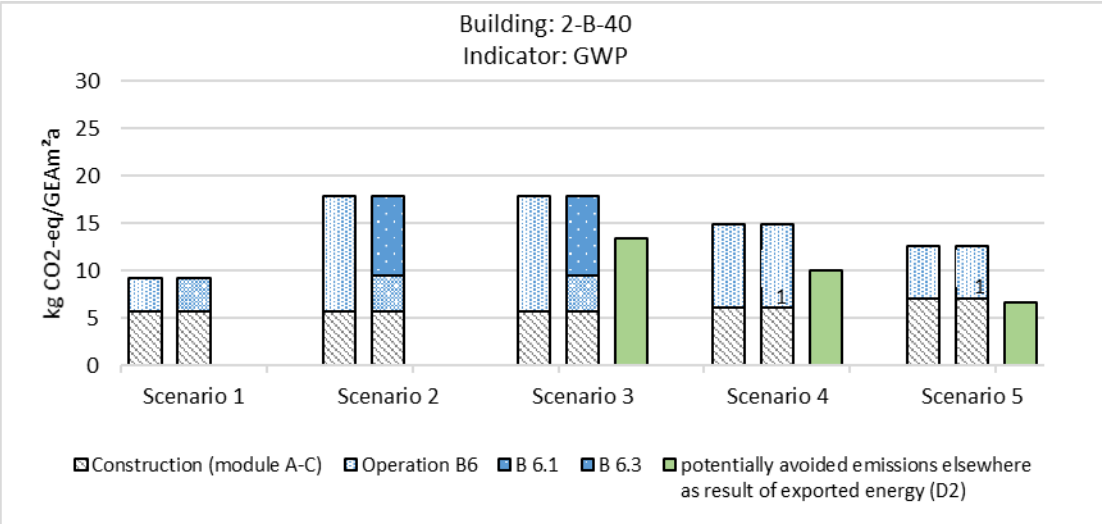

Figure 7: LCA results for the 5 scenarios for indicator GWP for Variant B.

(1) There is no mapping of reduction effects between B6.1 and B6.3. Generally, B6 is lower.

5. Discussion and Conclusion

In Germany, the transition from a bottom-up approach, in which benchmarks are formed using type proxies, to a top-down approach, in which benchmarks are derived from planetary boundaries, is not yet complete. The question of technical and economic feasibility continues to play a vital role. The chosen approach of selecting actually realized buildings as type representatives provides the opportunity to demonstrate practical feasibility. It is thus in line with the "best-in-class" approach to target values.
In the context of the benchmarks, we discuss (1) the granularity of the benchmarks, (2) issues of dealing with specific local conditions, (3) reference area issues, and (4) the future viability of the requirement levels.

In context of (1), it was decided not to make a distinction between small and large residential buildings and to give orientation values for both parts - the embodied and operational emissions. A limit on upfront emissions is under discussion. There are currently no additional allowances for (2) for difficult subsoil conditions. In (3), the suitability of reference areas is further discussed. The authors recommend reporting multiple reference units in parallel and reporting values per capita or per full hours of use. (4) The authors suggest introducing a balanced emissions target (net zero) as an additional target value, first in operation and later in the life cycle, to account for absolute planetary boundaries.

The final benchmarks derived from the procedures can be found in [20].

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