Life Cycle Assessment and Circularity in Practice: A Level(s) 2 Case Study of the GEFION Timber-Based Small Campus Building

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August 22, 2025

Abstract

This report presents a Level(s) 2 assessment of the GEFION campus prototype, a small, timber-based building designed for circularity and reuse.

Using Indicator 1.2 (Global Warming Potential, GWP) as the central metric, the analysis shows a total GWP_{100} of 1611 kg CO_2eq (Modules A–C), driven primarily by the photovoltaic components and the limited usable floor area. When excluding replacements in Module B4—due to high uncertainty regarding their actual occurrence—the GWP decreases to 731 kg CO_2eq. This highlights the significant impact of modeling assumptions for B4, which account for more than 50 % of the total GWP. A scenario comparison further reveals that with only three conventional material substitutions (OSB, polycarbonate, mineral wool), the GWP would have increased about 45 %, underlining the climate benefits of reused timber components.

The operational energy performance, assessed via Indicator 1.1 (Use stage energy performance), was evaluated through thermal simulation. Three design scenarios were compared, including varying insulation and window configurations. The results show that heating demand could be reduced by up to 27 %, but not all design changes led to improved life cycle performance. One scenario achieved only minor energy savings while increasing embodied emissions. This highlights the importance of balancing operational efficiency with material-related impacts in early-stage design decisions.

The project also reports on Level(s) Indicator 2.4 (Design for Deconstruction) reaching a high Circularity Score of 91.5 %, indicating substantial reuse potential at the system level. This score complements the GWP analysis, which underrepresents material circularity due to methodological limitations in life cycle modeling. The data highlight the need for early-stage sustainability assessments to avoid oversizing and misaligned design choices.

A tailored two-phase process—Preparation and Optimization—enabled scenario modeling and transparent LCA calculations. The results in this report underscore the importance of integrating replacement modeling, digital workflows, and qualitative indicators into holistic Level(s) 2 assessments.

Contents

1 Introduction

This report presents a Level(s) 2 sustainability assessment for the GEFION building prototype, a circular, timber-based small campus unit constructed in Germany in 2023. The aim of the assessment was to provide a robust evaluation of environmental performance in the design and construction phase, in line with the European Level(s) indicator framework as outlined by Dodd, Donatello, and Cordella 2021a.

The Level(s) define a common reporting system for assessing the sustainability of buildings using harmonized life cycle indicators. It is structured around three application levels, which reflect the availability of data at different stages of a project. In GEFION, Level(s) 2 was selected as the reporting level, as it corresponds to the design and construction phase and allows for a full life cycle assessment (LCA) based on modelled or calculated data. While elements of Level(s) 1 (e.g., qualitative checklists and early goal setting) were used during the design preparation phase, this report does not cover Level(s) 3 post-construction validation.

To ensure meaningful and transparent application of Level(s) 2, the GEFION team developed a structured two-phase process consisting of a *Preparation Phase* and an *Optimization Phase*. These phases enabled the alignment of stakeholder goals with Level(s) indicators, the setup of a tailored digital workflow for data handling and LCA calculation, and a refinement of design decisions prior to construction. The resulting framework is introduced in sec. 4.1 and sec. 4.2, and was essential to deliver actionable insights despite time and resource constraints.

The assessment focuses on a targeted selection of Level(s) indicators with strong relevance to GEFION's sustainability goals: Indicator 1.2 (Global Warming Potential) as the central quantitative metric, supported by Indicator 1.1 (Use Stage Energy Performance), Indicator 2.1 (Bill of Quantities), Indicator 2.4 (Design for Deconstruction / Circularity Score), and Indicators 5.2/5.3 (Climate Risk). The methodology and results for each indicator are presented in sec. 4.

In addition to presenting indicator results, the report highlights practical challenges in applying Level(s), such as EPD availability, digital integration, and stakeholder coordination. The reflections in sec. 5 and the outlook in sec. 6 suggest pathways for further development of both the Level(s) framework and its application in practice.

2 GEFION Project Overview

The study presented in this report is based on a multi stakeholder project called GEFION[1] funded by Invest BW in the federal state Baden-Württemberg, Germany. At its core, is a timber-based small campus building that was planned and

[1] For further information about GEFION visit `https://gefion.info/`

constructed, and will be used and ultimately deconstructed over a project duration of approximately two years. The project aimed to demonstrate how sustainability and circular economy principles can be efficiently applied in construction. GEFION combined applied research—including energy scenario modeling and quantification of CO_2 storage in timber for potential future carbon certification—with the practical realization of a timber building across all life cycle stages, from construction to deconstruction. All stages were implemented by the GEFION team. The team involved the architectural office andOFFICE from Stuttgart, responsible for the design, planning and guiding the construction process. It further involved separate teams from Hochschule Esslingen, who were responsible for energy scenario modeling, technical engineering and optimization of building services engineering, on the one hand, and for developing a methodology for quantifying biogenic carbon stored in biobased material components of the building, on the other. It included the sustainability consultancy IREES with extensive expertise in life cycle assessments and the software engineering company NETSYNO as a technical and software partner to realize technical components alongside the not-for-profit consultancy WoodenValley gGmbH which was responsible for integrating different sustainability assessments and processes, for developing digital products to manage ESG and sustainability reporting data, and for coordinating stakeholder efforts. The project was organized into nine working packages, including: Business Model, Architecture and BIM, Digital Twin, Life Cycle Assessment (LCA), Certificates, Building File, Documentation, Sustainability and Public Relations.

The design concept of the GEFION timber-based house is illustrated in fig. 1 (left). The structure consists of two floors.

The first floor serves as a workspace and meeting area for students of the Göppingen Campus. The second floor was planned to house the buildings technical equipment. The building's technical systems include:

1. A movable photovoltaic (PV) system with a battery for electricity storage, enabling primarily solar-powered operation. The building is not connected to the electricity grid.

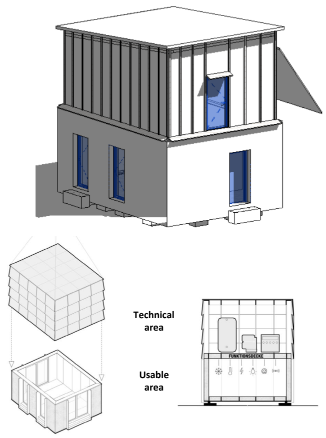
2. An infrared heating system, powered by the PV-generated electricity.

3. Electricity meters to monitor detailed consumption data for heating, lighting, and device use (e.g. laptops,projectors).

4. Environmental sensors to measure indoor temperature, air quality e.g. CO_2 levels and humidity.

5. Note: The building is not connected to a water supply. Nearby campus facilities will be used for sanitary purposes.

Additional information about the overall project are shown in fig. 1 (right) reported in the format of the "Building Description" used in Level(s) Dodd, Donatello, and Cordella 2021a. Additional supporting information is provided in the GEFION Building Description, see append. A.1.



Level(s) Building Description		
Parameter		**Office buildings**
1. Location	1.1 Country and region	Germany, Region Stuttgart - Göppingen
	1.2 Heating and cooling degree days	HDD: 2000 - 3000 & CDD: 50 - 200
	1.3 Climate zone	Zone 4
2. Building typology and age	2.1 New build or major renovation	New build
	2.2 The year of construction	2025
	2.3 Market segment	Seminar building for students at the Campus Göppingen, which is part of the Hochschule Esslingen, Germany
3. How the building will be used	3.1 Conditions of use	Work places, seminars, meetings
	3.2 Building occupation and usage patterns	
	3.2.1 Projected occupancy density	Medium density of occupation: 8 to 13 m^2 per workspace
	3.2.2 Projected pattern of occupation	Usage: 20 - 30 hours per week and person
	3.3 The intended (or required) service life	2 years
4. The building model and characteristics	4.1 The building form	Other - Wooden Tiny House, Free standing on the Campus ground
	4.2 Total useful floor area	20,9 m^2 (NUF) + 7,3 m^2 (VF) = 28,2 m^2
	4.3 The scope of building elements to be assessed and the categorisation system used	
	4.3.1 The scope of building elements to be assessed	Shell (Foundations, Load bearing structural frame, rood, facades) Core (Heating systems, lighting system, energy generation and distribution)
	4.3.2 The building element categorisation system used	System uses BIM

Figure 1: *Left:* Architectural timber-based Campus Building with movable PV system located on the Campus Göttingen. On the bottom we show a schematic of the two floors. The first floor is used by students for working, meeting or seminars. The top floor is used only for technical equipment. (Design picture provided by andOffice.) *Right:* Further GEFION project details using the "Building Description" reporting format from the Level(s) framework Dodd, Donatello, and Cordella 2021a. The total useful area of the building is 28,2 m² excluding the unheated technical area of approx. 30 m² located above the main volume.

3 Methods

This section describes the methodological basis for the Level(s) assessment and the process structure developed within the GEFION project. The actual implementation and outcomes of this process are presented in sec. 4. Here, we focus on the framework and reasoning that informed our approach to applying the Level(s) indicators at design stage.

3.1 Level(s) framework and selected indicators

The Level(s) framework is a European approach developed by Dodd, Donatello, and Cordella 2021a to sustainability assessment for buildings developed to harmonize the measurement of building performance across the EU. It can be applied to a new building project as well as to a major renovation project (Dodd et al., 2021, UM2) and it is made to be used by architects, developers, investors, engineers, designers, property owners and specialist consultants equally. It aims to support the transition to a low-carbon, resource-efficient, and circular building sector by providing a common set of indicators for building assessments.

The framework is structured around six macro-objectives (Dodd, Donatello, and Cordella 2021a) that capture the core goals of sustainable building:

1. Greenhouse gas and air pollutant emissions along a building's life cycle: Reduce the life cycle impacts of buildings on climate change, including both embodied and operational emissions.

2. Resource efficient and circular material life cycles: Optimize the use of resources and materials, including the reduction of construction and demolition waste.

3. Efficient use of water resources: Minimize water consumption during the use stage and encourage water reuse where possible.

4. Healthy and comfortable spaces: Create indoor environments that promote health, comfort, and productivity.

5. Adaptation and resilience to climate change: Design buildings that can withstand and adapt to changing climate conditions.

6. Optimized life cycle cost and value: Reduce life cycle costs and optimize the long-term value of buildings.

Each of these objectives are assessed and supported through the use of a range of indicators which are in total 16 (see Figure 3). Not all indicators require quantitative assessments. Indicators 4.3, 4.4, 5.2, 5.3 and 6.2 are assessed through a qualitative checklist, whereas the Bill of Quantities, materials and lifespans (Indicator 2.1) only requires information reporting.

Table 1 provides an overview of the macro-objectives, their indicators, and units of measurement, adapted from Dodd et al. (2021, UM1, p. 10).

The Level(s) framework is organized into three assessment levels, each representing a different phase of the building lifecycle:

- Level 1 – Conceptual Design: Early design decisions, qualitative prescreening.

- Level 2 – Detailed Design and Construction: Quantitative assessment, life cycle analysis.

- Level 3 – As-Built and In-Use: Validation and performance measurement based on real data.

In this report we focus on Level(s) 2 (Detailed Design and Construction) analysis and optimization. All results are based on modelled and calculated data. Elements of Level 1 were used to frame early discussions and indicator scoping. No in-use data was collected or evaluated.

The GEFION assessment focuses on a subset of Level(s) indicators selected for their methodological relevance to early design-stage evaluation and data availability. The included indicators are:

Table 1: Overview of all Level(s) Macro-Objectives, Indicators and Units of Measurement adapted from Dodd, Donatello, and Cordella 2021a

Macro-objective	Indicator	Unit of Measurement
1. Greenhouse gas and air pollutant emissions along a building's life cycle	1.1 Use stage energy performance	kWh/m^2/yr
	1.2 Life cycle Global Warming Potential	kg CO_2 eq./m^2/yr
2. Resource efficient and circular material life cycles	2.1 Bill of quantities, materials and lifespans	Unit quantities, mass and years
	2.2 Construction & demolition waste and materials	kg of waste and materials per m^2 total useful floor area
	2.3 Design for adaptability and renovation	Adaptability score
	2.4 Design for deconstruction, reuse and recycling	Circularity score
3. Efficient use of water resources	3.1 Use stage water consumption	m^3/yr of water per occupant
4. Healthy and comfortable spaces	4.1 Indoor air quality	Parameters for ventilation, CO_2 and humidity
	4.2 Time outside of thermal comfort range	% of the time out of range during the heating and cooling seasons
	4.3 Lighting and visual comfort	Level 1 checklist
	4.4 Acoustics and protection against noise	Level 1 checklist
5. Adaptation and resilience to climate change	5.1 Protection of occupier health and thermal comfort	Projected % time out of range in the years 2030 and 2050
	5.2 Increased risk of extreme weather events	Level 1 checklist (under development)
	5.3 Increased risk of flood events	Level 1 checklist (under development)
6. Optimised life cycle cost and value	6.1 Life cycle costs	Euros per m^2 per year (€/m^2/yr)
	6.2 Value creation and risk exposure	Level 1 checklist

- Indicator 1.2 – Global Warming Potential (GWP)
- Indicator 1.1 – Use-stage Energy Performance
- Indicator 2.1 – Bill of Quantities, Materials and Lifespan
- Indicator 2.4 – Design for Deconstruction (Circularity Score)
- Indicator 5.2 and 5.3 – Increased Risk of Extreme Weather and Flood Events

The logical structure and interdependencies of these indicators in the GEFION project are summarized in fig. 2. Methodological details are provided in the following sections.

3.2 Indicator 1.2 – Global Warming Potential (GWP)

This indicator quantifies the climate change impact of buildings in kg CO_2-eq per m^2 per year. It follows EN 15978 (Deutsches Institut für Normung 2012) and is calculated based on a Building Life Cycle Assessment (LCA) covering modules A–C. The GWP calculation is based on component quantities exported from the digital building model, further detailed in sec. 4.3.

Indicator 1.2 requires scenario-based reporting to demonstrate the influence of design choices on embodied carbon. As such, the GEFION project includes a comparison between the final selected design option – the so-called "Actual Case Scenario" – (based on reuse and timber components) and a "Worst Case Scenario" that reflects plausible material substitutions with higher GWP. This approach illustrates the sensitivity of climate impact results to typical cost-driven or low-effort design alternatives. The definition and implementation of both scenarios are further detailed in sec. 4.4.

3.2.1 Life Cycle Assessment (LCA) methodology

The backbone of the GEFION sustainability assessment is a Building Life Cycle Assessment (LCA), performed in accordance with DIN EN 15643 (Deutsches Institut für Normung 2021) and DIN EN 15978 (Deutsches Institut für Normung 2012). The LCA model covers the full life cycle of the building, from cradle to grave, and incorporates all relevant life cycle modules A–C, while excluding Module D to avoid speculative future crediting.

The LCA stages include:

- **Production stage (A1–A3):** raw material extraction, transport and manufacturing;
- **Construction stage (A4–A5):** transport to site and installation;
- **Use stage (B1–B7):** use, maintenance, repair, replacement (B4), and energy use (B6);

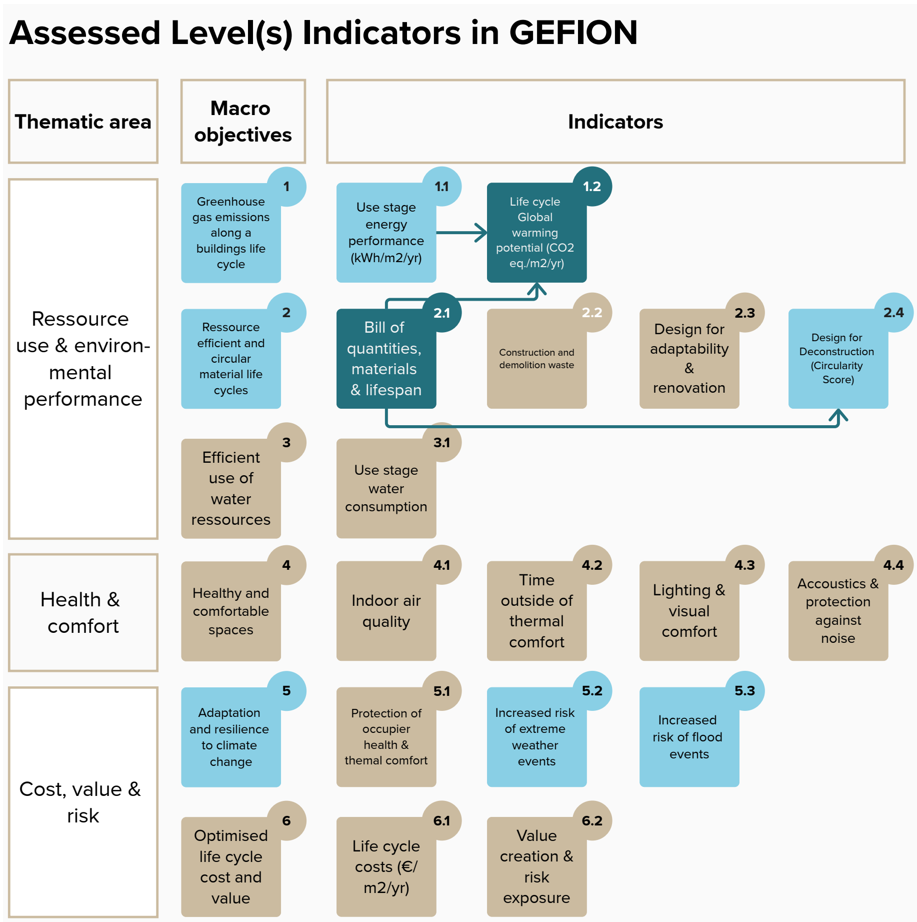


Figure 2: Logical structure of the selected Level(s) indicators in the GEFION project. The central indicators 1.2 (Global Warming Potential) and 2.1 (Bill of Quantity) are shown in dark turquoise. The additional indicators used in GEFION are shown in light blue. Not used indicators of the Level(s) framework are shown in brown.

- **End-of-life stage (C1–C4):** deconstruction, waste processing and disposal.

Although Module D (benefits beyond the building life cycle) may be considered in Level(s), it was not included in the GWP calculation for this project. The decision follows a conservative interpretation of the cut-off approach (International Organization for Standardization 2006a) and avoids assigning speculative benefits to future use cycles.

The life cycle assessment (LCA) was calculated directly by the project team instead of relying solely on commercial software. The main reason is that many tools operate with calculation methods that are not always transparent, which makes it difficult to trace underlying assumptions. While the use of standardized default datasets, such as those provided by ÖKOBAUDAT, is acceptable and even recommended, their integration into tool environments often lacks clarity. For this reason, a manual calculation process was implemented to ensure full methodological transparency and reproducibility of results (see sec. 4.3).

3.2.2 Data sources and EPDs

Environmental Product Declarations (EPDs) were the primary data source for the LCA. They were accessed primarily via the German ÖKOBAUDAT platform and supplemented by product-specific EPDs where needed. All data sources follow the EN 15804+A2 standard (Deutsches Institut für Normung 2019). Data was integrated into the model through a BoQ–BoM workflow (see sec. 4.3). Further it is important to note that GWP values disclosed in Environmental Product Declarations are modeled estimates. They often rely on generic inputs and modeled system processes, and therefore must be interpreted as carrying moderate to high levels of uncertainty. Moreover, when values from EPDs are aggregated, uncertainties accumulate. To further disaggregate such uncertainties, EPDs would need to disclose value ranges or confidence intervals, which they currently do not. While these values may lack precision, they can still serve as heuristics to guide decision-making.

3.2.3 Component lifetime and replacement (Module B4)

The modeling of material replacement in Module B4 followed a hierarchical approach to estimate component lifetimes:

1. If available, the component lifetime was taken from the Environmental Product Declaration (EPD).
2. If the component lifetime was not provided by EPD, it was taken from the official service life table provided within the German Assessment System for Sustainable Building (BNB), which is developed and maintained by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) on behalf of the Federal Government [2].
3. If the component life time was neither provided by EPD or BNB, it was taken from the Level(s) framework.
4. If none of the option was available, component lifetime were taken according to literature.

If replacement was needed within the 50-year timeframe, a full exchange was modeled at integer intervals. This means A and C impacts for the new component were added to the component LCA and reported in Module B as seperate Module B4.1 to allow tracability of this impact.

[2] The Service Life Table (BNB Nutzungsdauern von Bauteilen) is available at: https://www.nachhaltigesbauen.de/austausch/nutzungsdauern-von-bauteilen/

3.2.4 ReUse modeling

To reflect reused components without speculative crediting, Module D was excluded. Instead, a cut-off approach was applied following ISO 14040 and ISO 14044 (International Organization for Standardization 2006b & International Organization for Standardization 2006a). In this model, recycled or reused materials carried no production or disposal burdens according to the polluter-pays-principle (A1–A3, C1–C4), but included installation and use impacts only.

3.2.5 Hotspot analysis

To support interpretation of GWP results, a hotspot analysis was applied. The Level(s) framework proposes a structured procedure for identifying hotspots in the Global Warming Potential (GWP) of a building, as outlined in Indicator 1.2 (Dodd, Donatello, and Cordella 2021a). These hotspots refer to life cycle stages, processes, or products that together account for the majority of GWP impacts. The GEFION project followed this framework but adapted it to the use of product-level data from Environmental Product Declarations (EPDs), as provided through the German *ÖKOBAUDAT* and supplementary sources.

Hotspots were determined by cumulative contribution, identifying those elements that together cause 80 % or more of the total GWP. The process consisted of two complementary approaches:

1. **Stage-based hotspot analysis:** First, the most relevant life cycle modules were identified by ranking all modules (A1–C4 and B4) by their GWP contribution and adding them until 80 % of the total GWP was reached. Within these modules, contributing products were again ranked by their share of module-specific GWP and selected based on the same 80 % threshold. Module D was excluded from this analysis.

2. **Direct product-based hotspot analysis:** Independently, all products in the BoQ-based LCA were ranked by their total GWP contribution, regardless of life cycle module. Products were then included until the cumulative GWP reached 80 % of the overall building GWP.

This dual approach ensured consistency between component-level results and aggregated stage-level insights. All emissions were modeled for a 50-year building lifespan, including replacements (Module B4) according to the methodology described in sec. 3.2. Module D was not included in the hotspot analysis.

The hotspot analysis also served as a basis for assessing data quality of Environmental Product Declarations (EPDs) via the the Data Quality Index (DQI) by narrowing the focus to the most GWP-relevant materials.

3.2.6 Data Quality Index (DQI)

The Level(s) framework recommends the use of a Data Quality Index (DQI) to assess the reliability of datasets used in life cycle assessments. In the GEFION project, DQI scores were determined for each material or system based on Environmental Product Declarations (EPDs), primarily sourced from the German ÖKOBAUDAT database.

The DQI methodology evaluates each dataset along four quality dimensions:

- **Technological representativeness (TeR)** – How well the dataset reflects the actual product and its technical characteristics.
- **Geographical representativeness (GR)** – Relevance of the dataset for the specific regional context of the project.
- **Time-related representativeness (TiR)** – Age of the dataset relative to the reference year of the assessment.
- **Uncertainty (U)** – Completeness and transparency of the modeling, including assumptions and system boundaries.

Each aspect is rated on a scale from 0 (very poor) to 3 (very good), using the criteria defined in the Level(s) Indicator 1.2 manual. For reference, the full scoring table is shown in fig. 9.

The DQI for an individual dataset is calculated using:

$$\mathrm{DQI_{EPD}} = \frac{\mathrm{TeR} + \mathrm{GR} + \mathrm{TiR}}{3} + \frac{U}{2} \tag{1}$$

To obtain an overall score for the building assessment, the DQIs of all datasets are weighted by their contribution to the total GWP:

$$\mathrm{DQI_{weighted}} = \frac{\sum_i DQI_i \cdot GWP_i}{\sum_i GWP_i} \tag{2}$$

This approach allows data quality to be directly linked to the environmental significance of each component in the life cycle assessment.

3.3 Indicator 1.1 – Use-stage Energy Performance

Indicator 1.1 of the Level(s) framework assesses energy demand and energy consumption of a building to maintain thermal comfort, lighting, hot water, and ventilation. It is expressed in kilowatt hours per square meter per year (kWh/m^2/yr) and serves as an input for calculating life cycle global warming potential (Indicator 1.2 - GWP).

The framework allows for either calculated or measured data, depending on the assessment level (1–3), and recommends compatibility with national methodologies or with EN ISO 52000-1 (Dodd and Cordella 2021). Level(s) defines four main components for operational energy performance: space heating, space cooling, domestic hot water (DHW), and lighting. Optional contributions may include ventilation and auxiliary energy.

For this report, energy demand was calculated using thermal building simulation. The simulation was conducted using the open-source software *OpenStudio*[3] in combination with the *EnergyPlus* engine[4]. It followed German standards (DIN V 18599 Deutsches Institut für Normung 2018a) for regulatory compatibility and used material and geometry data exported from the BIM model[5].

Details on how energy demand was applied in the sustainability assessment are provided in sec. 4.5.

3.4 Indicator 2.1 – Bill of Quantities, Materials and Lifespans

Indicator 2.1 of the Level(s) framework requires a systematic overview of the materials used in a building, expressed in terms of quantities and material characteristics (see Donatello, Dodd, and Cordella 2021). It forms the basis for assessing resource use and embodied impacts in later indicators, particularly Indicator 1.2 (Global Warming Potential) and Indicator 2.4 (Design for Deconstruction).

The indicator is applicable across all Level(s) stages. At Level 1, it is used as a qualitative design tool to identify opportunities for reuse and material reduction. At Level 2, it requires a quantitative inventory including material type, volume, weight, and estimated service life. At Level 3, it is updated and validated using as-built documentation.

Furthermore the BoQ is structured into tiers, which provide a hierarchical breakdown of building components. Tier 1 represents the overall building level, Tier 2 groups the main building systems (e.g. foundations, structural frame, roof, façades), and Tier 3 specifies individual elements and materials within these systems. This tiered structure ensures consistency and comparability across different projects.

In the GEFION assessment, Indicator 2.1 was applied at Level 2. A comprehensive Bill of Quantities (BoQ) was compiled to represent all building components relevant for life cycle analysis. The BoQ served as the central reference for material data and was used as the input for mapping Environmental Product Declarations (EPDs) to each construction element.

3.5 Indicator 2.4 – Design for Deconstruction (Circularity Score)

Indicator 2.4 from the Level(s) framework assesses the design-related potential for future reuse, recycling or recovery of building components. It evaluates how well components can be disassembled, separated, and reintegrated into future value chains. The indicator is applied at Level(s) 2 and does not require real

[3] `https://www.openstudio.net`

[4] `https://energyplus.net`

[5] Building Information Modeling (BIM) refers to the digital representation of physical and functional characteristics of a building. It serves as a shared knowledge resource for information throughout the life cycle of a built asset.

performance or end-of-life data. Instead, it is based on design characteristics, material properties, and construction methods.

The evaluation follows a structured decision tree that defines the best practical outcome for each assessed building component. This outcome is derived through a sequence of questions:

- Can the component be removed without damage?
- Are the fixings reversible and non-destructive?
- Are there hazardous substances present that would inhibit reuse?
- Is technical and economic reuse or recycling viable?
- Are appropriate end-of-life pathways available or in development?

Each component is assessed independently using this logic. The result is the best practically achievable outcome for that element at its future end-of-life, assuming careful deconstruction. Actual demolition practice is not considered; the focus lies on what the design enables in principle.

The outcome is then mapped to a circularity score between 0.00 and 1.00. The scoring matrix defined in the Level(s) manual (Dodd, Donatello, and Cordella 2021a) links qualitative outcomes to numerical values as follows:

- 1.00 – Direct reuse without reprocessing
- 0.90 – Preparation for reuse
- 0.60 – Recycling into similar-value product
- 0.30 – Downcycling (low-value recycling)
- 0.20 – Incineration with energy recovery
- 0.10 – Incineration without energy recovery
- 0.00 – Landfill or uncontrolled disposal

The final building-level score is reported as a weighted average across all assessed components. A value of 1.00 would indicate that 100 % of the assessed components are designed for direct reuse without the need for processing.

3.6 Indicators 5.2 and 5.3 – Increased Risk of Extreme Weather and Flood Events

Indicators 5.2 Increased risk of extreme weather events and 5.3 Increased risk of flood events are defined in the Level(s) framework as Level 1 checklist indicators. Their purpose is to raise awareness of location-specific natural hazards in the early design phase and to support strategic resilience planning.

Both indicators are based on qualitative screening rather than quantitative modelling. According to the Level(s) manual, no performance data or monitoring is required. Risk assessment may be based on regional hazard maps, public databases, expert judgement, or external tools.

The indicators cover a broad range of climate-related risks, including storm, hail, heatwaves, heavy precipitation, wildfire, and flooding. Level(s) recommends assessing both the expected hazard level and the associated uncertainty.

In the GEFION assessment, these indicators were evaluated using the GIS-ImmoRisk tool[6]. The tool provides georeferenced site-specific risk classifications across multiple hazard types and supports qualitative Level 1 risk screening in accordance with Indicators 5.2 and 5.3.

3.7 GEFION Sustainability Assessment Process

While the sustainability analysis in the GEFION project is formally based on the EU Level(s) framework, we developed a tailored process to guide its application in practice. Rather than treating the Level(s) stages 1 to 3 as sequential reporting blocks, we embedded them into a structured three-phase approach: Preparation, Optimization, and Comparison and are described in the following sections.

In the Preparation phase, we used Level(s) stages 0 and 1 to define project-specific priorities, select indicators, and clarify the analytical scope—while already anticipating later steps in Level(s) 2 and 3. The Optimization phase corresponds to a full application of Level(s) 2 and includes the development of LCA models, the creation of scenarios, and the refinement of the core indicators such as GWP and Circularity Score. Finally, the Comparison phase integrates both Level(s) 2 and Level(s) 3 elements, aiming to verify and update the initial results based on as-built data and measured operational values. Unfortunately the results of this Phase were not yet available at the time of this report.

This integrated structure allowed the GEFION team to use the Level(s) framework not only as a compliance tool but as a flexible methodological backbone for sustainability-driven design and validation.

4 Results

In order to evaluate, calculate, and optimize sustainability performance in line with the Level(s) framework, the GEFION project established a two-stage analytical process consisting of a Preparation Phase and an Optimization Phase. This structured approach was developed to support efficiency in the analysis

[6] GIS-ImmoRisk: Climate Impact and Environmental Risk Tool, developed by BBSR (BBR) with BMWi, project execution by IIÖ – Institute for Real Estate Economics GmbH in cooperation with LFRZ GmbH. Online available via `https://www.gisimmorisknaturgefahren.de/`, accessed 28th of May 2025.

process by evaluating in advance indicator calculation effort, data availability, technical realization, etc. and ultimately meet the reporting requirements for Level(s) 2, particularly regarding Indicator 1.2 (Global Warming Potential), Indicator 1.1 (Use Stage Energy), and others.

The two phases are detailed in sections 4.1 and 4.2. Section 4.3 explains the digital data infrastructure required to enable this workflow, including the transition from BIM to LCA.

A third phase, intended to compare design expectations against actual building performance (as defined under Level(s) 3), was initially foreseen but could not be implemented for this report due to the lack of in-use data and commissioning documentation.

The subsequent sections present the results for each selected Level(s) 2 indicator, along with reflections on their implications for design performance, material strategies, and climate risk resilience.

4.1 GEFION - Level(s) Preparation Phase

In order to enable an efficient sustainability assessment in GEFION—balancing meaningful results regarding ReUse, timber construction, and overall sustainability with feasibility in a multi-stakeholder context with limited resources—we conducted an upfront scoping analysis. This step, referred to as the *Preparation Phase*, defined the analytical scope, selected indicators, and assessed data and technical constraints within the Level(s) framework.

Tab. 2 summarizes the four steps in this process and how they align with the Level(s) structure. While the same logic could support Level(s) 3 assessments, such aspects are not included in this report.

The first step involved pre-selecting a main indicator aligned with GEFION's sustainability goals. Indicator 1.2 (Global Warming Potential) was chosen as it reflects both the ReUse strategy and the carbon storage potential of timber construction. This selection was made by the team responsible for life cycle assessment and sustainability analysis.

In a second step, the focus was aligned with other stakeholders using the Level(s) 1 report format. The checklist for Indicator 1.2 served to refine the scope and was discussed jointly. The finalized Level(s) 1 report is shown in tab. 3. Stakeholders ultimately prioritized optimized material utilization, extended service life, and design for deconstruction to strengthen the ReUse focus. An initial interest in optimizing the NZEB[7] design was also expressed, which we address below.

The third and fourth steps established the analytical setup for Indicator 1.2. This included identifying the necessary secondary indicators—Indicator 2.1 (Bill of Quantities, Materials and Lifespan) and Indicator 1.1 (Use stage energy performance)—and evaluating the required methodology and data availability. This process revealed several important constraints:

[7] Nearly Zero Energy Building

1. Indicator 1.1 would be available only late in the process, as the responsible team first needed to select and test the simulation software. As a result, the originally planned NZEB focus was deprioritized.

2. Furthermore, use-stage energy demand was expected to be fully met by the building's photovoltaic system. Consequently, the GWP contribution from electricity use would be zero.

3. The GEFION GWP assessment therefore focuses on embodied emissions from the production phase and deconstruction.

4. As there is no standardized methodology for quantifying ReUse in LCA, Indicator 2.4 (Design for Deconstruction / Circularity Score) was added as an independent and complementary metric.

5. No standardised or transparent process was available to extract quantity data directly from planning models. Moreover, many LCA tools lacked transparency regarding how data is handled. Therefore, we chose to calculate GWP via EPD data manually using a project-specific workflow (see sec. 4.3) and relied primarily on data from open sources such as ÖKOBAUDAT.

In summary, the Preparation Phase redefined the scope of the GEFION Level(s) assessment. Energy optimization was retained in a simplified form (see sec. 4.5), the Circularity Score from Indicator 2.4 was added, and a tailored GWP workflow was developed.

4.2 GEFION - Level(s) Optimization Phase

Based on the findings of the Preparation Phase (see sec. 4.1), the refined sustainability scope for GEFION is summarized in tab. 3. The table follows the Level(s) 1 reporting structure for Indicator 1.2 (Global Warming Potential) and documents the design intentions regarding key life cycle considerations. It shows that the project emphasized circular material strategies and long service life, while aspects such as building adaptability or NZEB construction were deprioritized due to methodological and data constraints.

Fig. 3 illustrates the GEFION Optimization Process during the planning stage. The process is structured around two interconnected strands: (1) the life cycle assessment (LCA) path for Indicator 1.2, and (2) the analysis of supporting indicators, namely Indicator 2.4 (Circularity Score) and Indicator 1.1 (Use Stage Energy Performance). The structure reflects the project's ambition to evaluate and improve the building design prior to construction, in alignment with the Level(s) 2 reporting logic.

The optimization process was built on the following elements:

- Indicator 1.2 (Global Warming Potential) was confirmed as the leading metric to guide design decisions.

GEFION Process Step	Description	Level(s) Stage
Pre-Select Indicator	Select the primary Level(s) indicator and ensure compatibility with project sustainability goals. For GEFION we choose Indicator 1.2 Global Warming Potential (GWP).	-
Align Stakeholder Expectations	Stakeholder workshop to define project-specific sustainability priorities using the Level 1 reporting format for Indicator 1.2 GWP.	1
Prepare Indicator Analysis	Identify which secondary indicators are mandatory for the main indicator. Review methodology, technical requirements and assess data availability.	2
Detailed analysis on technical, methodical and data requirements	Evaluate required infrastructure (e.g., software, EPD data, data formats) and applicable methodologies. Adjust the scope if necessary to ensure an efficient analysis process.	2

Table 2: GEFION Preparation Phase

- For its calculation, a detailed Bill of Quantities (Indicator 2.1) was created and extended to a Bill of Materials by mapping materials to Environmental Product Declarations (EPDs).
- The resulting dataset was used to calculate a complete life cycle assessment (LCA), covering phases A to C. Phase D was excluded from reporting in accordance with the rationale explained in sec. 3.2.1.
- Indicator 1.1 was used to support design scenarios comparing insulation and energy system configurations (see sec. 4.5).
- Indicator 2.4 was calculated in parallel to evaluate reuse potential and disassembly capability of assemblies (see sec. 4.7).
- Both analysis strands were iteratively applied to improve overall GWP performance and compare alternative design options.
- Once the scenario analysis was complete, the final material and system configuration was fixed. This "design freeze" served as the basis for all Indicator 1.2 and Level(s) 2 reporting.

This structure ensured that the GEFION optimization phase remained consistent with the Level(s) 2 framework while addressing project-specific sustainability priorities.

No.	Life cycle design description	Addressed?	How has it been incorporated into the building design concept?
1	Efficient building shape and form	No	
2	Optimised NZEB (Nearly Zero-Energy Building) construction	No	
3	Optimised material utilisation and circular value	Yes	Focus on re-useable and nature-based materials, e.g. timber and mycelium.
4	Extending building and component service life	Yes	Include lifespan of materials and components in the LCA (Indicator 1.2 GWP).
5	Design for adaptability	No	
6	Design for deconstruction	Yes	Plan to re-built the full building later or at minimum use the parts for another project. Add Indicator 2.4 Circularity Score to quantify deconstruction potential.

Table 3: Final Level(s) 1 assessment reflecting project-specific sustainability focus

4.3 Digital Workflow: From architectural design to Level(s) reporting

Based on the result from the Preparation Phase (see sec. 4.1) to perform our own LCA calculation, we developed an integrated digital workflow that connects the architectural model to the LCA, energy simulation and sustainability reporting. This process is visualized in fig. 4) and consists of four main stages: Architecture, Digital LCA, Reporting, and Certification.

First, the Building Information Model (BIM), e.g. using Autodesk Revit, is created by the architects. The architectural model includes component-level geometry and material data, classified according to DIN 276 (Deutsches Institut für Normung 2018b) cost groups. This classification system enables the mapping of each building element to the corresponding indicators and tiers of the Level(s) framework. Additional project information—such as location, building usage, and technical systems—is also collected to support downstream simulation and reporting.

In a second step, from the BIM, three data exports are generated:

1. A BIM schedule, used for material take-offs. It is used to link the materials/components used in the architectural design with EPDs and lifespans. It is also used as basis for the weight calculation of the project.

2. An IFC export[8] is created for detailed quantity data (volume, area, units).

[8]An IFC export is a standardized data export based on the Industry Foundation Classes (IFC)

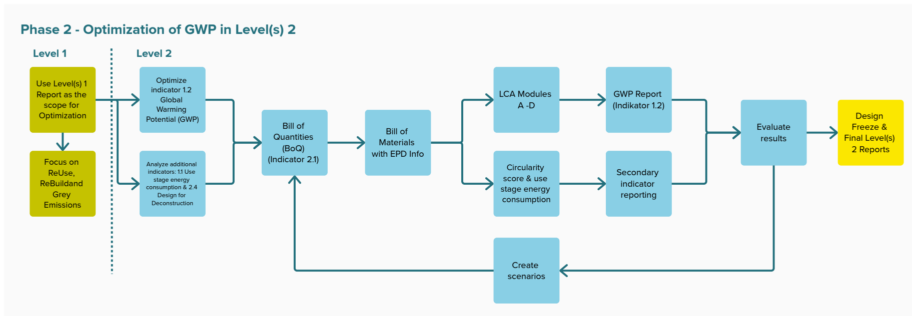


Figure 3: GEFION Optimization Process for the planning phase. The process includes the calculation of Indicator 1.2 (Global Warming Potential) based on full LCA analysis, as well as the calculation of secondary indicators such as the Circularity Score (Indicator 2.4) and Use Stage Energy Consumption (Indicator 1.1). The Circularity Score reflects the stakeholder decision to focus on ReUse strategies. Indicator 1.1 (Use Stage Energy Consumption) also supports scenario analysis. For a detailed explanation of each step, see main text.

3. A gbXML file[9], used to transfer the building geometry and thermal properties to the energy simulation model.

In the third step, the BIM Material Take-off and the IFC are further processed in Power BI linking Material with Environmental Product Declarations (EPDs)—initially generic, then updated to product-specific—sourced from Ökobaudat (Federal Ministry for Housing, Urban Development and Building 2024) and other verified databases. The EPD data is stored in a central database, maintained by the project team and WoodenValley.

Finally within Power BI, the quantities and material properties are aggregated to generate the Bill of Quantities (BoQ) as required by Indicator 2.1. This in turn serves as an input for the following calculations:

- Global Warming Potential (1.2) via product-based LCA,
- Use Stage Energy Performance (1.1) via simulation results,
- Design for Deconstruction & Circularity Score (2.4) using material and assembly-level metadata.

A core feature of this setup is the Power BI interface, which serves as a user-friendly reporting tool. It visualizes indicators, supports hotspot analysis and comparisons, and enables intuitive filtering and result exploration by users without LCA expertise. The dashboard is designed to be easily transferable to

format, used to enable interoperability between different BIM software by sharing detailed building models and information.

[9]A gbXML file is a standardized XML-based format used to exchange building geometry and performance data between BIM software and energy or sustainability analysis tools.

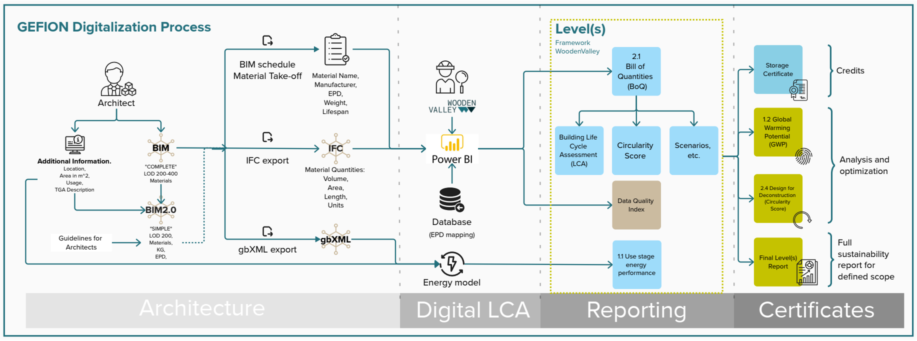


Figure 4: GEFION Digital Workflow: Schematic overview of the digital workflow developed in the GEFION project. The process connects architectural modeling (left) with life cycle assessment, energy simulation, and Level(s) indicator reporting (center), culminating in certification outputs (right). Central to the process is a structured flow of data—from BIM exports to EPD integration—combined with automated aggregation in Power BI and result archiving in the Digital Building File.

other projects, and has already been successfully applied in multiple use cases beyond GEFION.

All results are compiled in the final Level(s) report, including scenarios, the Data Quality Index (DQI).

Through out the Digital Workflow all relevant data are systematically archived in a Digital Building File, which functions as a traceable, versioned repository. It ensures that all inputs and results can be reconstructed transparently—both during and after the project lifecycle.

4.4 Indicator – 1.2 Global Warming Potential

In this section, we report on the final Global Warming Potential (GWP) results for the GEFION project as required under Level(s) Indicator 1.2. Following the methodology described in Section 3, reporting at Level(s) 2 includes not only the final GWP for the actual design but also a Worst Case Scenario for comparison as well as hotspot and data quality index analysis.

4.4.1 Final Level(s) 2 Report: Detailed Design and Construction

In line with Level(s) 2 requirements, tab. 4 follows the official Level(s) 2 reporting format for Indicator 1.2. It provides a structured breakdown of GWP across three emission categories—fossil, biogenic, and land use change (LULUC)—and disaggregates values by life cycle stages (A–C), consistent with EN 15978.

The table distinguishes:

- GWP–fossil: Emissions from fossil sources such as fuel combustion or petrochemical-based materials.

- GWP–biogenic: Emissions and removals related to biogenic carbon, in our case from the timber-based products.
- GWP–GHGs: Aggregates emission from GWP-fossil and GWP-biogenic.
- GWP–luluc: Emissions due to land use and land use change (e.g., deforestation, soil disturbance).
- GWP–Overall: adds land use emissions to GWP-GHGs.

Each column represents one of the LCA stages:

- A1–A3: Production stage (raw material supply, transport, manufacturing)
- A4–A5: Construction stage (transport to site, installation)
- B1–B7: Use stage without B4
- B4: Replacements (Separately shown for transparancy reasons, see sec. 3.2)
- C1–C4: End-of-life stage (deconstruction, disposal)
- Row total per category: Sum of all modules A-C per category.

Values without brackets refer to the GWP values for the final Level 2 Design and Construction scenario (the so-called Actual Case). The bracketed values indicate the Worst Case Scenario as required by Levels(s) in Phase 2 GWP (see sec. 3.2) and will be explained in the next section.

Highlighted in grey, the table presents two key results: the overall GWP of 1611 kg CO_2eq/m^2 and significant contribution from the GWP-fossil in Module B of 880 kg CO_2eq/m^2 caused by replacement. The more than twofold increase of the overall GWP by B4 Module illustrates the critical role of B4 and future decisions in life cycle modeling. This issue is further examined in sec. 4.4.3.

The second largest contribution to GWP-fossil after B4 is driven primarily by emissions in A1–A3 and accounts to 660 kg CO_2eq/m^2 . This value is significantly higher than typical benchmarks. For example, a benchmark study from DGNB[10] in 2021 proposed a limit of 365 kg CO_2eq/m^2 for new building for upfront emissions in modules A1-A3 excluding biogenic carbon (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen e. V. 2021). This discrepancy is largely attributable to the small useful floor area of only 28.2 m^2. The second floor of the GEFION building, initially planned for technical equipment, was excluded from the usable area, as it is unheated, lacks windows, and is only accessible by ladder. If this space (approx. 30 m^2) were included, the GWP-fossil in Phase A1-A3 would fall to roughly 330 kg CO_2eq/m^2 —well within the DGNB benchmark. This highlights the value of early-stage GWP assessment to identify optimization potential in both functional area definitions and design choices.

[10] Deutsche Gesellschaft für Nachhaltiges Bauen.

Table 4: Level(s) 2 GWP breakdown by life cycle stage and emission type (Actual Case, values in brackets: Worst Case). The GWP values are shown in kg CO_2eq/m^2 based on a 50 years period as required in Level(s).

GWP category	A1–A3	A4–A5	B1–B7	B4	C1–C4	Total
(1) GWP - fossil	660	1	36	880	43	1620
	(1156)	(15)	(36)	(880)	(236)	(2323)
(2) GWP - biogenic	-778	0	0	0	768	-10
	(-515)	(17)	(0)	(0)	(502)	(2327)
GWP - GHGs (1) + (2)	-118	1	36	880	801	1610
	(641)	(32)	(36)	(880)	(738)	(1447)
(3) GWP - land use and land use change (luluc)	1	0	0	0	0	1
GWP - Overall (1) + (2) + (3)	-117	1	36	880	801	1611
	(642)	(32)	(36)	(880)	(738)	(2328)

Despite the high GWP-fossil, the GWP-Overall of phase A1–A3 yields a remarkable result: a negative GWP–Overall of –117 kg CO_2eq/m^2 . This reflects the net carbon storage effect of timber used in the structure, which outweighs fossil and land-use emissions during production. Such negative values are rare and indicate the potential of long-term carbon sequestration in timber-based construction. Under EN 15978, however, this benefit is reversed in end-of-life modeling (C1–C4), where stored carbon is assumed to be released. As a result, the biogenic GWP contribution over the life cycle of timber products trends toward zero. Nevertheless, the production-stage result underscores the mitigation potential of renewable building materials when responsibly sourced and applied.

4.4.2 Worst Case Scenario

Level(s) 2 requires the development of a Worst Case Scenario to evaluate the impact of less sustainable material choices (see sec. 3.2). The GEFION Worst Case is not a hypothetical extreme, but a plausible material variant based on standard construction practice. It reflects minor substitutions of three components with commonly used, cost-efficient alternatives: wood fibre insulation was replaced with mineral wool, untreated exterior timber cladding with polycarbonate panels, and solid wood interior cladding with oriented strand boards (OSB)[11].

These functionally equivalent but carbon-intensive substitutions lead to a sharp increase in fossil GWP emissions, especially in the production (A1–A3) and end-of-life (C1–C4) phases. As shown in tab. 4, GWP-Overall in the Worst Case reaches 2328 kg CO_2eq/m^2 , increasing the Actual Case result of 1611 kg CO_2eq/m^2 presented in the previous section by 717 kg CO_2eq/m^2 .

[11]OSB (Oriented Strand Board) is an engineered wood panel made from compressed wood strands bonded with synthetic resins. It is widely used in standard construction but typically has higher embodied emissions than solid timber.

This outcome underscores the potential of early design-stage analysis: with only three material decisions, about 30 % of embodied carbon could be avoided. The Worst Case thus serves not only as a reporting requirement, but also as a design tool to identify high-impact choices and inform more sustainable planning.

4.4.3 Hotspot analysis

The hotspot analysis identified the most emission-intensive stages and components of the GEFION building, based on the methodology described in sec. 3.2. All GWP contributions were calculated using BoQ-based life cycle modeling for a 50-year building lifespan, including replacements (Module B4).

To determine hotspots, contributions were ranked cumulatively until 80 % of the total GWP was reached. The total GWP of the Actual Case including replacements is 1611 kg CO_2eq/m^2 . Applying the 80 % threshold yields a cutoff of 1289 kg CO_2eq/m^2 .

Module based Hotspots The stage-based analysis revealed that the largest share of emissions occurs in Module B4, which accounts for 880 kg CO_2eq/m^2 — 54,6 % of the total. Another major contributor is the end-of-life biogenic emissions from Module C1–C4, with 768 kg CO_2eq/m^2 (47,7 %).

Within Module B4, 98,3 % (805 kg CO_2eq/m^2) of emissions stem from the replacement of the photovoltaic system. Including the battery for storing the generated system which accounts for 6,8 % (60 kg CO_2eq/m^2), the electricity system accounts for almost all the emission in B4 (For details see in appendix fig. 10) The high value results from the relatively short assumed service life and the system's substantial material footprint and highlights the effect of B4 and why it is so important to include. In Module C1–C4, biogenic emissions were primarily caused by the end-of-life release of carbon from spruce wood products used in the structure. In appendix fig. 11 it is shown, more than 80 % of these emissions stem from three products: sawn timber spruce (Schnittholz Fichte), structural solid timber (Konstruktionsvollholz), and flexible wood fibre insulation mat (Holzfaserdämmstoff flexible Matte).

Hence, avoiding end-of-life GHGs by extending the products lifetime will be essential in the future to avoid emissions.

Product-Based Hotspots The direct product-level analysis confirms and sharpens the result:

- The photovoltaic system contributes 805 kg CO_2eq/m^2 , representing 93.7 % of the top 80 % of product-based emissions.
- The battery system adds another 60 kg CO_2eq/m^2 (9.4 %), though its share is based on a generic EPD and may be overestimated or at least with a high uncertainty.

Together, these two components surpass the 80 % threshold by a wide margin. All other products contribute only minor shares in comparison.

Reflections While the building was designed to operate with near-zero operational emissions, the trade-off lies in the material impacts of enabling that functionality. The photovoltaic system and battery eliminate emissions during the use stage (Module B6), but dominate the cradle-to-grave footprint. This highlights the importance of full life cycle assessment when evaluating renewable energy systems.

The hotspot analysis also shows that reuse strategies in GEFION, while helpful for structural timber, did not address the primary emission drivers. A PV system with a longer life or reduced size would have significantly lowered the replacement-related impacts.

4.4.4 Data Quality Index (DQI)

The overall DQI score for the GWP result is 2.95[12], indicating high reliability of the underlying datasets for the dominant contributors. This score was calculated using the weighted average method defined in Eq. (2).

The two most emission-intensive components—photovoltaic system and battery—together account for over 90 % of total GWP and were therefore selected for individual DQI assessment. Both were evaluated using the scoring approach described in Eq. (1).

The photovoltaic system was modeled with a product-specific EPD from the ÖKOBAUDAT database. The dataset scored uniformly 3 in all three representativeness categories and for uncertainty, leading to a DQI of 3.0 according to Eq. (1).

The battery system was modeled using a generic European dataset. It scored uniformly 2 across all dimensions, leading to a DQI of 2.5 by the same method.

Weighting both scores by their respective GWP contributions, 1208 kg CO_2eq/m^2 for PV and 121 kg CO_2eq/m^2 for the battery, results in:

$$\text{DQI}_{\text{weighted}} = \frac{(3.0 \cdot 1208) + (2.5 \cdot 121)}{1208 + 121} = 2.95 \tag{3}$$

This value exceeds the Level(s) threshold of 2.0 and confirms that the hotspot analysis is based on high-quality data. While other components had slightly lower DQI scores, their contribution to total GWP was minor and did not affect the weighted average significantly.

The DQI analysis supports the robustness of the GWP results and confirms the relevance of the PV system and battery as dominant emission sources.

[12] The DQI ranges from 0 (very poor) to 3 (very good), see sec. 3.2.6

4.4.5 Interpretation and reflections

The GWP–fossil (see tab. 4) of 660 kg CO_2eq/m^2 appears high in comparison with typical benchmarks—such as <365 kg CO_2eq/m^2 proposed by DGNB in 2021 (DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen e. V. 2021). At first glance, this result may seem unexpected given the project's commitment to sustainable design: a lightweight timber structure, widespread use of reused and circular materials, and near-zero operational energy. The building's baseline is strong—and yet the GWP intensity remains above the commonly cited benchmarks.

Two main factors explain this outcome. First, the reported GWP is calculated over a very small useful floor area of just 28.2 m^2. An additional 30 m^2 of technical space had to be excluded from the usable area due to inaccessibility, lack of heating, and absence of daylight—disqualifying it under the Level(s) framework. In retrospect, dedicating such a large proportion of the building to non-usable technical space must be considered a planning error, as it artificially inflates the GWP per square meter and reduces functional utility. If the full built area were considered, the GWP-fossil would drop to roughly 330 kg CO_2eq/m^2 —well below the DGNB benchmark.

Second, the photovoltaic system—while environmentally motivated—accounts for a major share of total GWP, especially in A1–A3 and B4. Although an calculation of the overall electricity needs to meet the heating demand was performed, it was originally only assessed on an annual basis. The preliminary simulation results conducted later, suggest a seasonal mismatch: in winter, the PV system does not fully meet heating demand, while in summer, most electricity cannot be used or stored.

In retrospect, three options could have significantly reduced the life cycle impact of the electricity demand: (1) a smaller PV surface, better aligned with daily and monthly heating demand, would have lowered material input and reduced overproduction; (2) reconsidering the off-grid strategy altogether: using grid electricity—depending on the regional mix—might have resulted in lower overall GWP than producing electricity on-site through oversized infrastructure. This trade-off between production emissions (A1–A3) and operational energy emissions (B6) was never assessed; (3) selecting a higher-quality system with extended service life would have reduced replacement cycles and their associated impacts in Module B4.

This case illustrates that even ambitious sustainability projects can be undermined by a small number of unresolved decisions. Scenario-based analysis in early design phases is not merely a regulatory formality—it is a strategic tool to ensure that renewable systems, material choices, and design intent are aligned.

4.5 Indicator 1.1 – Energy simulation and scenarios

Indicator 1.1 of the Level(s) framework covers the energy demand for space heating, space cooling, domestic hot water (DHW), and lighting (see sec. 3.3). In the GEFION assessment, only the space heating demand was considered,

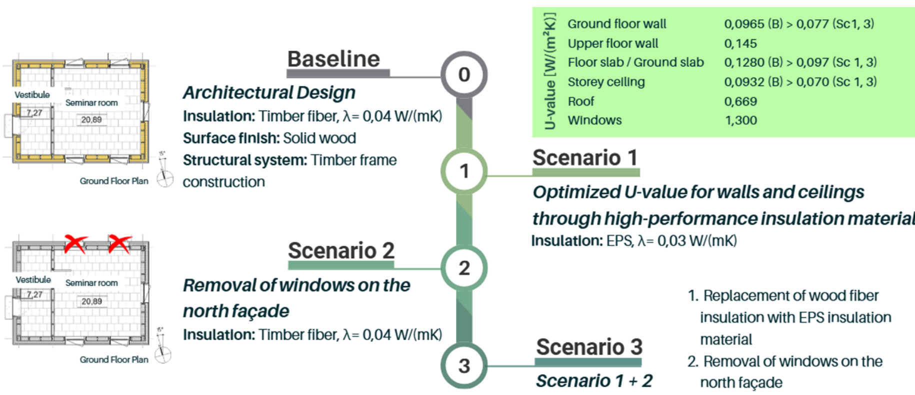


Figure 5: Scenario configurations (source: authors)

as the building does not include systems for cooling or DHW, and lighting was not assessed separately. The electricity demand corresponds directly to the operation of an infrared heating system, fully powered by the building's rooftop photovoltaic system (PV). As no grid electricity is used for heating, the operational energy demand does not contribute to the life cycle global warming potential (GWP) at Level(s) 2.

The thermal simulation was conducted using the open-source software *OpenStudio* in combination with the *EnergyPlus* engine, based on DIN V 18599 (Deutsches Institut für Normung 2018a). Material and geometry data were derived from the BIM model[13]. The simulation was used to compare different design scenarios and understand their implications for operational energy demand and embodied emissions.

Four scenarios were tested, including a base case (Scenario 0) and three design alternatives. Scenario 1 included EPS insulation, Scenario 2 reduced the north-facing window area, and Scenario 3 combined both measures. Figure 5 summarizes the scenario configurations.

The simulation results, shown in fig. 6, indicate that Scenario 2 achieved a 25 % reduction in heating energy demand with a slight improvement in embodied emissions. Scenario 3 achieved the highest energy savings (-27 %) but caused significantly higher embodied emissions due to the use of synthetic insulation. Scenario 1 yielded only a small energy reduction (-2 %) and considerably increased embodied impacts.

Based on the trade-off between thermal performance and material-related GWP, Scenario 2 was selected for implementation. While operational energy is not included in the GWP due to the building's energy autonomy, the simulation was crucial for identifying the most balanced solution.

This highlights the importance of energy modeling even when operational

[13] Building Information Modeling (BIM) refers to the digital representation of physical and functional characteristics of a building. It serves as a shared knowledge resource for information throughout the life cycle of a built asset.

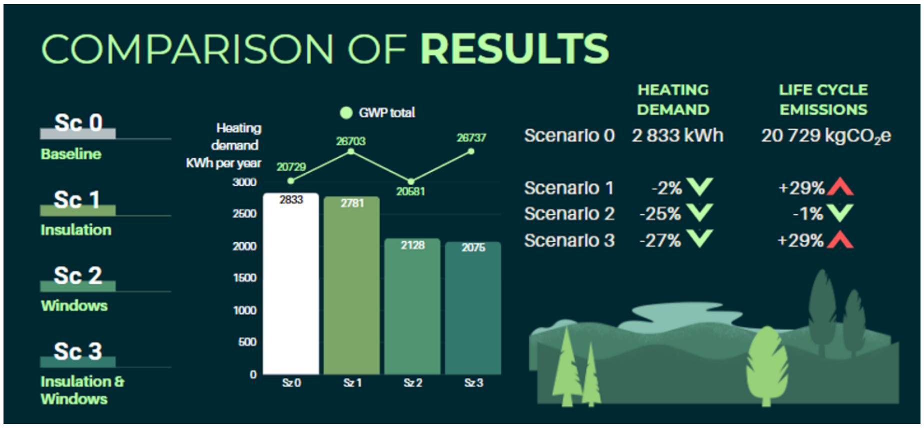


Figure 6: Comparison of heating demand and embodied GWP across scenarios

impacts are excluded from the climate balance. The combination of BIM-based simulation and life cycle assessment enabled early-stage optimization that aligned design decisions with material performance. Simulation thus remained a central component for evaluating scenarios, supporting the role of Indicator 1.1 as a guiding tool for performance-based design, even under GWP-neutral operating conditions.

4.6 Indicator 2.1 – Bill of Quantities, Materials and Lifespans

The Bill of Quantities (BoQ) compiled for the GEFION project provided the quantitative foundation for all material-based life cycle assessments. It includes all major components of the building with quantity specifications in terms of surface area, volume, and calculated weight. For each material entry, a matching Environmental Product Declaration (EPD) was assigned, forming the input for the subsequent Global Warming Potential (GWP) calculation and Circularity Score assessment.

An excerpt of the BoQ is included in the appendix and illustrates the structure used for both the Actual Case (fig. 12 & 13) and the Worst Case scenario (fig. 14 & 15). It shows the component group, quantity (area and/or weight), and the linked EPD. The appendix extract is limited to the sections relevant for GWP calculation. A full export of the digital BoQ is available upon request.

4.7 Indicator 2.4 – Design for Deconstruction (Circularity Score)

The Circularity Score methodology of Indicator 2.4 Design for Deconstruction introduced in sec. 3.5 was applied to all major components of the GEFION building. The following example illustrates how the decision logic translates into a practical component-level outcome.

The GEFION prototype uses a cast-in-place reinforced concrete foundation. While concrete is generally considered difficult to recover due to its monolithic nature, the specific detailing in this project allows for partial removal and reuse of the structural elements under controlled conditions.

According to the Level(s) Indicator 2.4 logic, the component meets several positive criteria: it can be removed without destruction, uses reversible connections, contains no hazardous substances, and could be technically reused with adequate preparation. A full reuse market is not yet established, but in the GEFION project, the concrete slabs used for the foundation were in fact sourced from a previous construction project—demonstrating that material circulation is already taking place on a small scale.

Based on these conditions, the best practical outcome was classified as "preparation for reuse," resulting in a Circularity Score of 0.90[14]. Full documentation of this and other scoring decisions is available in the Circularity Score Assessment Report in Appendix fig. 16 and 17.

The resulting overall circularity score for the GEFION prototype is 91.5 %, calculated as a mass-weighted average across all assessed components. This high score reflects the prioritisation of reversible, mono-material construction strategies and shows that clean detailing and conscious material choices can enable real reuse and recovery potential.

Figure 7 shows the distribution of material masses across the building's functional subsystems, referred to as Tier 2 elements in the Level(s) framework (see sec. 3.4). These include foundations, structural frame, upper floors, roof, internal partitions, and façade openings. The diagram groups materials by their assessed end-of-life outcome—from Reuse (direct) to Hazardous waste—based on the Level(s) scoring matrix.

- More than 80 percent of the building's material mass falls into the highest circularity categories: Reuse (direct) and Reuse (preparing for).
- These contributions stem primarily from mono-material timber components such as KVH (solid-sawn structural timber) and glulam (glued laminated timber), used in the load-bearing frame and floor structures.
- Lower circularity categories—including Recycling (mixed stream) and Recovery (energy)—are mostly assigned to membranes, vapour barriers, and adhesives.
- No components were classified as hazardous waste.

The high circularity score achieved in GEFION demonstrates that reuse-oriented design is feasible even in small-scale buildings. Through careful material selection, mono-material assemblies, and reversible detailing, the project shows how circular construction can be integrated into real-world architecture without compromising functionality or aesthetics.

[14] The Circularity Score ranges from 0 to 1 (0% to 100%) where 0 reflects the worse case "Landfill or uncontrolled disposal" and 1 the best case "Direct reuse without reprocessing. For the full scala see sec.3.5

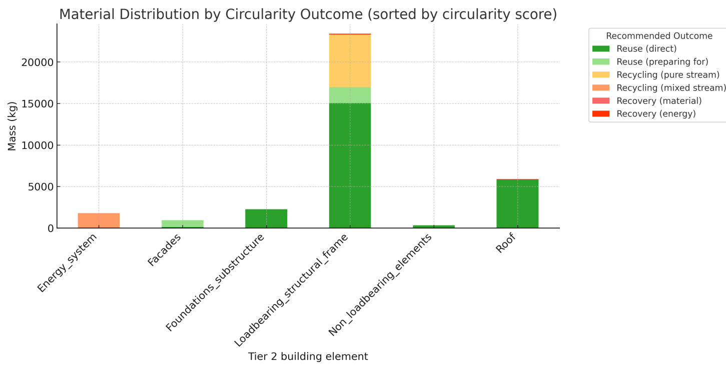


Figure 7: Material mass by recommended circularity outcome, grouped by Tier 2 building element. Bar segments are coloured from green (Reuse) to red (Hazardous waste) to reflect circularity potential.

4.8 Indicator 5.2 and 5.3 – Increased Risk of Extreme Weather and Flood Events

To assess climate-related exposure at the building site, the GIS-ImmoRisk (see sec. 3.6) was used. This georeferenced online tool supports property owners and planners in identifying natural hazard risks such as heat, hail, heavy rainfall, storm, wildfire, lightning, and earthquakes. For each hazard, it provides qualitative risk levels and uncertainties based on publicly available data.

As shown in fig. 8, the most relevant natural risks for the GEFION campus building include hail, lightning, and future heat extremes. These results correspond to the Level(s) Indicators 5.2 and 5.3, which recommend assessing such risks during the early design phase.

Due to the building's robust and well-insulated construction, the structural vulnerability to these hazards is considered low. The evaluation served primarily to support awareness and early design discussion, in line with the Level(s) intention for these qualitative indicators.

5 Discussion

The GEFION project set out to explore whether timber-based construction in combination with reuse strategies can achieve a favourable GWP footprint in accordance with Level(s) indicator 1.2, while also supporting long-term material circularity. The results show a nuanced picture. On the one hand, GEFION achieved an excellent circularity score, with over 80 % of material mass falling into the highest reuse categories. On the other hand, the GWP-fossil —despite careful material choices—remains significantly above common benchmarks such as the DGNB reference value of <365 kg CO_2eq/m^2 .

This contrast highlights that even in a reuse-oriented timber building, em-

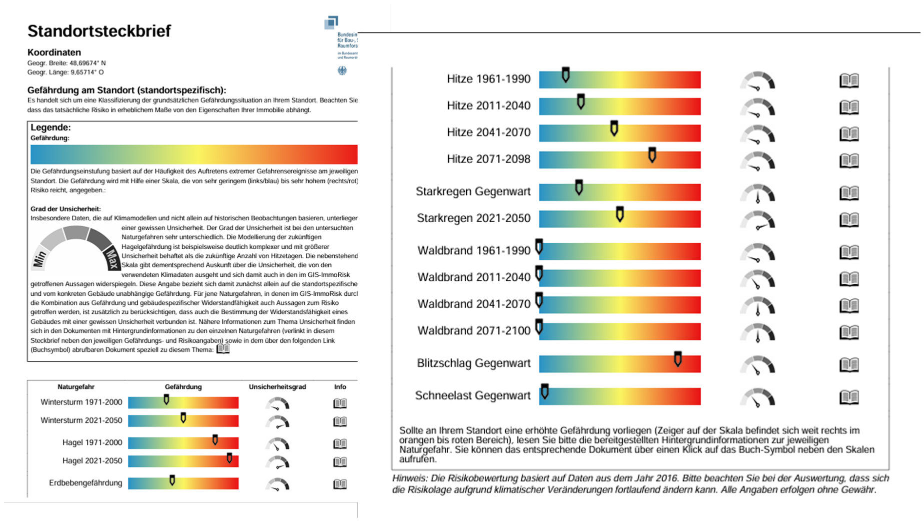


Figure 8: GIS-ImmoRisk profile for the GEFION building site, showing risk categories for multiple natural hazards. Source: Umweltbundesamt, accessed May 2025.

bodied carbon is often dominated by other factors. In GEFION, a major driver was the oversized PV system, which contributed the majority of GWP in both the production and replacement phases. Due to a lack of early-stage calculation and scenario comparison, the system was not challenged in terms of quality, dimensioning, or trade-offs with grid electricity. This outcome underlines the importance of comprehensive GWP assessments prior to construction. Reuse and renewable energy alone are not sufficient to guarantee low-carbon performance if critical design decisions remain unchecked.

To address this challenge, the project developed a two-phase approach: a Preparation Phase for indicator scoping and data infrastructure, and an Optimization Phase for scenario-based assessment and design decisions. These process layers enabled a systematic Level(s) 2 report even though many digital and procedural barriers remained unresolved. Most notably, the project suffered from delays in BoQ delivery, lack of transparency in architectural data models, and limited integration of sustainability data into planning tools. While a digital workflow was developed to enable GWP calculation via EPD data, it required substantial manual effort due to absent IFC standards and poor data quality in several domains—particularly technical building services.

These findings reflect structural issues that go beyond the GEFION case. LCA tools remain fragmented and deliver divergent results, often without disclosing underlying assumptions. Environmental Product Declarations (EPDs), while essential for Level(s), are not consistently available across all material groups—particularly for technical building systems—and often vary in quality, level of detail, and update cycles. Moreover, EPD data frequently lack harmonised reporting for critical parameters such as carbon content, density, or replacement cycles. As described in sec. 4.3, these limitations motivated the implementation of a transparent manual calculation process. At the same time, selected commercial tools were used for comparison, and results showed good consistency with the Madaster platform[15].

In addition, further research is needed to establish ways of dealing with uncertainty of values disclosed in EPDs. While LCA tools and software typically allow for sensitivity analysis and uncertainty quantification (Marsh, Allen, and Hattam 2023), low access and non-expert processes based on EPDs for quantification are in need of better workflows to accommodate uncertainties of their results.

BIM is not reliably equipped to support LCA workflows unless explicitly commissioned and carefully managed. In many projects, LCAs are still only conducted if mandated for certification; optimization in early design phases remains the exception. The widespread perception that life cycle modelling is costly and non-essential unless required leads to late integration and missed opportunities for carbon and energy reduction and hence cost saving.

This situation suggests that multistakeholder projects need more than methodological guidance—they require clear procedural responsibilities, transparent data standards, and alignment on design freezes and reporting timelines. The GEFION Preparation and Optimization Phases serve as a practical framework to address this need. Although the final Level(s) 3 monitoring phase could not be implemented within the timeframe, the project established the foundation for future data validation and iteration.

In this light, GEFION demonstrates that even under non-ideal conditions, Level(s) 2 can be implemented in a meaningful way. More importantly, it shows that ReUse and timber-based design are valuable strategies—but only if embedded in a robust, verifiable assessment logic. The GEFION workflow offers a replicable example for future projects aiming to turn sustainability ambitions into measurable outcomes.

6 Outlook

The GEFION project demonstrated that Level(s) can be applied in real-world design and construction processes, even under limited resources. Several opportunities emerge for improving both implementation and policy alignment in the coming years.

One immediate opportunity lies in improving digital integration. Manual mapping between design tools and sustainability software, particularly between architectural models and life cycle databases, remains a significant barrier. Embedding sustainability assessments directly into planning environments could accelerate both learning and practice.

A second improvement concerns the availability and consistency of Environmental Product Declarations (EPDs). Especially for technical building sys-

[15] `https://madaster.com`

tems, EPD data is often incomplete, inconsistent, or missing entirely. More robust datasets, harmonised service lives, and transparent modelling would strengthen LCA accuracy and comparability.

Digital integration and interoperability is another important enabler. In GEFION, a centralised Digital Building File was used to manage all models, simulations, and assessment results. This anticipates the upcoming Energy Performance of Buildings Directive (EPBD), which will require all new buildings over 1,000 m^2 to have a digital logbook from 2028 on and all new buildings from 2030 on (European Commission 2021). Such digital repositories are essential for traceability, transparency, and long-term reusability of sustainability data.

A particularly encouraging development is the introduction of regulatory GWP benchmarks in some European countries. Denmark and France have already implemented limit values for embodied emissions in new buildings (Construction 2024; Council 2024). These pioneering approaches demonstrate how policy can provide clear orientation for sustainable construction. Embedding such benchmarks into national implementation of Level(s) could significantly support its uptake.

Finally, GEFION shows that GWP alone may not fully capture the value of reversible and low-impact construction methods. For instance, the building's high share of reusable materials is not fully reflected in the GWP due to the dominance of other components, such as the photovoltaic system. Complementary indicators such as the Circularity Score make these strategies more visible and highlight their importance.

Looking forward, the integration of multiple indicators, combined with better digital workflows and data transparency, offers a promising path for future sustainability assessments. However, projects like GEFION also reveal current limitations: the absence of standardized data exchange between planning and assessment tools, incomplete product data, and planning processes that often lack early sustainability alignment. Addressing these gaps—through improved design coordination, earlier design freeze points, and more robust digital infrastructures—will be essential to realize the full potential of frameworks like Level(s) in practice.

7 Contributions

- Dr. Nadine Foerster: Method, GWP and Circularity Analysis, Overall Writing
- Hanna Fiegenbaum: Method, GWP Hotspot and DQI Analysis, Writing
- Vanessa Schindler: LCA Method, Risk Analysis, Writing
- Élida Marques Dreer: Heat Energy Scenario Analysis, Writing
- Natalia Andrea Valenzuela: Architectual Design, Heat Energy Scenario Analysis

- Kai Matzdorf: Technical Implementation EPDs and Power BI
- Lucas Alves Vinha: Technical Implementation Energy Simulation

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A Appendix

A.1 GEFION Building Description

Gebäude-
beschreibung
V2.0

von *„ Gefion_ReBuild_Szenario 2 "*

28.03.2025

1 Projekthintergrund

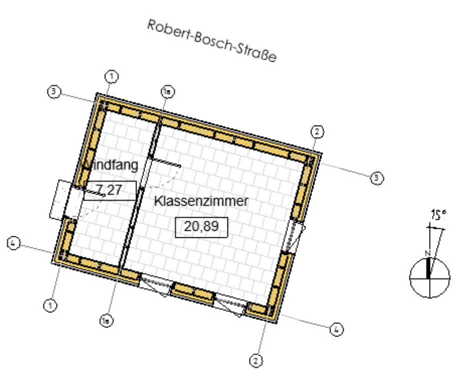
In diesem Dokument werden die in der digitalen Datei <ReBuild_250129_Sz2> modellierten Elemente und Materialien zusammengefasst und beschrieben. **Diese Beschreibung basiert auf dem ursprünglichen Modell <ReBuild_250129>, wobei die einzige Änderung darin besteht, dass die Fenster an der Südfassade entfernt wurden.**

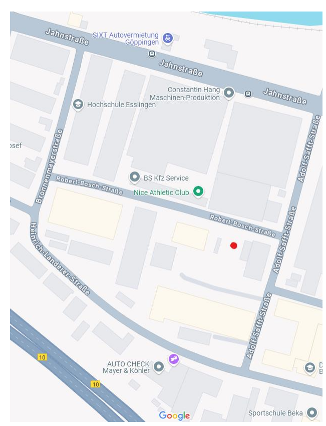
1.1 Standort

Addresse: Robert-Bosch-Straße 6
73037 Göppingen
Germany
Projekt Operator: Hochschule Esslingen
Projekt Anfangsdatum: Juli 2023 **Enddatum**: August 2025

Latitud: 48°41'48"N
Longitude: 9°39'25.64"E

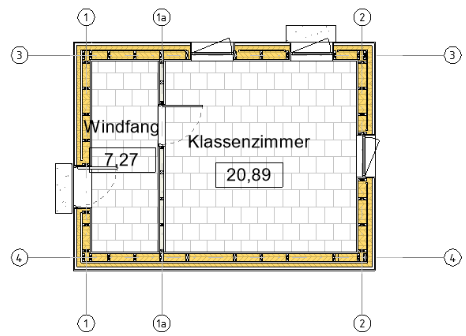
Lagerplan:

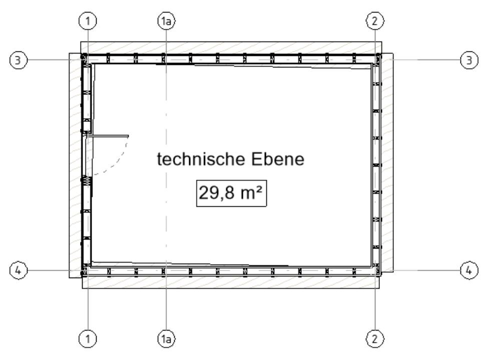




1.2 Area

Bruto Grundfläche (BGF)	**74.1m²**	
Netto Raumfläche (NRF)	57.9m²	
Nutzungsfläche (NUF)	20.9 m²	useful internal floor
Verkehrsfläche (VF)	7.3 m²	
Technikfläche (TF)	29.8m²	
Konstruktions-Grundfläche (KGF)	16.2m²	





Area Type	Level	Area
Gross Building Area	Level 0	39,3 m²
Gross Building Area	Level 1	34,8 m²
Bruto Grundfläche (BGF)		74,1 m²

1.3 Nutzung

Nutzung: Lehrnraum (Hochschule)

Nutzung Zeit: 5 mal in der Woche – 4 Stunden pro Tag
Nutzer: 8 Nutzer gleichzeitig

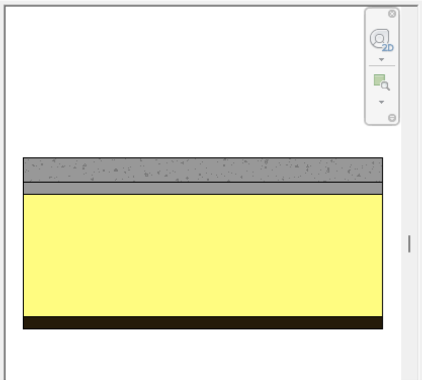
1.4 Räume

Raum	Number	Level	Beheizt	Area
Klassenzimmer	1	Level 0	Ja	20.9 m2
Windfang	2	Level 0	Nein	7.3 m2
Techniche Ebene	3	Level 1	Nein	29.9 m2
Netto Raumfläche (NRF)				57.9 m2

2 Gebäudehülle

2.1 Floor

Gefion Boden UG



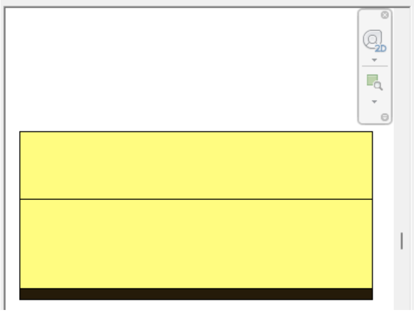
Family: Floor
Type: Gefion_Boden
Total thickness: 0,4200 (Default)
Resistance (R): 7,8107 (m²·K)/W
Thermal Mass: 224,23 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	Finish 1 [4]	Betonwerkstein	0,0600
2	Substrate [2]	Kies, Splitt/Bausch	0,0300
3	Membrane Layer	Dampfsperre	0,0000
4	**Core Boundary**	**Layers Above Wrap**	**0,0000**
5	Structure [1]	Holzfaserdämmsto	0,3000
6	**Core Boundary**	**Layers Below Wrap**	**0,0000**
7	Finish 2 [5]	Schnittholz Fichte	0,0300

Insert Duplicate Delete Up

Gefion Zwischendecke



Family: Floor
Type: Gefion_Zwischendecke
Total thickness: 0,4500 (Default)
Resistance (R): 10,7308 (m²·K)/W
Thermal Mass: 89,10 kJ/(m²·K)

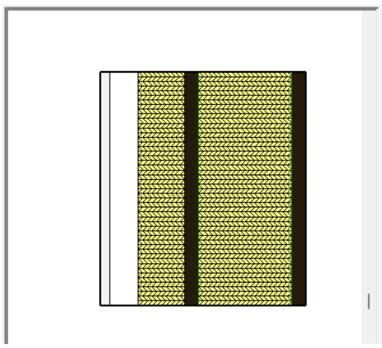
Layers

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0,0000**
2	Structure [1]	Holzfaserdämmstof	0,1800
3	Structure [1]	Holzfaserdämmstof	0,2400
4	**Core Boundary**	**Layers Below Wrap**	**0,0000**
5	Membrane Layer	Dampfsperre	0,0000
6	Finish 2 [5]	Schnittholz Fichte	0,0300

KG	Type	Thickness	Count	Level	Area	Heat Transfer Coefficient (U)	Thermal Resistance (R)
351	Gefion_Boden	42cm	1	EG	28.89	0.128	7.8107
351	Gefion_Zwischendecke	45cm	1	OG	29.77	0.0932	10.7308

2.2 Wall

Gefion Wand EG



Family: Basic Wall
Type: Gefion_Wand_EG
Total thickness: 44,00 cm (Default)
Resistance (R): 7,9615 (m²·K)/W
Thermal Mass: 22,12 kJ/(m²·K)

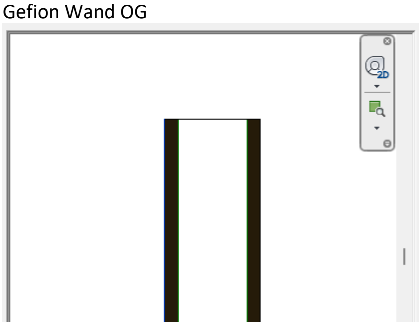
Layers

EXTERIOR SIDE

	Function	Material	Thickness
1	Finish 2 [5]	Boden-Deckel-Schalung	2,00 cm
2	Finish 1 [4]	Hinterlüftung	6,00 cm
3	Membrane Layer	Unterspannbahn	0,00 cm
4	Substrate [2]	Holzfaserdämmstoff	10,00 cm
5	Substrate [2]	Schnittholz Fichte	3,00 cm
6	**Core Boundary**	**Layers Above Wrap**	**0,00 cm**
7	Thermal/Air Layer [3]	Holzfaserdämmstoff	20,00 cm
8	Membrane Layer	Dampfsperre	0,00 cm
9	**Core Boundary**	**Layers Below Wrap**	**0,00 cm**
10	Finish 1 [4]	Schnittholz Fichte	3,00 cm

INTERIOR SIDE

Gefion Wand OG



Family: Basic Wall
Type: WALL_Holz struktu_Aussenwandverkleidung
Total thickness: 0,2210 (Default)
Resistance (R): 6,8661 (m²·K)/W
Thermal Mass: 4,95 kJ/(m²·K)

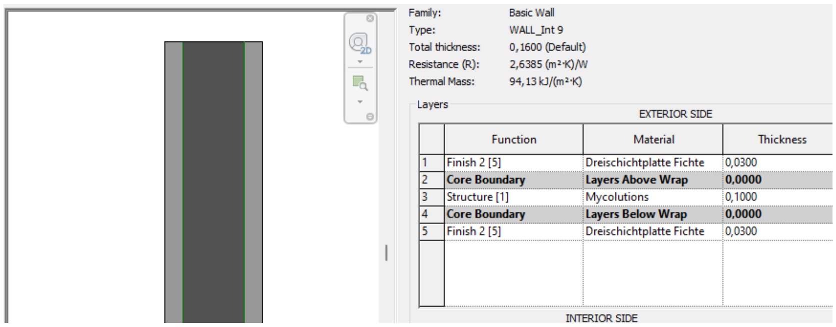
Layers

EXTERIOR SIDE

	Function	Material	Thickness
1	Finish 2 [5]	Dampfsperre	0,0010
2	Finish 2 [5]	Schnittholz Fichte	0,0300
3	**Core Boundary**	**Layers Above Wrap**	**0,0000**
4	Thermal/Air Layer [3]	Hinterlüftung	0,1600
5	**Core Boundary**	**Layers Below Wrap**	**0,0000**
6	Structure [1]	Schnittholz Fichte	0,0300

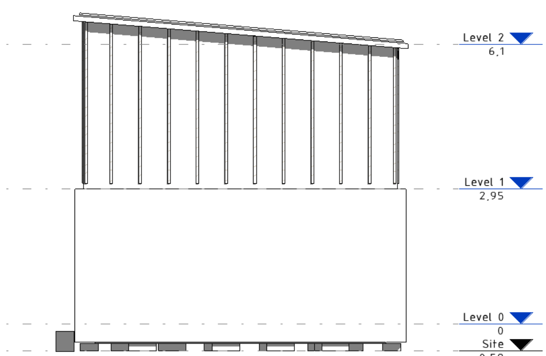
INTERIOR SIDE

Gefion Innenwand

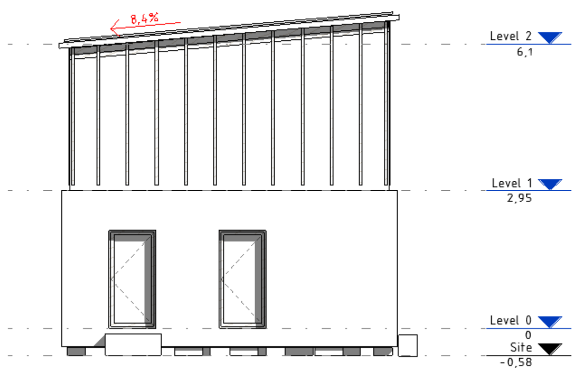


KG	Type	Width	Count	Area	Heat Transfer Coefficient (U)	Thermal Resistance (R)
330	Gefion_Wand_EG	44 cm	4	66,06 m²	0.0965 W/(m²·K)	10.3615 (m²·K)/W
330	WALL_Holz struktu_Aussenwandverkleidung	22,1 cm	4	75,35 m²	0.1456 W/(m²·K)	6.8661 (m²·K)/W
340	WALL_Int 9	16 cm	1	9,33 m²	0.3790 W/(m²·K)	2.6385 (m²·K)/W

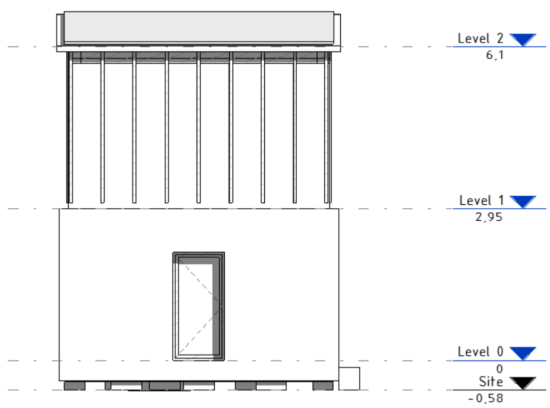
2.2.1 South Wall: 43.6m2



2.2.2 North Wall: 43.6m2

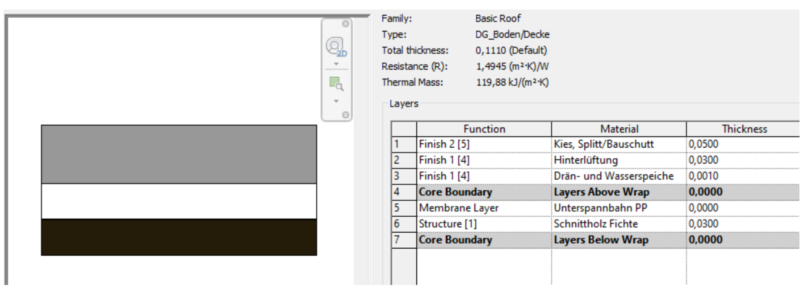


2.2.3 East Wall: 31.8m2



2.2.4 West Wall: 35.2m2

2.3 Roof



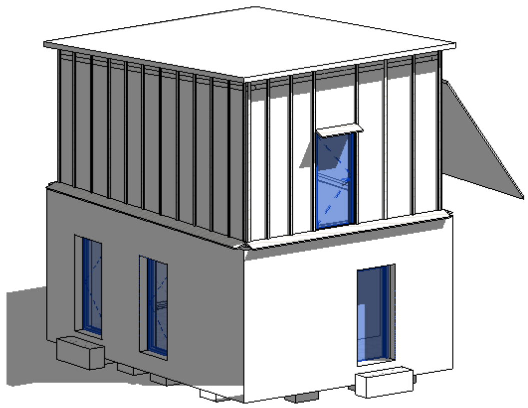
Family: Basic Roof
Type: DG_Boden/Decke
Total thickness: 0,1110 (Default)
Resistance (R): 1,4945 (m²·K)/W
Thermal Mass: 119,88 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	Finish 2 [5]	Kies, Splitt/Bauschutt	0,0500
2	Finish 1 [4]	Hinterlüftung	0,0300
3	Finish 1 [4]	Drän- und Wasserspeiche	0,0010
4	**Core Boundary**	**Layers Above Wrap**	**0,0000**
5	Membrane Layer	Unterspannbahn PP	0,0000
6	Structure [1]	Schnittholz Fichte	0,0300
7	**Core Boundary**	**Layers Below Wrap**	**0,0000**

KG	Type	Base Level	Count	Area	Heat Transfer Coefficient (U)	Thermal Resistance (R)
361	DG_Boden/Decke	Level 2	1	40,5 m²	0.6691 W/(m²·K)	1.4945 (m²·K)/W

2.4 Doors and Windows



Type	Level	Count	Height	Width	Area	Heat Transfer Coefficient (U)	Thermal Resistance (R)
Fenster 100X210cm	Level 0	1	210 cm	100 cm	2,1 m²	1,3000 W/(m²·K)	0,7692 (m²·K)/W
Fenster 100X210cm	Level 0	1	210 cm	100 cm	2,1 m²	1,3000 W/(m²·K)	0,7692 (m²·K)/W
Fenster 100X210cm	Level 0	1	210 cm	100 cm	2,1 m²	1,3000 W/(m²·K)	0,7692 (m²·K)/W
Fenster 100X210cm	Level 0	1	210 cm	100 cm	2,1 m²	1,3000 W/(m²·K)	0,7692 (m²·K)/W
Fenster 100X210cm	Level 0	1	210 cm	100 cm	2,1 m²	1,3000 W/(m²·K)	0,7692 (m²·K)/W

Type	Level	Count	Height	Width	Area	Heat Transfer Coefficient (U)	Thermal Resistance (R)
Eingangtür- 90 x 200	Level 0	1	208 cm	95 cm	1,97 m²	3.7021 W/(m²·K)	0.2701 (m²·K)/W
OG Tür - 100x210	<varies>	2	208 cm	95 cm	3,94 m²	1,8737 W/(m²·K)	0,5337 (m²·K)/W

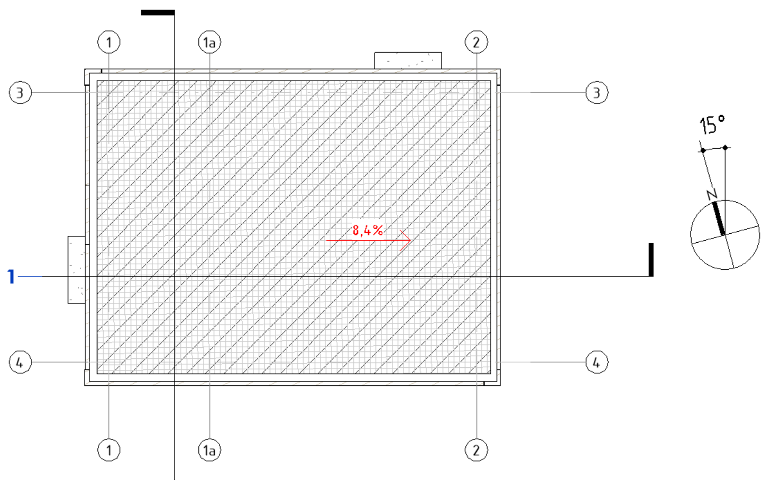
3 Heiz- und Kühlsystem

4 Stück 1,0kW IR-Heizungen an der Decke

Keine dezentralen Lüfter. Es wird nur natürlich über die Fenster gelüftet.

4 Fotovoltaikanlage/Solaranlage

Area: 37m2
Neigung: 8.4°
Solarorientierung: 15° süd-westen.



5 Technische Gebäudeausrüstung (TGA)

91-Mechanical & Technical Equipment			
KG	Type	Material: Count	Energie Bedarf / unit
450	Windsensor	1	
442	12KW Speicher	1	
444	Wechselrichter Multiplus II	1	
444	Laderegler	1	
455	5" Display	1	
455	Kommunikationsmodul Victron	1	
459	Schaltschrank metall 0,3x0,3x0,2 metall	1	
459	Verteilerschrank aus metall	1	

457	Steuerungseinheit Raffsore	1	
457	Bewegungsmelder	1	
445	Deckenleuchten	5	
445	Wandleuchte	1	
423	1,0kW IR-Heizungen	4	1kW
440	abgehängte Steckdosenwürfel (Steckdosen)	2	
440	Steckdosen	5	
440	Ausschalter	2	
457	Rauchmelder	3	

Impressum

WoodenValley gGmbH
in Verantwortungseigentum
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70376 Stuttgart

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A.2 Level(s) Data Quality Index (DQI)

Rating aspect	*Brief description of each aspect*	Rating score			
		0	**1**	**2**	**3**
Technological representativeness	Degree to which the dataset reflects the true population of interest regarding technology (e.g. the technological characteristics, including operating conditions)	No evaluation made	The data used does not reflect satisfactorily the technical characteristics of the system (e.g. Portland Cement, without other specifications)	The data used reflects partially the technical characteristics of the system (e.g. Portland Cement type II, without further specifications)	The data used reflects the technical characteristics of the system (e.g. Portland Cement type II B-M)
Geographical representativeness	Degree to which the dataset reflects the true population of interest regarding geography (e.g. the given location/site, region, country, market, continent)	No evaluation made	The data used refer to a totally different geographic context (e.g. Sweden instead of Spain)	The data used refers to a similar geographic context (e.g. Italy instead of Spain)	The data used refers to the specific geographic context (e.g. Spain)
Time-related representativeness	Degree to which the dataset reflects the specific conditions of the system being considered regarding the time/age of the data (e.g. the given year compared to the reference year of the analysis)	No evaluation made	There are more than 6 years between the validity of the data used and the reference year to which the data applies.	There are between 2 and 4 years between the validity of the data used and the reference year to which the data applies.	There are less than 2 years between the validity of the data used and the reference year to which the data applies.
Uncertainty	Qualitative expert judgment or relative standard deviation expressed as a percentage.	No evaluation made	Modelled/similar data is used. Accuracy and precision of the data has been estimated qualitatively (e.g. by expert judgment of suppliers and process operators)	Modelled/similar data is used which is considered to be satisfactorily accurate and precise with the support of a quantitative estimation of its uncertainty (e.g. representative data from trade associations for which a sensitivity	Site specific and validated data is used which is considered to be satisfactorily accurate and precise (e.g. window system for which a verified EPD is available) The allocation hierarchy has been respected.

Figure 9: Level(s) Data Quality Evaluation Matrix extracted from Dodd, Donatello, and Cordella 2021b, p.35-36

A.3 Level(s) 2 Reporting - Full Tables

A.3.1 Indicator 1.2 GWP

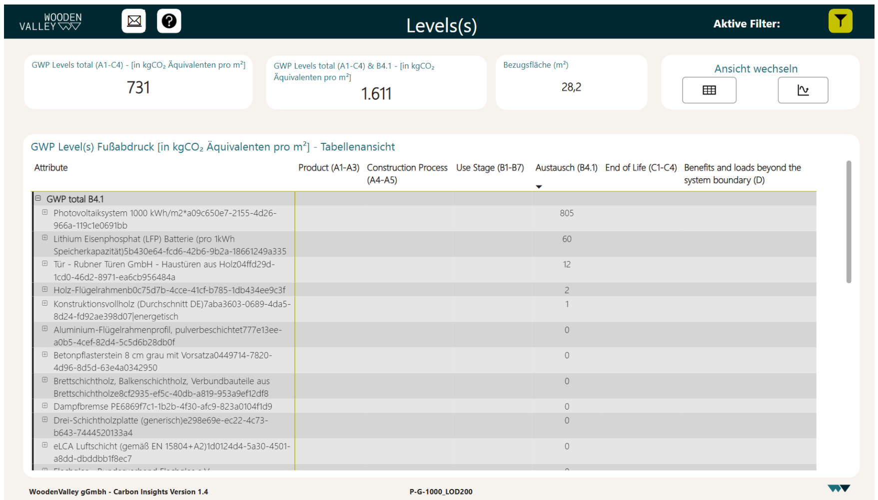


Figure 10: List of contributing materials to LCA Module B4 - Replacement.

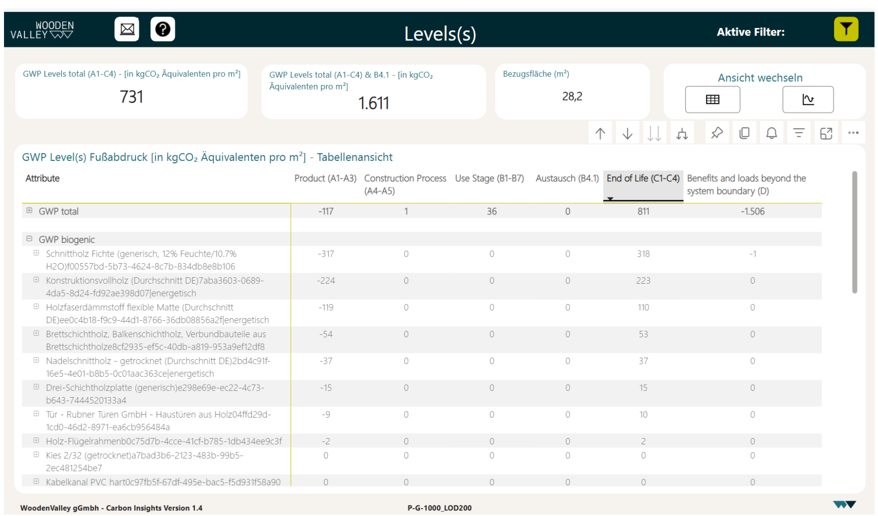


Figure 11: List of contributing materials to GWP-biogenic in Phase C1-C4. Sawn timber spruce (Schnittholz Fichte), structural solid timber (Konstruktionsvollholz) and flexible wood fibre insulation mat (Holzfaserdämmstoff flexible Matte) account for 81,5 % of the GWP in this phase.

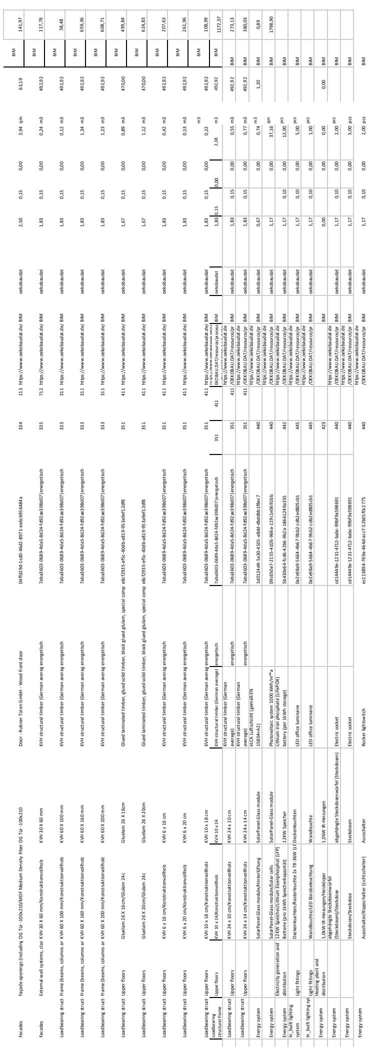
A.3.2 Indicator 2.1 BoQ

Bill of quantities organised by the main building parts and elements

Fictive entries have been added below for illustration purposes, please delete any information in the green or yellow cells before starting

Tier 1 building element	Tier 2 building element	Tier 3 building element	Optional further description of the product/material being purchased	Bauteil	EPD-Name	Szenario	EPD-UUID	KG (DIN276)	KG Subcode (BNB)	EPD-URL	Source EPD Name	EPD Programmh	DQI	Circularity (2.4)	Reuse	Bill of Quantities (number of units)	Unit	Conversion factor (kg/unit)	Source Conversion factor	TOTAL (kg)
				Zusätzliche Spalten für uns zum Arbeiten - gerne erweitern, wenn sinnvoll																
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Boden-Deckel-Schalung	Gefion_Wand_EG	Coniferous lumber - kiln dried (Germa	energetisch	2bd4c91f-16e5-4e01-b8b5-0c01aac363ce|energetisch	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	1,40	m3	484,51	BIM	676,17
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Dampfsperre	Gefion_Wand_EG	Damp insulation PE		6869f7c1-1b2b-4f30-afc9-823a0104f1d9	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	70,26	qm	0,20	BIM	0,00
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Hinterlüftung	Gefion_Wand_EG	eLCA Luftschicht (gemäß EN 15804+A2)		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	0,67		0,00	3,88	m3	1,20	BIM	4,66
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Holzfaserdämmstoff	Gefion_Wand_EG	Wood fiber insulation - dry process (G	energetisch	ee0c4b18-f9c9-44d1-8766-36db08856a2f|energetisch	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	19,40	m3	50,00	BIM	2911,09
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Schnittholz Fichte	Gefion_Wand_EG	Timber spruce (generic, 12% moisture / 10.7% H2O content)		f00557bd-5b73-4624-8c7b-834db8e8b106	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	3,88	m3	481,60	BIM	1869,31
Shell	Loadbearing structu	External walls	Gefion_Wand_EG/Unterspannbahn PP	Gefion_Wand_EG	Underroof membrane PP		b4634111-dc95-4873-8614-9ab38bd11d42	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	70,26	qm	0,15	BIM	0,00
Shell	Loadbearing structu	External walls	WALL_Holz struktu_Aussenwandverkleidung/	WALL_Holz struktu_Aussenwandverkleidung	Damp insulation PE		6869f7c1-1b2b-4f30-afc9-823a0104f1d9	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	75,26	qm	0,20	BIM	97,10
Shell	Loadbearing structu	External walls	WALL_Holz struktu_Aussenwandverkleidung/	WALL_Holz struktu_Aussenwandverkleidung	eLCA Luftschicht (gemäß EN 15804+A2)		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	0,67		0,00	12,04	m3	1,20	BIM	14,45
Shell	Loadbearing structu	External walls	WALL_Holz struktu_Aussenwandverkleidung/	WALL_Holz struktu_Aussenwandverkleidung	Timber spruce (generic, 12% moisture / 10.7% H2O content)		f00557bd-5b73-4624-8c7b-834db8e8b106	331	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	4,52	m3	481,60	BIM	2175,23
Shell	Non-load bearing e	Internal walls, partitions a	WALL_Int 9/Dreischichtplatte Fichte	WALL_Int 9	Three layer laminated timber board (generic)		e298e69e-ec22-4c73-b643-7444520133a4	342	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	0,56	m3	472,00	BIM	309,08
Shell	Non-load bearing e	Internal walls, partitions a	WALL_Int 9/Mycolutions	WALL_Int 9				342	311		BIM		0,00		0,00	0,00		0,00	BIM	40,13
Shell	Foundations (subst	Piles	Fundament_Gehwegplatten/Betonpflasterste	Fundament_Gehwegplatten	Concrete paving stone 8 cm grey		a0449714-7820-4d96-8d5d-63e4a0342950	322	112	https://www.oekobaudat.de/	BIM	oekobaudat	2,33	0,50	0,00	0,48	qm	177,00	BIM	519,94
Shell	Foundations (subst	Piles	Fundament_Gehwegplatten 2/Betonpflasters	Fundament_Gehwegplatten 2	Concrete paving stone 8 cm grey		a0449714-7820-4d96-8d5d-63e4a0342950	322	112	https://www.oekobaudat.de/	BIM	oekobaudat	2,33	0,50	0,00	4,56	qm	177,00	BIM	1756,23
Shell	Loadbearing structu	Upper floors	Gefion_Boden/Betonwerkstein	Gefion_Boden	Lightweight concrete block from 100% natural pumice		a1deced7-6fa9-4266-bc86-da75b3653b06	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,50	0,00	1,73	m3	500,00	BIM	4174,22
Shell	Loadbearing structu	Upper floors	Gefion_Boden/Dampfsperre	Gefion_Boden	Damp insulation PE		6869f7c1-1b2b-4f30-afc9-823a0104f1d9	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	28,89	qm	0,20	BIM	0,00
Shell	Loadbearing structu	Upper floors	Gefion_Boden/Holzfaserdämmstoff	Gefion_Boden	Wood fiber insulation - dry process (G	energetisch	ee0c4b18-f9c9-44d1-8766-36db08856a2f|energetisch	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	8,67	m3	50,00	BIM	1300,48
Shell	Loadbearing structu	Upper floors	Gefion_Boden/Kies, Splitt/Bauschutt	Gefion_Boden	Gravel 2/32 (dried)		a7bad3b6-2123-483b-99b5-2ec481254be7	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,50	0,00	2254,17	kg	1,00	BIM	2254,17
Shell	Loadbearing structu	Upper floors	Gefion_Boden/Schnittholz Fichte	Gefion_Boden	Timber spruce (generic, 12% moisture / 10.7% H2O content)		f00557bd-5b73-4624-8c7b-834db8e8b106	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	0,87	m3	481,60	BIM	417,54
Shell	Loadbearing structu	Upper floors	Gefion_Zwischendecke/Dampfsperre	Gefion_Zwischendecke	Damp insulation PE		6869f7c1-1b2b-4f30-afc9-823a0104f1d9	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	34,11	qm	0,20	BIM	0,00
Shell	Loadbearing structu	Upper floors	Gefion_Zwischendecke/Holzfaserdämmstoff	Gefion_Zwischendecke	Wood fiber insulation - dry process (G	energetisch	ee0c4b18-f9c9-44d1-8766-36db08856a2f|energetisch	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	14,33	m3	50	BIM	2149,54
Shell	Loadbearing structu	Upper floors	Gefion_Zwischendecke/Schnittholz Fichte	Gefion_Zwischendecke	Timber spruce (generic, 12% moisture / 10.7% H2O content)		f00557bd-5b73-4624-8c7b-834db8e8b106	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	1,02	m3	481,60	BIM	492,96
Shell	Roofs	Structure	DG_Boden/Decke/Drän- und Wasserspeicher	DG_Boden/Decke				361	111		BIM		0,00		0,00	0,00		0	BIM	52,21
Shell	Roofs	Structure	DG_Boden/Decke/Hinterlüftung	DG_Boden/Decke	eLCA Luftschicht (gemäß EN 15804+A2)		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	361	111	https://www.oekobaudat.de/	BIM	oekobaudat	0,67		0,00	1,21	m3	1,20	BIM	1,46
Shell	Roofs	Structure	DG_Boden/Decke/Kies, Splitt/Bauschutt	DG_Boden/Decke	Gravel 2/32 (dried)		a7bad3b6-2123-483b-99b5-2ec481254be7	361	111	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,50	0,00	5261,95	kg	1,00	BIM	5261,95
Shell	Roofs	Structure	DG_Boden/Decke/Schnittholz Fichte	DG_Boden/Decke	Timber spruce (generic, 12% moisture / 10.7% H2O content)		f00557bd-5b73-4624-8c7b-834db8e8b106	361	111	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	1,21	m3	481,60	BIM	584,81
Shell	Roofs	Structure	DG_Boden/Decke/Unterspannbahn PP	DG_Boden/Decke	Underroof membrane PP		b4634111-dc95-4873-8614-9ab38bd11d42	361	111	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,15	0,00	40,48	qm	0,15	BIM	0,00
Shell	Facades	Façade openings (including	Fenster 100X210cm/Aluminium-Rahmenprofi	Fenster 100X210cm	Aluminium wing sash profile, powder coated		777e13ee-a0b5-4cef-82d4-5c5d6b28db0f	334	211	https://www.oekobaudat.de/	BIM	oekobaudat	1,17		0,00	18,60	m	0,98	BIM	234,97
Shell	Facades	Façade openings (including	Fenster 100X210cm/Flachglas_2 Layers	Fenster 100X210cm	Flat glass - Bundesverband Flachglas e.V - Insulating glass unit double structu		1fd9f4eb-e087-49ba-a09d-a5f9f7162c42	334	211	https://www.oekobaudat.de/	BIM	oekobaudat	1,17	0,25	0,00	6,30	qm	21,21	BIM	72,25
Shell	Facades	Façade openings (including	EG Tür-Eingang-100x210/Aluminium-Rahmer	EG Tür-Eingang-100x210	Aluminium wing sash profile, powder coated		777e13ee-a0b5-4cef-82d4-5c5d6b28db0f	334	112	https://www.oekobaudat.de/	BIM	oekobaudat	1,17		0,00	6,05	m	0,98	BIM	43,59
Shell	Facades	Façade openings (including	EG Tür-Eingang-100x210/Aluminum_Door	EG Tür-Eingang-100x210	Door - heroal-Johann Henkenjohann GmbH & Co. KG - Aluminium commercial		835b163b-3a44-4c9f-9fb8-9a2beb20d520	334	112	https://www.oekobaudat.de/	BIM	oekobaudat	1,50	0,50	0,00	1,97	qm	36,13	BIM	240,46
Shell	Facades	Façade openings (including	OG Tür -100x210/Holz-Rahmenprofile für Fas	OG Tür -100x210	Window sash (spruce)		b0c75d7b-4cce-41cf-b785-1db434ee9c3f	334	113	https://www.oekobaudat.de/	BIM	oekobaudat	1,17		0,00	12,10	m	2,11	BIM	87,19

Figure 12: GEFION Actual Case Scenario - Extraction from Level(s) 2 Report Bill of Quantity (BoQ) including EPD Information. Page 1



Shell	Facades	Façade openings (including	OG Tür -100x210/MDF Medium Density Fiber OG Tür -100x210		Door - Rubner Türen GmbH - Wood front door		04ffd29d-1cd0-46d2-8971-ea6cb956484a	334	113	https://www.oekobaudat.de/	BIM	oekobaudat	2,50	0,15	0,00	3,94	qm	63,19	BIM	141,97
Shell	Facades	External wall systems, clad	KVH 30 X 60 mm/Konstruktionvollholz	KVH 30 X 60 mm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	335	712	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	0,24	m3	492,92	BIM	117,76
Shell	Loadbearing struct	Frame (beams, columns ar	KVH 60 X 100 mm/Konstruktionvollholz	KVH 60 X 100 mm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	0,12	m3	492,92	BIM	58,48
Shell	Loadbearing struct	Frame (beams, columns ar	KVH 60 X 160 mm/Konstruktionvollholz	KVH 60 X 160 mm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	1,34	m3	492,92	BIM	659,36
Shell	Loadbearing struct	Frame (beams, columns ar	KVH 60 X 200 mm/Konstruktionvollholz	KVH 60 X 200 mm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	1,23	m3	492,92	BIM	608,71
Shell	Loadbearing struct	Upper floors	Gluelam 26 X 16cm/Glulam 24c	Gluelam 26 X 16cm	Glued laminated timber, glued solid timber, block glued glulam, special comp		e8cf2935-ef5c-40db-a819-953a9ef12df8	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,67	0,15	0,00	0,89	m3	470,00	BIM	499,84
Shell	Loadbearing struct	Upper floors	Gluelam 26 X 20cm/Glulam 24c	Gluelam 26 X 20cm	Glued laminated timber, glued solid timber, block glued glulam, special comp		e8cf2935-ef5c-40db-a819-953a9ef12df8	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,67	0,15	0,00	1,12	m3	470,00	BIM	624,83
Shell	Loadbearing struct	Upper floors	KVH 6 x 16 cm/Konstruktionvollholz	KVH 6 x 16 cm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	0,42	m3	492,92	BIM	207,63
Shell	Loadbearing struct	Upper floors	KVH 6 x 20 cm/Konstruktionvollholz	KVH 6 x 20 cm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	0,53	m3	492,92	BIM	261,96
Shell	Loadbearing struct	Upper floors	KVH 10 x 18 cm/Konstruktionvollholz	KVH 10 x 18 cm	KVH structural timber (German averag	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/	BIM	oekobaudat	1,83	0,15	0,00	0,22	m3	492,92	BIM	108,99
Shell	Loadbearing structural frame	Upper floors	KVH 10 x 24/Konstruktionvollholz	KVH 10 x 24	KVH structural timber (German average)	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/OEKOBAU.DAT/resource/process	BIM	oekobaudat	1,83	0,15	0,00	2,38	m3	492,92	BIM	1172,37
Shell	Loadbearing struct	Upper floors	KVH 24 x 10 cm/Konstruktionvollholz	KVH 24 x 10 cm	KVH structural timber (German average)	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,83	0,15	0,00	0,55	m3	492,92	BIM	273,13
Shell	Loadbearing struct	Upper floors	KVH 24 x 14 cm/Konstruktionvollholz	KVH 24 x 14 cm	KVH structural timber (German average)	energetisch	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,83	0,15	0,00	0,77	m3	492,92	BIM	380,03
Core	Energy system		SolarPanel-Glass module/Hinterlüftung	SolarPanel-Glass module	eLCA Luftschicht (gemäß EN 15804+A2)		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	440		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	0,67		0,00	0,74	m3	1,20	BIM	0,89
Core	Energy system		SolarPanel-Glass module/Solar cells	SolarPanel-Glass module	Photovoltaic system 1000 kWh/m²*a		09c650e7-2155-4d26-966a-119c1e0691bb	440		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17		0,00	37,16	qm		BIM	1798,90
Core	Energy system	Electricity generation and distribution	12KW Speicher/Lithium Eisenphosphat (LFP) Batterie (pro 1kWh Speicherkapazität)	12KW Speicher	Lithium iron phosphate (LiFePO4) battery (per 1kWh storage)		5b430e64-fcd6-42b6-9b2a-18661249a335	442		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	12,00	pcs		BIM	
Core	In_built lighting system	Light fittings	Deckenleuchten/Rasterleuchte 2x T8-36W (LF	Deckenleuchten	LED office luminaire		0e2e98a9-5664-4b67-9bb2-cdb2ed805cb1	445		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	5,00	pcs		BIM	
Core	In_built lighting sys	Light fittings	Wandleuchte/LED Bürobeleuchtung	Wandleuchte	LED office luminaire		0e2e98a9-5664-4b67-9bb2-cdb2ed805cb1	445		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	1,00	pcs		BIM	
Core	Energy system	Heating plant and distribution	1,0KW IR-Heizungen/Heizkörper	1,0KW IR-Heizungen				423			BIM		0,00		0,00	0,00		0,00	BIM	
Core	Energy system		abgehängte Steckdosenwürfel (Steckdosen)/Steckdose	abgehängte Steckdosenwürfel (Steckdosen)	Electric socket		cd14449e-1231-4f12-babc-99bf9a598691	440		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	2,00	pcs		BIM	
Core	Energy system		Steckdosen/Steckdose	Steckdosen	Electric socket		cd14449e-1231-4f12-babc-99bf9a598691	440		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	5,00	pcs		BIM	
Core	Energy system		Ausschalter/Kippschalter (Lichtschalter)	Ausschalter	Rocker lightswitch		ec113894-769a-464d-acc7-52b01f0c1775	440		https://www.oekobaudat.de/OEKOBAU.DAT/resource/pr	BIM	oekobaudat	1,17	0,10	0,00	2,00	pcs		BIM	

Figure 13: GEFION Actual Case Scenario - Extraction from Level(s) 2 Report Bill of Quantity (BoQ) including EPD Information. Page 2

Bill of quantities organised by the main building parts and elements

Fictive entries have been added below for illustration purposes, please delete any information in the green or yellow cells before starting

Tier 1 building element	Tier 2 building element	Tier 3 building element	Optional further description of the product/material being purchased	EPD-Name	EPD-UUID	KG (DIN276)	KG Subcode (BNB)	EPD-URL	Source EPD Name	EPD Programmh	DQI	Circularity (2.4)	Reuse	Bill of Quantities (number of units)	Unit	Conversion factor (kg/unit)	Source Conversion factor	TOTAL (kg)
				Zusätzliche Spalten für uns zum Arbeiten - gerne erweitern, wenn sinnvoll														
Shell	Loadbearing struct	External walls	Gefion_Wand_EG/Mineralwolle-Dämmstoff	Mineralwolle-Dämmstoff im mittlere	699e3d57-72b4-402d-a0ee-cebb06f3cdf1	331	311	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,10	0	18,10	m3	100	BIM	1810,43
Shell	Loadbearing struct	External walls	Gefion_Wand_EG/OSB	Oriented Strand Board (Durchschnitt	aab0ed28-e5b0-43d6-a932-4cdc4770c518 |energetisch	331	311	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	2,17	m3	600	BIM	1303,51
Shell	Loadbearing struct	External walls	Gefion_Wand_EG/Polycarbonatplatte	Polycarbonatplatte	dcfd896b-9b7d-42a5-b47b-3643a8870e6a	331	311	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,50	0	788,70	kg	1	BIM	788,70
Shell	Loadbearing struct	External walls	Gefion_Wand_EG/Unterspannbahn PP	Unterspannbahn PP	b4634111-dc95-4873-8614-9ab38bd11d42	331	311	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,15	0	65,86	m2	0,15	BIM	0
Shell	Loadbearing struct	External walls	WALL_Holz struktu_Aussenwandverkleidung	Oriented Strand Board (Durchschnitt	aab0ed28-e5b0-43d6-a932-4cdc4770c518 |energetisch	331	311	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	1,35	m3	600	BIM	812,21
Shell	Loadbearing struct	External walls	WALL_Holz struktu_Aussenwandverkleidung	Polycarbonatplatte	dcfd896b-9b7d-42a5-b47b-3643a8870e6a	331	311	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,50	0	902,42	kg	1	BIM	902,42
Shell	Non-load bearing e	Internal walls, partitions a	WALL_Int 9/Dreischichtplatte Fichte	Drei-Schichtholzplatte (generisch)	e298e69e-ec22-4c73-b643-7444520133a4	342	311	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,15	0	0,56	m3	472	BIM	311,07
Shell	Non-load bearing e	Internal walls, partitions a	WALL_Int 9/Mineralwolle-Dämmstoff	Mineralwolle-Dämmstoff im mittlere	699e3d57-72b4-402d-a0ee-cebb06f3cdf1	342	311	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,10	0	0,94	m3	100	BIM	93,92
Shell	Foundations (subst	Piles	Fundament_Gehwegplatten/Betonpflasters	Betonpflasterstein 8 cm grau mit Vor	a0449714-7820-4d96-8d5d-63e4a0342950	322	112	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,50	0	0,96	m2	177	BIM	1039,88
Shell	Foundations (subst	Piles	Fundament_Gehwegplatten 2/Betonpflaste	Betonpflasterstein 8 cm grau mit Vor	a0449714-7820-4d96-8d5d-63e4a0342950	322	112	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,50	0	4,56	m2	177	BIM	1756,23
Shell	Loadbearing struct	Upper floors	Gefion_Boden/Betonwerkstein	Leichtbetonstein aus 100% Naturbim	a1deced7-6fa9-4266-bc86-da75b3653b06	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,50	0	1,75	m3	500	BIM	4205,43
Shell	Loadbearing struct	Upper floors	Gefion_Boden/Dampfsperre	Dampfbremse PE	6869f7c1-1b2b-4f30-afc9-823a0104f1d9	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,15	0	29,11	m2	0,20	BIM	0
Shell	Loadbearing struct	Upper floors	Gefion_Boden/Kies, Splitt/Bauschutt	Kies 2/32 (getrocknet)	a7bad3b6-2123-483b-99b5-2ec481254be7	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,50	0	1615,92	kg	1	BIM	1615,92
Shell	Loadbearing struct	Upper floors	Gefion_Boden/Mineralwolle-Dämmstoff	Mineralwolle-Dämmstoff im mittlere	699e3d57-72b4-402d-a0ee-cebb06f3cdf1	351	411	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,10	0	8,73	m3	100	BIM	873,47
Shell	Loadbearing struct	Upper floors	Gefion_Boden/OSB	Oriented Strand Board (Durchschnitt	aab0ed28-e5b0-43d6-a932-4cdc4770c518 |energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,52	m3	600	BIM	314,45
Shell	Loadbearing struct	Upper floors	Gefion_Zwischendecke/Mineralwolle-Dämm	Mineralwolle-Dämmstoff im mittlere	699e3d57-72b4-402d-a0ee-cebb06f3cdf1	351	411	https://www.oekobaudat.de	BIM	oekobaudat	2,33	0,10	0	14,33	m3	100	BIM	1433,03
Shell	Loadbearing struct	Upper floors	Gefion_Zwischendecke/OSB	Oriented Strand Board (Durchschnitt	aab0ed28-e5b0-43d6-a932-4cdc4770c518 |energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,61	m3	600	BIM	368,49
Shell	Roofs	Structure	DG_Boden/Decke/Drän- und Wasserspeicherelement			361	111		BIM		0		0	0		0	BIM	52,21
Shell	Roofs	Structure	DG_Boden/Decke/Hinterlüftung		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	361	111	https://www.oekobaudat.de	BIM	oekobaudat	0,67		0	1,21	m3	1,20	BIM	1,46
Shell	Roofs	Structure	DG_Boden/Decke/Kies, Splitt/Bauschutt	Kies 2/32 (getrocknet)	a7bad3b6-2123-483b-99b5-2ec481254be7	361	111	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,50	0	3744,08	kg	1	BIM	3744,08
Shell	Roofs	Structure	DG_Boden/Decke/Schnittholz Fichte	Schnittholz Fichte (generisch, 12% Fe	f00557bd-5b73-4624-8c7b-834db8e8b106	361	111	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,15	0	1,21	m3	481,60	BIM	584,81
Shell	Roofs	Structure	DG_Boden/Decke/Unterspannbahn PP	Unterspannbahn PP	b4634111-dc95-4873-8614-9ab38bd11d42	361	111	https://www.oekobaudat.de	BIM	oekobaudat	1,17	0,15	0	40,48	m2	0,15	BIM	0
Shell	Facades	Façade openings (includin	Fenster 100X210cm/Aluminium-Rahmenpro	Aluminium-Flügelrahmenprofil, pulve	777e13ee-a0b5-4cef-82d4-5c5d6b28db0f	334	211	https://www.oekobaudat.de	BIM	oekobaudat	1,17		0	31	m	0,98	BIM	140,83
Shell	Facades	Façade openings (includin	Fenster 100X210cm/Flachglas_2 Layers	Flachglas - Bundesverband Flachglas	1fd9f4eb-e087-49ba-a09d-a5f9f7162c42	334	211	https://www.oekobaudat.de	BIM	oekobaudat	1,33	0,25	0	10,50	m2	21,21	BIM	120,42
Shell	Facades	Façade openings (includin	EG Tür-Eingang-100x210/Aluminium-Rahme	Aluminium-Flügelrahmenprofil, pulve	777e13ee-a0b5-4cef-82d4-5c5d6b28db0f	334	112	https://www.oekobaudat.de	BIM	oekobaudat	1,17		0	6,05	m	0,98	BIM	15,68

Figure 14: GEFION Worst Case Scenario - Extraction from Level(s) 2 Report Bill of Quantity (BoQ) including EPD Information. Page 1

Shell	Facades	Façade openings (includin	EG Tür-Eingang-100x210/Aluminum_Door	Tür - heroal-Johann Henkenjohann GmbH & Co. KG - Aluminium-Objekttür (EN 15804+A2)	835b163b-3a44-4c9f-9fb8-9a2beb20d520	334	112	https://www.oekobaudat.de	BIM	oekobaudat	1,50	0,50	0	1,97	m2		36,13	BIM	240,46
Shell	Facades	Façade openings (includin	OG Tür -100x210/Holz-Rahmenprofile für Fa	Holz-Flügelrahmen	b0c75d7b-4cce-41cf-b785-1db434ee9c3f	334	113	https://www.oekobaudat.de	BIM	oekobaudat	1,17		0	12,1	m		2,11	BIM	31,36
Shell	Facades	Façade openings (includin	OG Tür -100x210/MDF Medium Density Fibe	Tür - Rubner Türen GmbH - Haustüre	04ffd29d-1cd0-46d2-8971-ea6cb956484a	334	113	https://www.oekobaudat.de	BIM	oekobaudat	2,50	0,15	0	3,94	m2		63,19	BIM	141,97
Shell	Facades	External wall systems, clac	KVH 30 X 60 mm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	335	712	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,24	m3		492,92	BIM	117,76
Shell	Loadbearing struct	Frame (beams, columns a	KVH 60 X 100 mm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,12	m3		492,92	BIM	58,48
Shell	Loadbearing struct	Frame (beams, columns a	KVH 60 X 160 mm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	1,34	m3		492,92	BIM	659,36
Shell	Loadbearing struct	Frame (beams, columns a	KVH 60 X 200 mm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	333	311	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	1,23	m3		492,92	BIM	608,71
Shell	Loadbearing struct	Upper floors	Gluelam 26 X 16cm/Glulam 24c	Brettschichtholz, Balkenschichtholz, \	e8cf2935-ef5c-40db-a819-953a9ef12df8	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,91	m3	470		BIM	508,27
Shell	Loadbearing struct	Upper floors	Gluelam 26 X 20cm/Glulam 24c	Brettschichtholz, Balkenschichtholz, \	e8cf2935-ef5c-40db-a819-953a9ef12df8	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	1,13	m3	470		BIM	635,37
Shell	Loadbearing struct	Upper floors	KVH 6 x 16 cm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,43	m3		492,92	BIM	210,65
Shell	Loadbearing struct	Upper floors	KVH 6 x 20 cm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,54	m3		492,92	BIM	267,25
Shell	Loadbearing struct	Upper floors	KVH 10 x 18 cm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,23	m3		492,92	BIM	112,46
Shell	Loadbearing struct	Upper floors	KVH 10 x 24/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	2,43	m3		492,92	BIM	1197,08
Shell	Loadbearing struct	Upper floors	KVH 24 x 10 cm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,55	m3		492,92	BIM	273,13
Shell	Loadbearing struct	Upper floors	KVH 24 x 14 cm/Konstruktionvollholz	Konstruktionsvollholz (Durchschnitt [	7aba3603-0689-4da5-8d24-fd92ae398d07|energetisch	351	411	https://www.oekobaudat.de	BIM	oekobaudat	1,83	0,15	0	0,77	m3		492,92	BIM	380,03
Core	Energy system		SolarPanel-Glass module/Hinterlüftung		1d0124d4-5a30-4501-a8dd-dbddbb1f8ec7	440		https://www.oekobaudat.de	BIM	oekobaudat	0,67		0	0,74	m3		1,20	BIM	0,89
Core	Energy system		SolarPanel-Glass module/Solar cells	Photovoltaiksystem 1000 kWh/m2*a	09c650e7-2155-4d26-966a-119c1e0691bb	440		https://www.oekobaudat.de/ OEKOBAU.DAT/resource/proc	BIM	oekobaudat	1,17		0	37,16	m2			BIM	1798,90
Core	Energy system	Electricity generation and distribution	12KW Speicher/Lithium Eisenphosphat (LFP	Lithium Eisenphosphat (LFP) Batterie (pro 1kWh	5b430e64-fcd6-42b6-9b2a-18661249a335	442		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	12	pieces			BIM	
Core	In_built lighting sy	Light fittings	Deckenleuchten/Rasterleuchte 2x T8-36W (LFL)	LED Bürobeleuchtung	0e2e98a9-5664-4b67-9bb2-cdb2ed805cb1	445		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	5	pieces			BIM	
Core	In_built lighting system	Light fittings	Wandleuchte/LED Bürobeleuchtung	LED Bürobeleuchtung	0e2e98a9-5664-4b67-9bb2-cdb2ed805cb1	445		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	1	pieces			BIM	
Core	Energy system	Heating plant and distribution	1,0kW IR-Heizungen/Heizkörper			423			BIM		0		0	0		0		BIM	
Core	Energy system		abgehängte Steckdosenwürfel (Steckdosen)/Steckdose	Steckdose	cd14449e-1231-4f12-babc-99bf9a598691	440		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	2	pieces			BIM	
Core	Energy system		Steckdosen/Steckdose	Steckdose	cd14449e-1231-4f12-babc-99bf9a598691	440		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	5	pieces			BIM	
Core	Energy system		Ausschalter/Kippschalter (Lichtschalter)	Kippschalter (Lichtschalter)	ec113894-769a-464d-acc7-52b01f0c1775	440		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,10	0	2	pieces			BIM	
Core	Energy system		Kabelführung aufputz, farbige stränge/Kabelkanal PVC hart	Kabelkanal PVC hart	0c97fb5f-67df-495e-bac5-f5d931f58a90	440		https://www.oekobaudat.d e/OEKOBAU.DAT/resource/	BIM	oekobaudat	1,17	0,50	0	34,65	kg	1		BIM	34,65

Figure 15: GEFION Worst Case Scenario - Extraction from Level(s) 2 Report Bill of Quantity (BoQ) including EPD Information. Page 2

A.3.3 Indicator 2.4 Circularity Score

Level(s) indicator 2.4 design for deconstruction calculator

Tier 1 building element	Tier 2 building element	Tier 3 building element	(Tier 4) Further explanation of entry (optional)	Quantity (kg)	Value (EUR)	Circularity (best practical outcome)	Circularity coefficient	Circularity score (by mass)	Circularity score (by value)
Core	Energy_system		SolarPanel-Glass module/Hinterlüftung	0,89		Recycling (pure stream)	0,75	0,6675	
Core	Energy_system		SolarPanel-Glass module/Solar cells	1798,9		Recycling (mixed stream)	0,50	899,45	
Core	Energy_system		12KW Speicher/Lithium Eisenphosphat (LFP) Batterie (pro 1kWh Speicherkapazität)	125		Recycling (mixed Stream)	0,50	62,5	
Core	In_built_lighting_system	Light fittings	Deckenleuchten/Rasterleuchte 2x T8-36W (LFL)						
Core	In_built_lighting_system	Light fittings	Wandleuchte/LED Bürobeleuchtung						
Core	Energy_system		1,0kW IR-Heizungen/Heizkörper						
Core	Energy_system		abgehängte Steckdosenwürfel (Steckdosen)/Steckdose						
Core	Energy_system		Steckdosen/Steckdose						
Core	Energy_system		Ausschalter/Kippschalter (Lichtschalter)						
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Boden-Deckel-Schalung	676,17		Reuse (direct)	1,00	676,17	
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Dampfsperre	0		Recovery (energy)	0,15	0	
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Hinterlüftung	4,66		Reuse (preparing for)	0,90	4,194	
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Holzfaserdämmstoff	2911,09		Recycling (pure stream)	0,75	2183,3175	
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Schnittholz Fichte	1869,31		Reuse (preparing for)	0,90	1682,379	
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Unterspannbahn PP	0		Recovery (energy)	0,15	0	
Shell	Loadbearing_structural_frame	External walls	WALL_Holz struktu_Aussenwandverkleidung/Dampfsperre	97,1		Recovery (energy)	0,15	14,565	
Shell	Loadbearing_structural_frame	External walls	WALL_Holz struktu_Aussenwandverkleidung/Hinterlüftung	14,45		Reuse (direct)	1,00	14,45	
Shell	Loadbearing_structural_frame	External walls	WALL_Holz struktu_Aussenwandverkleidung/Schnittholz Fichte	2175,23		Reuse (direct)	1,00	2175,23	
Shell	Non_loadbearing_elements	Internal walls, partitions and doors	WALL_Int 9/Dreischichtplatte Fichte	309,08		Reuse (direct)	1,00	309,08	
Shell	Non_loadbearing_elements	Internal walls, partitions and doors	WALL_Int 9/Mycolutions	40,13		Reuse (preparing for)	0,90	36,117	
Shell	Foundations_substructure	Piles & shallow foundations	Fundament_Gehwegplatten/Betonpflasterstein	519,94		Reuse (direct)	1,00	519,94	
Shell	Foundations_substructure	Piles & shallow foundations	Fundament_Gehwegplatten 2/Betonpflasterstein	1756,23		Reuse (direct)	1,00	1756,23	
Shell	Loadbearing_structural_frame	Upper floors	Gefion_Boden/Betonwerkstein	4174,22		Reuse (direct)	1,00	4174,22	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Overall circularity score (by mass)	Overall circularity score (by value)
91,5%	#DIV/0!

Building element specific circularity scores	By mass	By value
Piles or shallow foundations	100,0%	
Basements		
Retaining walls		
Frame (beams, columns and slabs)	100,0%	
Upper floors	94,3%	
External walls	87,1%	
Balconies		
Ground floor slab		
Internal walls, partitions and doors	98,9%	
Stairs and ramps		
External wall systems, cladding and shading devices	100,0%	
Façade openings (including windows and external doors)	90,0%	
External paints, coatings and renders		
(Roof) Structure		
(Roof) Weatherproofing		
[illegible]		

Figure 16: Level(s) 2 Report - Indicator 2.4 Design for Deconstruction (Circularity Score)

Tier 1 building element	Tier 2 building element	ier 3 building elemer	(Tier 4) Further explanation of entry (optional)	(best practical	Bauteilbeschreibun	Material/Ty	Bewertung	mended Outcome
Core	Energy_system		SolarPanel-Glass module/Hinterlüftung			Photovolta	Keine direkte Wiederverwendung (Leistung und Zertifizierung nach Alter begrenzt) Trennung möglich Recycling in reiner Fraktion (z. B. Glas) möglich, aber technisch aufwendig	Recycling (pure stream)
Core	Energy_system		SolarPanel-Glass module/Solar cells			Dünnschicl	Kein Reuse Getrennte Rückgewinnung schwierig Recycling erfolgt i. d. R. als Mischstrom	Recycling (mixed stream)
Core	Energy_system		12KW Speicher/Lithium Eisenphosphat (LFP) Batterie (pro 1kWh Speicherkapazität)			Lithium-Ba	Direkte Wiederverwendung nicht geplant/standardisiert Komplexes Recycling mit gemischten Fraktionen Teilweise als hazardous eingestuft, aber bei fachgerechter Entsorgung in Deutschland → kein Sondermüll, sondern Recycling (nach GRS-System etc.)	Recycling (mixed Stream)
Core	In_built_lighting_system	Light fittings	Deckenleuchten/Rasterleuchte 2x T8-36W (LFL)					
Core	In_built_lighting_system	Light fittings	Wandleuchte/LED Bürobeleuchtung					
Core	Energy_system		1,0kW IR-Heizungen/Heizkörper					
Core	Energy_system		abgehängte Steckdosenwürfel (Steckdosen)/Steckdose					
Core	Energy_system		Steckdosen/Steckdose					
Core	Energy_system		Ausschalter/Kippschalter (Lichtschalter)					
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Boden-Deckel-Schalung		Gefion_Wand_EG/Boden-Deckel-Schalung	Vollholz (Fichte/Tanne)	Reversibel montiert, gut rückbaubar, direkt wiederverwendbar	Reuse (direct)
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Dampfsperre		Gefion_Wand_EG/Dampfsperre	Kunststofffolie (z. B. PE/PA)	Dünne Folie, meist verklebt oder geklammert, geringe Wiederverwendungsmöglichkeiten	Recovery (energy)
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Hinterlüftung		Gefion_Wand_EG/Hinterlüftung	Holzlatten, mechanisch befestigt	Gut trennbar, sortenrein, teils direkt wiederverwendbar	Reuse (preparing for)
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Holzfaserdämmstoff		Gefion_Wand_EG/Holzfaserdämmstoff	Holzfaserplatte (z. B. Steico)	Rückbau ohne Zerstörung schwer, aber sortenreines stoffliches Recycling möglich	Recycling (pure stream)
Shell	Loadbearing_structural_frame	External walls	Gefion_Wand_EG/Schnittholz Fichte		Gefion_Wand_EG/Schnittholz Fichte	Massivholz, tragend	Sehr gute Wiederverwendungsmöglichkeiten bei unversehrtem Ausbau	Reuse (preparing for)

Figure 17: Circularity Score Decision per materials - In column T the decision basis for the circularity score of every material/component is explained.