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Benchmarking and target-setting for the life cycle-based environmental performance of buildings

Energy in Buildings and Communities Technology Collaboration Programme

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DOI (link to publication from Publisher):
10.5281/zenodo.7468752

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Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Lützkendorf, T., Balouktsi, M., Frischknecht, R., Peuportier, B., Rasmussen, F. N., Satola, D., Wiberg, A. H., Birgisdottir, H., Dowdell, D., Lupišek, A., Malmqvist, T., Obrecht, T. P., & Trigaux, D. (2023). *Benchmarking and target-setting for the life cycle-based environmental performance of buildings: Energy in Buildings and Communities Technology Collaboration Programme* . treeze Ltd. https://doi.org/10.5281/zenodo.7468752

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ANNEX 72

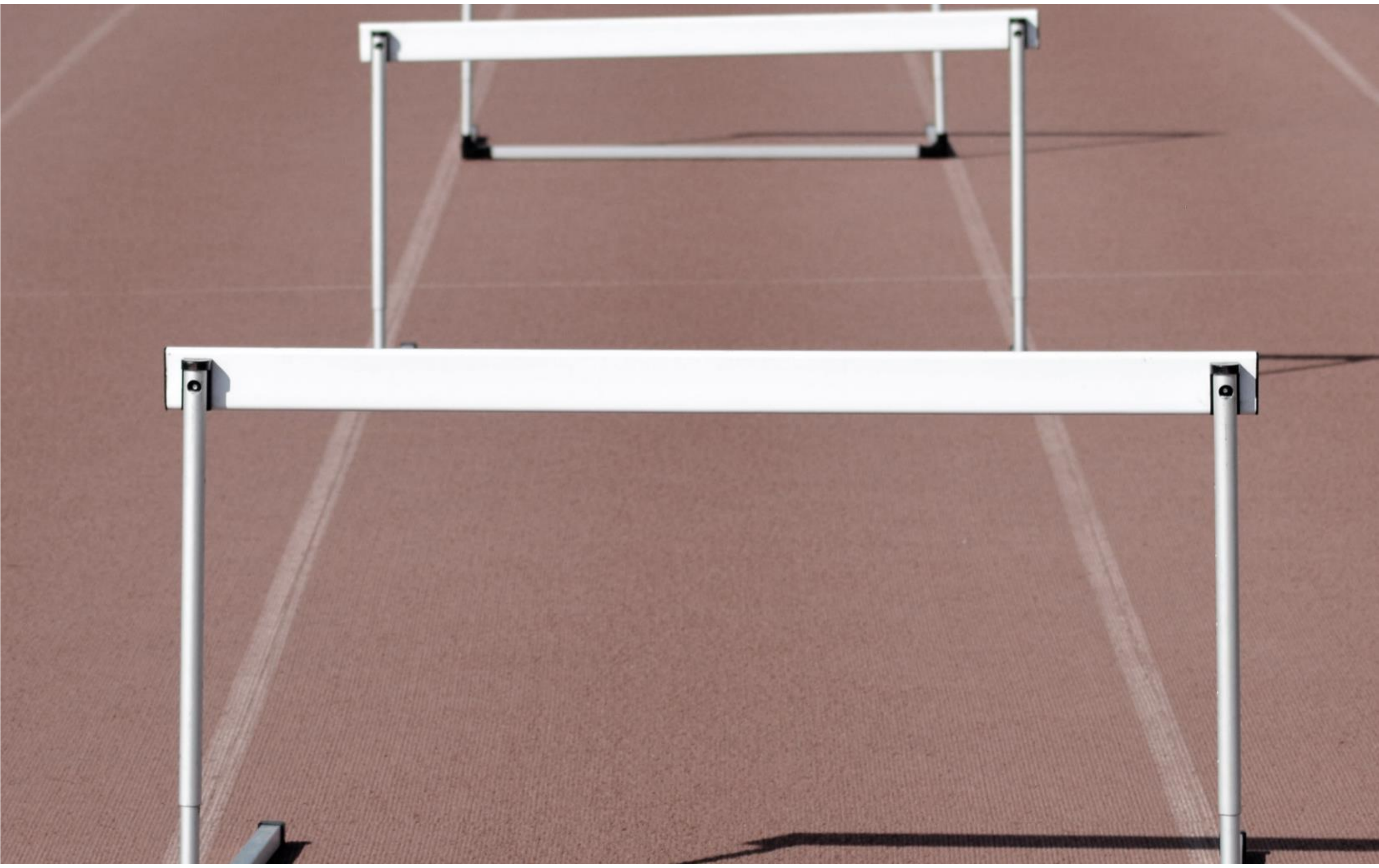
EBC
Energy in Building and Communities Programme

International Energy Agency

Benchmarking and target-setting for the life cycle-based environmental performance of buildings

Energy in Buildings and Communities Technology Collaboration Programme

February 2023



Technology Collaboration Programme
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Benchmarking and target-setting for the life cycle-based environmental performance of buildings

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February 2023

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Published by treeze Ltd., Kanzleistrasse 4, 8610 Uster, Switzerland

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ISBN: 978-3-9525709-4-4
DOI: 10.5281/zenodo.7468752

Participating countries in the EBC TCP: Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Turkey, United Kingdom and the United States of America.

Additional copies of this report may be obtained from: EBC Executive Committee Support Services Unit (ESSU), C/o AECOM Ltd, The Colmore Building, Colmore Circus Queensway, Birmingham B4 6AT, United Kingdom
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Funding
The work within Annex 72 has been supported by the IEA research cooperation on behalf of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology via the Austrian Research Promotion Agency (FFG, grant #864142), by the Brazilian National Council for Scientific and Technological Development (CNPq, (grants #306048/2018-3 and #313409/2021-8), by the federal and provincial government of Quebec and Canada coordinated by Mitacs Acceleration (project number IT16943), by the Swiss Federal Office of Energy (grant numbers SI/501549-01 and SI/501632-01), by the Czech Ministry of Education, Youth and Sports (project INTER¬EXCELLENCE No. LTT19022), by the Danish Energy Agency under the Energy Technology Development and Demonstration Programme (grant 64012-0133 and 64020-2119), by the European Commission (Grant agreement ID: 864374, project ATELIER), by the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) in France (grant number 1704C0022), by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Affairs and Climate Action (BMWK, the former Federal Ministry for Economic Affairs and Energy (BMWi)) in Germany, coordinated by the project management agency PTJ (project numbers 03SBE116C and 03ET1550A), by the University of Palermo - Department of Engineering, Italy, by the Research Centre for Zero Emission Neighbourhoods in Smart Cities (FME ZEN) funded by the Norwegian Research Council (project no. 257660), by the Junta de Andalucía (contract numbers 2019/TEP-130 and 2021/TEP-130) and the Universidad de Sevilla (contract numbers PP2019-12698 and PP2018-10115) in Spain, by the Swedish Energy Agency (grant number 46881-1), and by national grants and projects from Australia, Belgium, China, Finland, Hungary, India, The Netherlands, New Zealand, Portugal, Slovenia, South Korea, United Kingdom, and the United States of America.

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely ‘Objectives’ and ‘Means’. These two groups are distinguished for a better understanding of the different themes.

Objectives – The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of ‘low tech’, robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means – The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from ‘living labs’ to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the ‘objectives’ themes are final goals or solutions (or part of) for an energy efficient built environment, while the ‘means’ themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5 : Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities – Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

Introduction

To support the actors involved in decisions related to assessing and eventual influencing the environmental impacts in the life cycle of buildings not only the provision of specific calculation methods, environmental data, workflows and design tools is necessary, but also the development and application of suitable benchmarks and target values. The latter is the focus of this report. The definition of ambitious environmental target values considering the full life cycle of buildings is seen as one of the most important steps in pushing the construction and real estate sector in significantly reducing its environmental impacts to stay within planetary boundaries.

Objectives and contents of the report

The purpose of this report is to provide the foundations to responsible actors for further developing their specific methods to create life cycle related benchmarks for the non-renewable primary energy demand/consumption, GHG emissions and further environmental impacts of buildings and to increase the mainstreaming of practice globally.

This report covers:
- General principles and recommendations for the development of benchmarks and target values based on a bottom-up approach (technical and economic feasibility) and a top-down approach (science-based targets to define a safe operating space inside planetary boundaries)
- General principles and recommendations for the application and interpretation of benchmarks
- General principles and recommendations for the documentation and communication of benchmarks
- Recommendations for terms, definitions, system boundaries and accounting rules for buildings with an absolute zero or net zero GHG emission approach (climate neutral buildings).

The specific objectives of this report are to:
- clarify methodological questions with respect to the development of benchmarks to aid low carbon and low environmental impacts for construction, operation and end of life.
- provide a consistent and transparent basis for a reporting structure for environmental benchmarks in line with international standards
- contribute to the interpretation and supplementation of international standards to improve their applicability and support their dissemination
- promote long-term and life cycle-based thinking, by encouraging the early consideration of likely future environmental impacts regarding maintenance, repair and replacement as well as of durability and adaptability of building components and the building as a whole
- contribute to the overall efforts of national governments and standard makers to guide construction and real estate industry on how to respond to climate change and other mega trends like depletion of natural resources

Key messages

The following key messages arise as an inspiration for further improvement and development of life cycle-based environmental benchmarks and target values:

a. **Benchmarks and target values are indispensable tools for assessing and eventually influencing the environmental performance of buildings**. The development and application of lifecycle-based benchmarks and target values for the non-renewable primary energy use, GHG emissions and other environmental impact categories is necessary to support sustainability assessment systems, the definition of requirements and goals in the client's brief, the definition of requirements in funding programs and laws.
b. **Benchmarks must be described in detail based on ISO 21678.** A description of the background, system boundaries, calculation methods, geographical and temporal validity forms the basis for the correct selection, application and interpretation of benchmarks. If new benchmarks and target values are developed and introduced, this description must be published in a freely accessible manner or be attached to the assessment result.
c. **Benchmarks are inextricably linked to the system boundaries, calculation rules (or measurement specifications) and database(s) used for their development**. If one or more of these conditions change in the development of the environmental performance result to be assessed, the benchmarks must also be adjusted accordingly.
d. **Benchmark systems can be comprised of values representing different performance levels.** A benchmark can represent the upper or lower acceptable performance level on a performance scale (limit value), the state of the art or best practice (reference value) or an objective that goes beyond the reference value (target value).
e. **In addition to legally binding requirements, it is also necessary to specify reduction paths c that contains information about future benchmarks.** The future limit values can be seen as today's target values. This allows the building actors to already prepare for future requirements. Before introducing new benchmarks, there should be a lead time of at least one year and a maximum of two years.
f. **Benchmarks are subject to dynamic development**. Benchmarks must be regularly adapted to new findings regarding planetary boundaries, technical progress, changing boundary conditions and ambitions. This means that their temporal validity shall be narrowly defined.
g. **To deal with the time factor, a transition to dynamic considerations in LCA is an option currently discussed**. Physical discounting is excluded when developing and interpreting benchmarks; current and future greenhouse gas emissions are considered equivalent. However, a transition from static to dynamic considerations would have consequences for the benchmarks and target values, which would need to be adjusted accordingly. They can apply to individual years or as an average value for complete periods.
h. **Over a long period of time, benchmarks were based on best practice examples and target values on technical and economic feasibility**. This led to benchmarks adapted to regional, climatic, cultural and socio-political characteristics. It became necessary to limit the territorial validity.
i. **The need to respect and comply with planetary boundaries is leading to a new generation of benchmarks and target values that are science-based**. Adhering to planetary boundaries ensures the preservation of key Earth System processes. Especially the formulation of target values can no longer be based on the current economic feasibility. Rather, the focus should be on achieving socially recognized environmental targets with minimal effort, and without shifting burdens to other areas nor generations. The goal of respecting planetary boundaries leads to a transition from the bottom-up approach to the top-down approaches when developing benchmarks. Studies deriving planetary-based benchmarks are increasing. It is assumed that such benchmarks will also be developed to tackle resource depletion problem in a next step.

j. **The target value "climate neutrality" is a universal benchmark.** Climate neutrality - preferably expressed as a (net) zero GHG emission target - is a universal benchmark. It applies to all types of buildings worldwide. The verification of compliance must continue to be adapted to the specific type of building as well as to regional and climatic, cultural and socio-political characteristics.

k. **Benchmarks should be performance-oriented.** This means that benchmarks and the requirements they integrate should be product- and material-neutral and open to all types of technologies. However, in certain types of benchmarks, additional specifications that relate to proof of compliance are necessary. For example, in the case of net zero GHG emission targets, allowable technical solutions for balancing, offsetting or neutralising GHG emissions should be transparently provided.

l. **Benchmarks must find the right balance between completeness and granularity.** Environmental benchmarks and target values shall cover both the entire building and its life cycle. It is possible and useful to provide partial benchmarks covering different parts of the life cycle, e.g. embodied impacts versus operational impacts, as well as upfront impacts on the side of the complete embodied impacts. Furthermore, it is possible and useful to provide partial benchmarks covering different parts of the building such as building components and technical systems. Such partial benchmark values can serve as guide values (non-binding benchmarks) to support the design process.

m. **Several reference units should be examined in the creation of benchmarks.** The choice of a suitable reference unit can help the interpretation of indicator results. They all have specific advantages as well as disadvantages. Reference unit(s) must be chosen with care and be always declared. It makes sense and is possible to use several reference values in parallel in the form of guide values, along with the choice of one reference unit for binding benchmarks.

n. **Benchmarks and target values can be supplemented by additional qualitative requirements.** It is possible and useful to supplement benchmarks and target values with additional qualitative requirements. An example is the exclusion of refrigerants that contain F-gases.

o. **Benchmarks and target values are scalable, system limits can be expanded**. Benchmarks and target values at the level of national building stocks, institutions, municipalities and districts as well as individual buildings are related to each other. Consistency and connectivity from one level to the other must be observed.

Table of content

Abbreviations

Abbreviations	Meaning
AU	Australia
BE	Belgium
BECCS	Bioenergy with Carbon Capture Storage
BIPV	Building-integrated Photovoltaics
CA	Canada
CH	Switzerland
CIBSE	Chartered Institution of Building Services Engineers
CZ	Czech Republic
DE	Germany
DK	Denmark
EAC	Energy Attribute Certificate
EFA	Energy Floor Area
EPD	Environmental Product Declaration
ES	Spain
FR	France
GBC	Green Building Council
GFA	Gross Floor Area
GHG	Greenhouse Gas Emissions
GO	Guarantee of origin
GWP	Global Warming Potential
HFA	Heated Floor Area
HU	Hungary
IEA	International Energy Agency
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MFH	Multi-Family House
NET	Negative Emission Technology
NFA	Net Floor Area
NGO	Non-governmental Organisation
NL	Netherlands
NO	Norway
NZ	New Zealand
PE	Primary Energy
REC	Renewable Energy Certificate
RIBA	Royal Institute of British Architects
SBT	Science Based Targets
SDG	Sustainable Development Goal

SE	Sweden
SIA	Schweizerischer ingenieur- und architektenverein
SFH	Single-Family House
SP	Sharing Principle
WEF	World Economic Forum

Definitions

Definitions of general terms in the context of an environmental performance assessment are provided here. Many of these descriptions are based on definitions found in international standards. In some cases, definitions found in standards were modified. Topic-specific terms and definitions are explained in the topic-related sections of this report.

Benchmarking: process of collecting, analysing and relating performance data of comparable buildings or other types of construction works. Benchmarking is typically used for evaluating and comparing performance between or within objects of consideration (ISO, 2020).

Benchmark: reference point against which comparisons can be made (ISO, 2020).

Bottom-up approach: an approach where benchmarks are based on descriptive statistics such as different percentiles from a distribution of performances within a sample of buildings or are based on technical and/or economic feasibility or optimum.

Top-down approach: an approach where benchmarks are based on top-down goals, either politically determined or science-based (or both).

Budget: it represents the level of impact that is "allowable" over a period of time (also called allowance)

Client's brief: Brief is a document that states the requirements for a project and is approved by the client, the latter being the person or organization initiating and financing a project (ISO, 2017a).

Functional equivalent: It represents the quantified functional requirements and/or technical requirements for a building for use as a reference basis for comparison (ISO, 2022). For a more detailed discussion see also Section 4.1.2 of A72 report by Lützkendorf et al. (2022).

Granularity of benchmarks: the level of detail in the decomposition of whole-life benchmarks into partial values to assist the design process. The decomposition can be according to (i) building types; (ii) life cycle stages; (iii) building parts. See Section 4.3 for more details.

Indicator: quantitative, qualitative or descriptive measure (ISO, 2019).

Reference unit: Denominator of a characteristic value to which the numerator is related.

Performance scale: is an assessment system of performance levels on which an assessment result can be classified for the purpose of assessment. This scale is divided into individual levels or sections, e.g. performance levels against which the result is compared.

Performance level: It is a value indicating the relative performance required (or provided) for a particular attribute on a relative scale, from the level of the minimum/lower performance to the level of the upper/ best performance. Along with numerical values, performance levels can also be expressed with the help of labels, e.g. an "'A level' is achieved when …" (adapted from: ISO (2020)).

Best practice/ Best-in-class: It is the level representing best available real performance. This value evolves with time (ISO, 2020).

Limit value: It is the upper or lower acceptable performance level on a performance scale (ISO, 2020).

Reference value: It is performance level on a performance scale that represents state of the art or best practice. A reference value is subject to temporal changes (ISO, 2020).

Target value: It is the performance level on a performance scale that represents an objective that goes beyond the reference value. Target values can follow a top-down or bottom-up approach. A target value is the result of a target setting process. A subdivision into short-term, medium-term and long-term target values is possible (ISO, 2020).

Target-setting process: It the process of defining goals. In the context of this report, target-setting has two tasks. On the one hand, general target values must be defined for a system of performance levels. On the other hand, specific goals can and should be given in the early stages of a building project (e.g. to formulate goals for environmental, economic and social performance this is stated in EN 15643-1:2010 Sustainability of construction works - Part 1: General framework).

Planetary boundary: These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes.

Science-based target: SBT (or Science Based Targets) are top-down reduction targets for greenhouse gas emissions and other environmental indicators. They differ from regular goals in the sense that they are calculated on a scientific basis to ensure that fundamental ecosystem services are preserved.

Safe operating space: It is the safe space for human development estimated via thresholds/ boundary levels for key Earth System processes, if we are to avoid unacceptable global environmental change.

Life cycle: all consecutive and interlinked stages in the life of the object under consideration. The life cycle comprises all stages, from raw material acquisition or generation from natural resources to end-of-life (ISO, 2017b).

Life cycle assessment (LCA): LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a building, infrastructure, product or material throughout its lifecycle (ISO, 2006).

Upfront impacts: Environmental impacts (including GHG emissions) associated with the pre-use stages of a building, that is the materials production and construction stages of the life cycle (A1-5 modules according to EN 15978). Therefore, these impacts have already been caused before a building is occupied.

1. Introduction

1.1 General Context and Scope

The internationally recognized sustainable development goals (SDGs) are pursued worldwide. SDG 11 specifies global tasks relating to sustainable development of cities and communities and is closely interrelated with goals such as SDG 3 (Good health and wellbeing), 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industry innovation and infrastructure), 12 (responsible consumption and production), 13 (climate action). An important contribution to these SDGs is to take the environmental, economic and social implications into account in all design and investment decisions related to new construction and refurbishment projects, as well as the operation of buildings. The level of detail required for this goes far beyond that of the very general SDGs. It is necessary to analyse the goals and indicators of the respective SDGs and to take them into account in all decisions. To support the actors involved in such decisions, and particularly in relation to assessing and eventual reducing the environmental impacts in the life cycle of buildings, in addition to the provision of specific methods (see A72 report "Context-specific Assessment Methods for Life Cycle-related Environmental Impacts" by Lützkendorf et al. (2022)), data (see A72 report "World Building life-cycle based Databases and Repositories for Building and Construction Sector" and "Guidelines for establishing an easy to use National LCA Database for the Construction Sector" by Chae and Kim (2022) and Palaniappan et al. (2022) respectively) as well as workflows and design tools (see A72 report "Guidelines for design decision-makers" and "Life-cycle optimization of building performance: a collection of case studies" by Passer et al. (2022) and Longo et al. (2022) respectively), also the development and application of suitable benchmarks is necessary (i.e. focus of this report). The job-sharing of the different reports is shown in Figure 1.1.

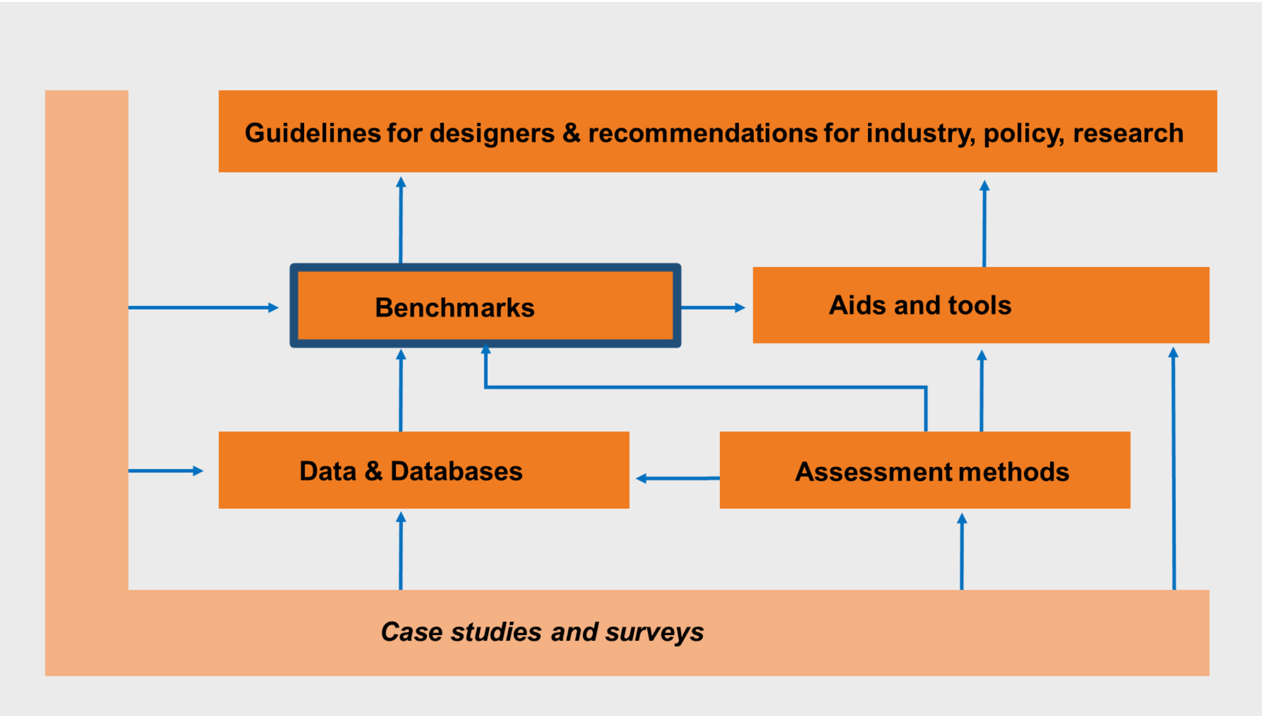

Figure 1.1: Overview of A72 main reports and their interconnections.

A benchmark is defined as a reference point against which comparisons can be made (ISO, 2020). Benchmarks are interpreted in a broader sense here; they include both values (performance levels) on a performance scale that represent state-of-the-art or best practice and specific limit and target values representing the lower (or upper) acceptable performance level and the lower (or upper) desired performance level respectively. This is illustrated in Figure 1.2.

Nowadays, life cycle-oriented environmental benchmarks are implemented in regulations, funding programmes, as well as sustainability assessment systems and rating tools. Limit values assist architects and building owners/investors in ensuring compliance with minimum legal requirements, reference values assist them in positioning themselves in the market and further pushing the construction sector in reducing its life cycle environmental impacts, and finally target values serve as a guide for specifying design goals in the client's brief.

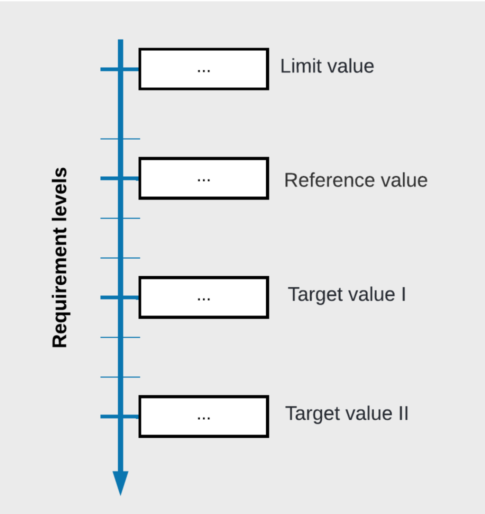

Figure 1.2: Types of benchmark values

Target values can also be used as an expression of a voluntary self-commitment by individuals or institutions, represent a recommendation for action by science, provide a basis for funding programs and sustainability assessment systems or give direction to the further development of legal requirements, sometimes in combination with a reduction path. They are the result of a target-setting process. The stricter the goals are set, the more the preservation of legal certainty in the long run can be ensured, as legal requirements tend to progressively become tighter.

The definition of ambitious environmental target values considering the full life cycle of buildings is seen as one of the most important steps in pushing the construction and real estate sector in significantly reducing its environmental impacts. This report acknowledges that such target values are no longer only developed on the basis of the technical and economic feasibility, but also more in the interest of preserving the natural foundations of life through respecting the so-called planetary boundaries (Steffen et al., 2015). The role of science is gaining in importance and science-based targets (i.e. targets consistent with the insights of global environment science) built on an understanding of planetary boundaries increasingly occur. The most prominent example of science-based targets with consensus on the global level is the 1.5°C target which serves to reduce GHG emissions as part of a key response to the current climate emergency. This new perspective is one of the focuses of this report.

Questions about the development and application of benchmarks have been discussed for a long time (Frischknecht et al., 2019; Häkkinen et al., 2012; König & Cristofaro, 2012; Trigaux et al., 2021). The recently published ISO 21678:2020 *Sustainability in buildings and civil engineering works — Indicators and benchmarks — Principles, requirements and guidelines* facilitate the introduction of a uniform basis. Particularly, this international standard provides the general principles and requirements to develop, use and interpret benchmarks for comparing and assessing the environmental, economic and social performance of buildings.

Requirements for the documentation and communication of benchmarks including their basis and background are addressed. However, current issues relating to the definition of a net zero energy or a net zero GHG emission level as target values and how to deal with offset options in emissions balances have not yet flowed into the development of the standard. To fill this gap, there is a plethora of government, NGO and industry led approaches worldwide (Satola et al., 2021). In addition, examples in the past have shown (including EN 15978 and ISO 21931-1 for environmental performance assessment) that it makes sense to interpret standards in a practical manner and to prepare them for individual target groups.

In the context of this guideline, the parts of ISO 21678:2020 that can contribute to the support of an environmental performance assessment are discussed, explained and supplemented. Where necessary and useful, the methodology of this standard is specified more precisely, as well as conveyed and developed further in a practice-oriented manner. This applies in particular to the specification of minimum documentation and verification requirements for the climate neutrality of buildings which is a subject not yet addressed by any international standard. Current developments are ongoing within the framework of ISO 14068 for "Greenhouse gas management and related activities – Carbon Neutrality".

Against this background, the present guideline deals with the basic principles for the determination, application and interpretation of life cycle-based benchmarks and target values for buildings for selected indicators quantifying environmental impacts and resource use. Benchmarks and target values for individual life cycle stages (e.g. operation) are not in the foreground. However, they are included as sub-targets and possible guide values for design. In addition, the necessity and possibility of a dynamic adjustment of benchmarks as well as the development of reduction paths, advantages and disadvantages of a bottom-up versus top-down approach in deriving specific benchmarks for buildings, questions about the specification of international standards for benchmarks are dealt with for buildings as well as the possibilities of integrating benchmarks into national standards and laws.

1.2 Process of developing Benchmarks and Target Values

1.2.1 Benchmarking vs target-setting

The process of developing and applying benchmarks is known as **benchmarking**. In the context of this report, using benchmarks involves comparing or contrasting numerical results for the environmental performance of buildings against an assessment scale comprised of performance levels or benchmarks. These numerical results are expressed in indicators for which quantitative statements are available based on calculations (e.g. greenhouse gas emissions in kg CO_2-eq), measurements (e.g. final energy consumption) or surveys (e.g. user satisfaction). The results of a calculation, measurement or survey can be compared (1) on a relative basis with the results of design alternatives or comparable buildings, or (2) with absolute benchmarks. This report focuses on the basic principles of the development and application of **absolute benchmarks**.

The process of specifically deriving and applying target values or design goals is known as **target-setting**. Target values are seen here as a special type of absolute benchmarks. A subdivision into short-term, medium-term and long-term target values is possible. Through a system of target levels, i.e. short-, medium- and long-term targets a "path" can be provided at the same time. The indication of long-term targets also allows industry and construction companies to adjust to more stringent requirements at an early stage. At the same time, funding programs can be geared towards medium to long-term target values. In the field of climate protection, it is common to specify targets for defined time periods or target years, e.g. "Until 2030" or "in the year 2050" (see examples of such paths in Figures 1.3-5 from different countries[1]).

[1] The examples were chosen only for illustration to present related activities in different countries and this choice is independent of the strictness of the benchmark values presented.

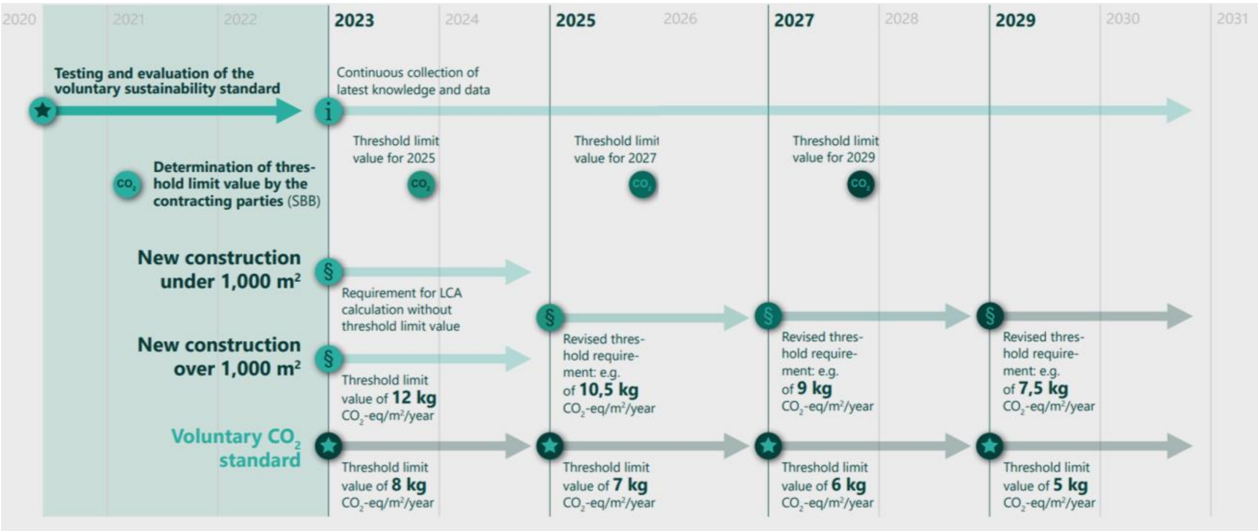

Figure 1.3: Denmark's timetable for tightening of greenhouse gas emissions requirements in the regulation and in the voluntary sustainability class (The Danish Housing and Planning Authority, 2021, p.12-13).

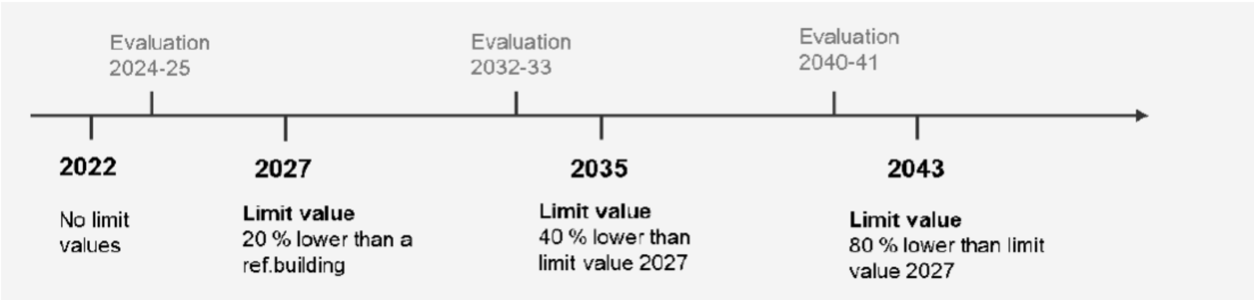

Figure 1.4: Sweden's plan to introduce limit values for greenhouse gas emissions in 2027 in the regulation for Climate Declaration for buildings, followed by a downward adjustment of limit values in 2035 and 2043. Reference buildings will be used to establish emission levels on which to base the 2027 limit values (Boverket, 2020).

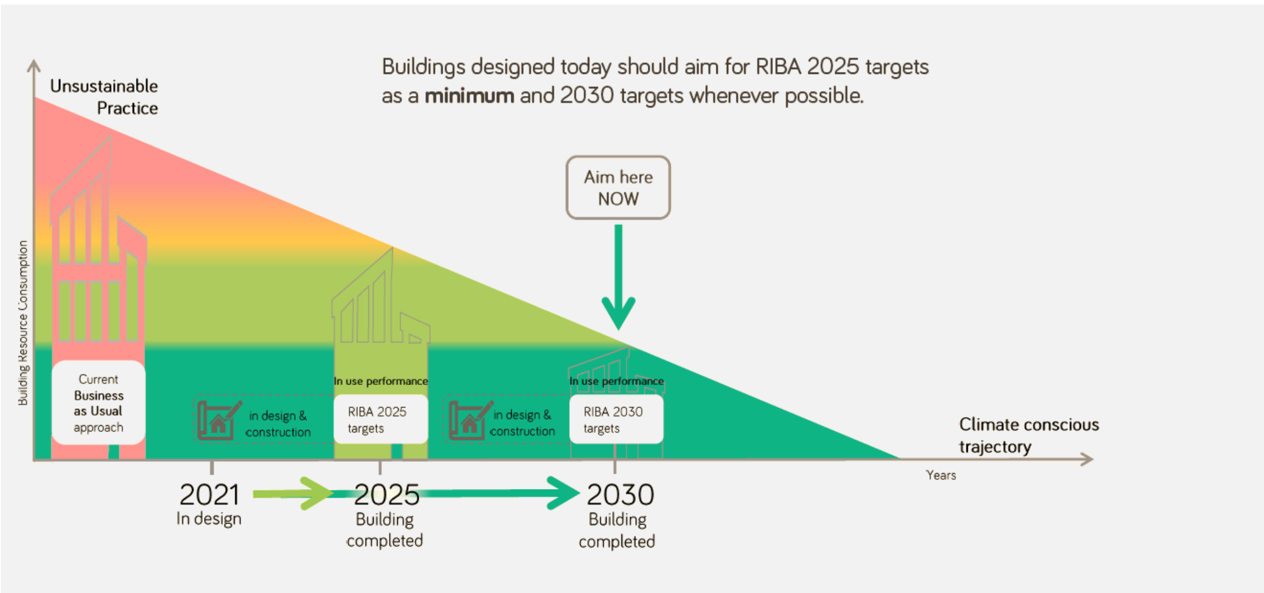

Figure 1.5: RIBA's voluntary performance targets for operational energy use, water use and embodied carbon as part of RIBA 2030 Climate Challenge (RIBA, 2021). For example, embodied GHG emissions of <750 $kgCO_2e/m^2$ (12.5 $kgCO_2e/m^2$/year) is targeted for non-domestic office buildings and <625 $kgCO_2e/m^2$ (10.5 $kgCO_2e/m^2$/year) for domestic buildings by 2030 (minimum 40% reduction in embodied GHG emissions compared to the current business as usual).

1.2.2 Bottom-up vs top-down approach

The procedure of generating benchmarks and/or target values can follow a top-down or bottom-up approach. Generation of target values based on best practices, as well as technical and/or economic feasibility to ensure that they are attainable, is here referred to as a bottom-up approach. Such target values are dependent on the technical and/or economic optimum of a certain moment and technology and are therefore subject to dynamic development as a result of technical progress and changing economic boundary conditions. Most countries' responsible institutions and organizations still rely on bottom-up approaches (based on best case examples) to define the highest 'possible' requirement level for different types of buildings (see Section 3.1). Key aspects to consider with respect to a bottom-up derivation of benchmarks, including target values, are discussed in Section 4.7.

A top-down approach defines target values based on global environmental goals or national policy targets translated to individual types of buildings or to the national, regional or institutional building stock. A target value derived from such an approach serves more as a benchmark of what is regarded as political necessity rather than of what is nowadays technically and economically feasible. Triggered by the emerging scientific discourse on planetary boundaries (i.e. quantitative thresholds for nine Earth-system processes whose transgression could seriously compromise our well-being) and the need to define a global safe operating space (SOS) within which social and economic development should be coordinated (Figure 1.6), there is now an interest by governments and other institutions/organisations in supplementing bottom-up approaches particularly with science-based top-down approaches as part of their responsibility to protect the natural foundations of life (Frischknecht et al., 2019). However, the introduction of such target values in legislation has so far only been discussed sporadically due to fear of limited social acceptance.

For the built environment, this means that global environmental budgets, such as the scientifically defined CO_2 emission budgets for the 1.5°or 2° scenarios (IPCC, 2021), are scaled down to the life-cycle of individual buildings (see Figure 1.7 which explicitly shows the different steps for carbon budget definition). Key aspects to consider with respect to a top-down derivation of target values are discussed in Section 4.8.

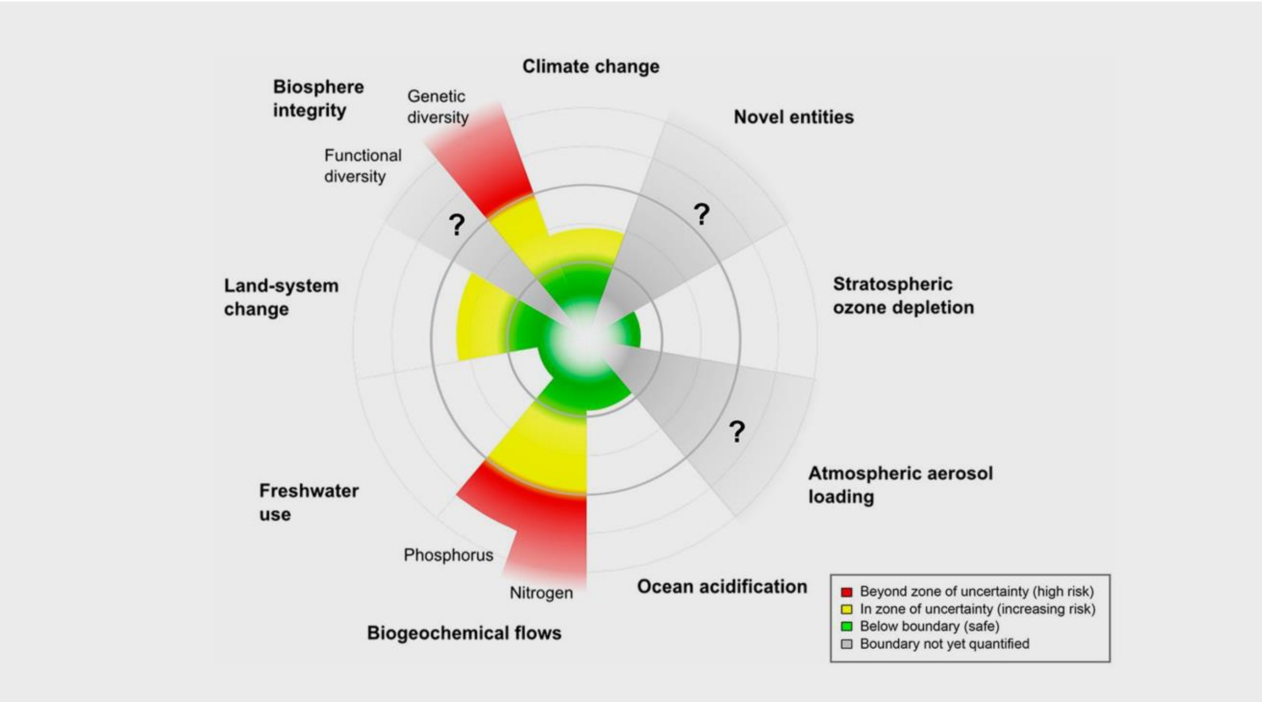

Figure 1.6: The current status of the control variables for seven of the nine planetary boundaries (taken from Steffen et al. (2015)). Note: The green zone is the safe operating space (below the boundary), yellow represents the zone of uncertainty (increasing risk), and red is the high-risk zone. Processes for which global-level boundaries cannot yet be quantified are represented by grey wedges

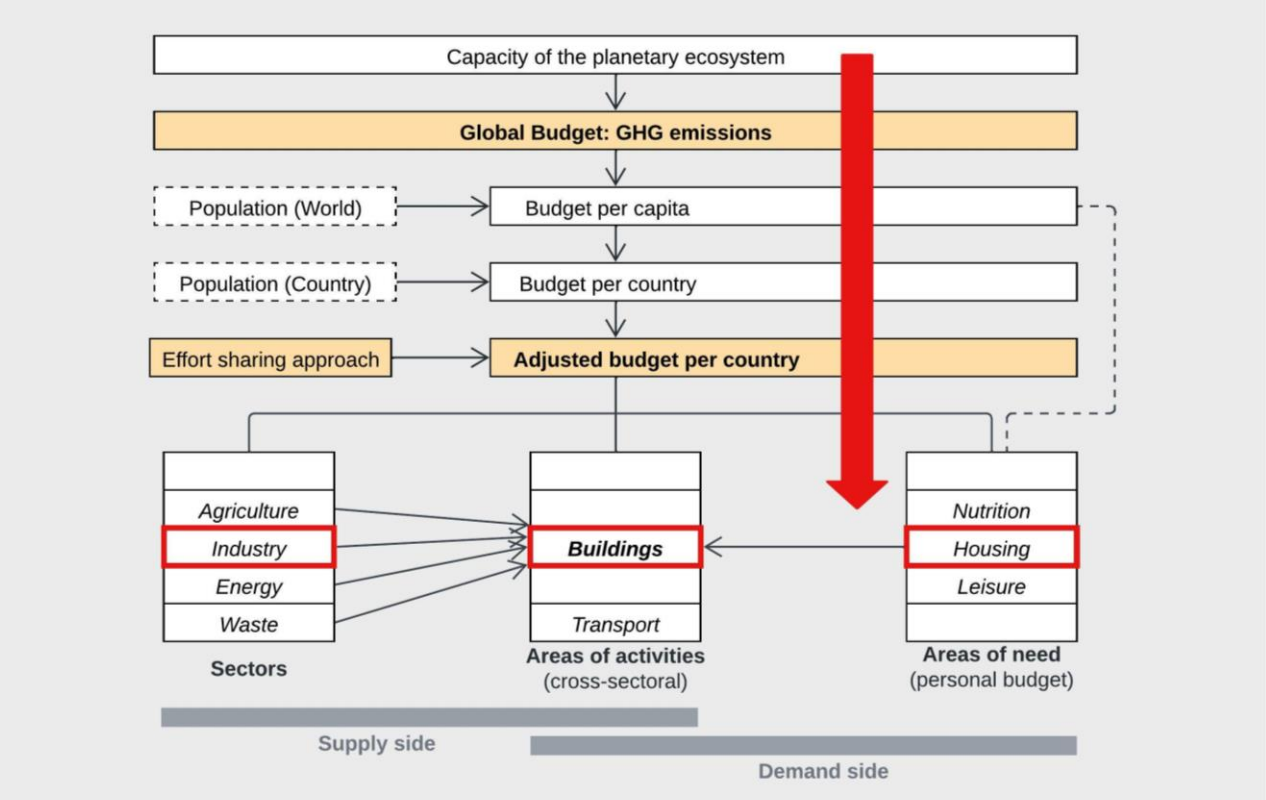

Figure 1.7 Different points of view for defining budgets across activities. The industry sector includes the construction product industry, construction industry and real estate industry. The agriculture sector includes by-products used as bio-based building materials (adapted from Habert et al., 2020).

Science-based targets are no longer geared to the technical and/or economic feasibility to achieve them, but on a scientifically justified necessity to respect the finite nature of the environment. However, the immediate adoption of such an approach would result in economic consequences as well as may not be socially acceptable yet.

Consensus on process is needed to narrow the gap between bottom-up approaches starting from technical and economic feasibility and top-down approaches, starting from planetary boundaries or different data sources (Habert et al., 2020). However, the question of reachability of science-based target values is no longer in the foreground. If these are not feasible in the short-term, they can be adopted as medium to long-term targets (here in terms of values that are to be achieved in 10 years and more) and can be supplemented by a step-by-step plan for achieving them. Bottom-up derived requirement levels and target values can always be in place for the present situation or for short-term considerations. They are to be interpreted as an intermediate step in the direction of the medium to long-term goals, resulting in a "lowering path". A detailed and temporally fixed lowering path offers industry and practice the opportunity to prepare for the next, now known, level of requirements as earlier mentioned.

In this report, the target of net zero carbon/GHG emissions, also called carbon neutrality or climate neutrality, is seen as a special type of top-down benchmark. It most likely involves the additional consideration of balancing and/or compensations (Section 5). Looking for a middle ground between science-based targets on the one hand (e.g. the climate neutrality necessary to maintain the ecosystem in its current form) and the consideration of technical and/or economic feasibility on the other hand has led to solutions such as "nearly zero" buildings in the past[2]. This can be interpreted in such a way that the goals identified as necessary should be achieved as far as possible. This compromise is unsatisfactory, especially if the “nearly” is not defined and there is room for multiple interpretations. This solution is therefore classified here as a phase of transition. Several countries (e.g. Denmark) continue to orientate themselves towards economic feasibility

[2] E.g. Germany’s Climate action plan 2050

when it comes to legal requirements, but are discussing top-down approaches in research (Andersen et al., 2020). In Germany, top-down approaches are being discussed for funding, while in Switzerland, they form the basis for standards since 2010 (e.g. SIA 2040). The term "nearly" has found widespread use, particularly in Europe, in connection with buildings with low energy requirements (nearly zero energy building)[3]. Although a "nearly" opens up political leeway and can contribute to acceptance in a transition phase, the disadvantages outweigh the advantages. Clear benchmarks are required when designing buildings, when providing evidence of compliance with legal requirements or requirements set as part of funding programs or sustainability assessment systems.

The development is currently being driven by different forces. While science concentrates on methodological questions and is oriented towards science-based targets, policy makers focus on the perception of responsibility and the fulfilment of a role model in building by the public sector. Appropriate coordination with business and the consideration of the economic feasibility in particular cost time. In some countries, the concept of economic efficiency is currently being reinterpreted. According to this, a socially recognized goal (e.g. climate neutrality) should now be achieved with the lowest (life cycle) costs. What is new is that city administrations are striving for a role of their own. If the legislative process takes too long, they try to compensate for this with local requirements[4].

1.2.3 Benchmarks vs set (system) of benchmarks

In the context of this report, it is assumed that more than one indicator is used to describe, assess and specifically influence the environmental performance of buildings. Each of these indicators must initially be provided with specific assessment criteria independently of the others. In the case of complex assessment tasks, it is possible to agree on a list of binding indicators, which can be supplemented voluntarily by additional indicators. A core list of indicators is mentioned in Section 4.4 of the A72 report by Lützkendorf et al. (2022) which is aligned with international standards such as ISO 21929-1:2011 and ISO 21931-1:2010 (under revision, new version expected in 2022), as well as European standards such as EN 15978:2011 (under revision, new version expected in 2022).

The revision of the latter standard which recommends the indicators to be used bindingly or voluntarily when assessing the environmental performance of buildings is in progress and has not yet been completed as of February 2022. The versions of 2010 and 2011 are still in force. The assessment of the environmental performance requires, among other things, the availability of suitable data on building products and technical systems. A list of current indicators to be used in Europe for the description of environmentally relevant properties of construction products is the subject of EN 15804: 2012 + A2: 2019. It contains both mandatory and voluntary indicators. Reference is made here to the fact that many non-European countries and in particular manufacturers, service providers and EPD program operators also use the current version of EN 15804 as a basis. There is a transition period for the provision of up-to-date product information. It cannot be assumed that these are immediately available. Nevertheless, it is recommended here to use the binding list of EN 15804 (2019) as a basis for a core list of indicators for an assessment of the environmental performance of buildings and to compare this later with the future EN 15978-1.

Some indicators may be considered more critical than others in the sense that they are important in different ways for the preservation of the natural foundations of life and sustainable development. ISO 15392 (2019) *Sustainability in buildings and civil engineering works — General principles* assumes, however, that criteria and indicators are derived from the objects of protection (usually identical to the endpoints of a life cycle assessment) and protection goals and that these are to be regarded as equal and must be considered simultaneously. In any case, the question of the importance of criteria and indicators arises when they are weighted or aggregated, or as soon as the indicators show conflicting trends and comparisons.

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[3] See: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_de
[4] See: https://www.london.gov.uk/sites/default/files/wlc_guidance_consultation_version_oct_2020.pdf and https://www.embodied-carbonpolicies.com/

In the context of this report, it is assumed that the aspects of resource conservation and environmental protection are equally important. Environmental protection includes climate protection. An extended number of environmental indicators can be applied to the: (1) Formulation of a system of environmental targets of equal importance ("design space"); (2) Formulation of secondary environmental requirements.

Apart from environmental requirements (which are here the focus), it is important to note that all resulting individual measures (e.g. for climate protection) must be subjected to a complete sustainability assessment. If there is a political or practical interest in a limited number of indicators, the following options exist:

– Selection of the most important indicator(s) (particularly critical for ...)
– Identification of proxy indicators (i.e. indicators that can reliably indicate the direction of multiple impacts - e.g. better PE results would always lead to better GWP results, but not in exact analogy)
– Partial or full aggregation of a longer list of indicator results using a weighting method

Bottom-up benchmarks can be statistically derived for any type of indicator as long as these are calculated for the same sample of buildings. In this way it can be ensured that the individual requirements are in a realistic relationship to one another, insofar as this is the goal. Of course, a "best in class" approach can alternatively be pursued and implemented for each individual indicator.

Science-based targets for individual topics / indicators are initially developed completely independently of one another and are based exclusively on the planetary boundaries. The sum of the science-based targets on relevant sub-topics forms the safe operating space, comparable to the "design space" or "target space" known from design processes. While top-down target values based on top-down approaches are of interest for all kinds of environmental impacts that are dealt with in Annex 72, individual attempts to specify target values have so far focused mainly on GHG emissions (see Table 1.1).

Table 1.1: Top-down targets (budgets) per m^2 for GHG emissions found in literature. Note: (1) Values refer to different types of buildings, cover various life cycle system boundaries and follow differing starting points for their derivation, which makes them incomparable (adapted and expanded from Habert et al. 2020); (2) the only studies looking at indicators other than GHG emissions are Andersen et al. (2020) and Brejnrod et al. (2017) (see Table 4.17).

Source		Top-down (life cycle-based) target values for GHG emissions (kg CO_2e/m^2yr)	
Literature	Bullen et al. (2021)	2.8-6	Office buildings
	Mclaren et al. (2020)	0.18-0.25	Residential buildings (various types)
	Andersen et al. (2020) Brejnrod et al. (2017)	0.6-8.8	Single-family houses
	Hoxha et al. (2020)	5.1-5.8	New and refurbished buildings
	Hollberg et al. (2019)	6	Single-family houses
	Pálenský & Lupíšek (2019)	16.5–26.8	Residential buildings (various types)
	am Tinkhof et al. (2017)	15-27	Various building types
	Hoxha et al. (2016)	11-20.3	Various building types
National method	SIA 2040 (SIA, 2017)	10-12	New and refurbished buildings
	LCAQuick (Dowdell et al., 2020)	5,9[5]	Single-family houses

[5] See: http://www.buildmagazine.org.nz/assets/PDF/Build-177-35-Design-Right-Design-To-Cut-Carbon-The-Time-Is-Now.pdf?. This number occurs if we assume 200m[2] floor area and 30 years' time period for the budget (decarbonization after 2050).

1.3 Use of Benchmarks Along a Project Management Process

Ideally, at the beginning of a new building or refurbishment project, requirements for its life cycle-related environmental performance are formulated, in addition to the agreed and assumed requirements for its functional and technical quality, as part of the client's brief (see EN 15643:2021). These can be defined for one or more indicators using benchmarks in the sense of limit/target values.

As far as they exist, legal requirements for energy performance, carbon performance, resource efficiency, protection of health and environment etc. must first be complied with. The client/ building owner (but also funding programme operator or sustainability assessment provider) is responsible for the additional requirements to be agreed upon. These can go beyond legal requirements and/or supplement them with additional topics/indicators. When setting such goals, the client/building investor or owner will initially orientate himself on sustainability assessment systems, funding programs, requirements and assessment criteria of banks or analysts, published target values, etc. In some cases, institutions (companies, the public sector) usually have in place their own requirements and target values; examples are green public procurement or voluntary commitments such as climate-neutral building stock, climate-neutral campus, etc. Individual clients/ building owners can also formulate goals that go far beyond legal requirements.

Compliance with statutory, agreed upon or self-selected benchmarks must or can be communicated to third parties (e.g. banks, insurance companies, society) in such a way that they can evaluate the level of environmental performance achieved or the level of achievement of selected partial parameters (carbon footprint). A process arises in which: i) the goals are defined at the beginning and, if necessary, become contractually fixed, ii) the fixed goals are continuously checked with regard to their attainment during design and, iii) the final degree of goal attainment is determined when the building is completed and at handover (as built") and, if necessary, is communicated to the client as well possible third parties. The process of "continuous improvement" begins during the use phase. The planned performance must be confirmed by the "real performance" achieved under actual conditions of use. If the actual use deviates from the originally planned use, the benchmarks must be adjusted to generate new target values. Such target values are important for facility management as far as consumption data (e.g. energy consumption) and variables derived from this (e.g. energy-related GHG emissions during the use phase, caused by operation) is concerned.

A few points to notice in connection with this ideal process are:

- **Selection of benchmarks**. The development defines and takes the context into account; the application is linked to the context taken into account in the development. Therefore, the benchmarks selected to support the design process must correspond to the object under consideration (building types/uses such as residential, office and hospitals, as well as new/refurbishment as variants) and be inextricably linked with the calculation rules and system boundaries as well as the data used.
- **Compliance with partial benchmarks and/or target values as an assumption (proxy) in the early design steps**. In the early design steps, the information required for detailed calculations of energy demand/energy consumption is often not yet available. This also includes information on the specific energy systems to be installed in the building. Nevertheless, expected operational energy consumption, expected GHG-emissions and/or expected operational energy costs (among others) must be determined early enough in the process. One approach is <u>to assume compliance</u> with the required or agreed limit or target values on energy demand or other 'physical' values. Assuming that e.g. the goals for energy performance are met, energy consumption, expected emissions and energy costs can be estimated without having already planned a specific heating or lighting system. Another approach is to use a tool allowing both energy and LCA calculations to be performed in early design, e.g. using default values.
- **Handling of different level of detail and/or databases during design and decision-making process**. In the early design steps, compliance with the chosen benchmarks is assessed on the basis of a more simplified level of design detail than in the later design steps. Sometimes specific data (generic, sector EPD) or data bases or specific parts of a data base are in place. To meet legal requirements or the

requirements mentioned in funding programs, evidence of compliance is often required as part of the design approval. There are still uncertainties at this phase regarding environmental performance - see A72 report by Lützkendorf et al. (2022). How to deal with these uncertainties needs to be clarified. The method on which the benchmark is based must clarify this by specifying scenarios, calculated values and safety margins, among others. The condition at handover is decisive for the proof of warranted characteristics/ compliance with requirements. However, the building permit is sometimes based on the results of earlier design steps. The problem may be solved on the side of benchmarks by introducing early design benchmarks and detailed design regulatory benchmarks[6]. Benchmarks based on planetary boundaries are and need to be independent of the design step. In these cases, the solution of the problem shifts to the side of the calculation rules which should include ways of dealing with uncertainties.

1.4 Target audience and application cases

Methods to determine and assess the greenhouse gas (GHG) emissions in the life cycle of a building as part of its life cycle environmental performance assessment has been the subject of scientific discussion for decades. The dissemination in science, policy as well as building design and construction practice has been furthered through the increasing availability of generally recognized bases for the life cycle assessment, the willingness of the industry to provide environmental product information as well as the development of new aids in the form of databases and design tools. Nevertheless, in the past, the use of the recommended indicators and methods remained limited to individual cases.

The results of an environmental performance assessment are nowadays having a growing impact on the rentability and marketability of buildings, the financial value of real estate and its development, the economic risk, the terms of financing and insurance, and the reputation of owners and users. In contrast to a more scientific discourse, one aim is now to arrive at legally binding/court-proof assessment statements based on generally recognized methods with no room for misinterpretation or multiple interpretations. This issue is currently being faced by countries that are carrying out or planning legislative procedures to limit GHG emissions in the life cycle of buildings and would like to transfer such procedures in future to other environmental impacts (e.g. impacts on human health, biodiversity losses, use/depletion of natural resources).

Table 1.2 identifies all actors / stakeholders to whom the content of this guideline document is primarily directed. A distinction is made between groups of actors who:

a. are directly involved in the development/refinement of life cycle-oriented environmental benchmarks to support environmental performance assessments of buildings
b. apply the benchmarks provided by actors under a), or integrate them into design tools, and therefore have an in-depth and ready-to-use methodological knowledge.

This specific report provides rules, recommendations and background information to support mainly, but not limited to the application cases outlined in Table 1.3 and Figure 1.8.

An **application case** is understood here as the use of this guideline by different actors for the purposes of developing and defining benchmarks, performance level and limit / target values. In contrast to the application case for the use of this guideline, **use cases** exist for the application/ use of the benchmarks themselves.

[6] It should be noted that the most usual case in different countries is to have benchmarks identical across all design steps.

Table 1.2: Structure for the group of actors – ready to identify the target group of the report

Nr.	Group of actors/stakeholders	Benchmark developer or user?	d – direct i - indirect
1	Researchers, - basic research on LCA	User	i
2	Researchers – applied research	Developer	i
3	Policy, regulation and law makers	Developer	d
4	National standardisation bodies	Developer	d
5	Developers and providers of funding programs	Developer	d
6	Developers and providers of sustainability assessment systems	Developer	d
7	Developers and providers of design tools	User (& sometimes developer)	i
8	Database developers and providers	User	i
9	Designers/architects and engineers	User	i
10	LCA consultants and service providers incl. sustainability/ESG consultants	User (& sometimes developer)	i
11	Construction product manufacturers	User (& sometimes developer)	i
12	Construction companies	User	i
13	Facility managers	User (& sometimes developer)	i
14	Valuation professionals	User	i
15	Sustainability assessors/auditors	User	i
16	Financial service providers/ Insurance companies	User	i
17	Clients / Investors / Owners – Individuals / institutional / public	Developer & user	d
18	Building users	User	i
19	Society	User	i
20	Media representatives – Specialised press/ general press	User	i

Table 1.3: Application cases for the creation and use of benchmarks / performance levels.

	Application case (purpose/task)	Application of guideline	Use of benchmarks
A	Definition of benchmarks (limit values) for legal requirements[7] (e.g. roadmap in Finland, Denmark)	X	
B	Definition of benchmarks/performance scales for funding programmes[8] (e.g. KfW in Germany from 2021)	X	
C	Definition of performance level for national standards[9] (e.g. SIA 2040)	X	
D	Definition of performance scale and level for assessment systems incl. net zero definition[10] (e.g. BNB/DGNB Germany)	X	
E	Definition of performance level for Taxonomy (see EC taxonomy)[11]	X	
F	Definition requirements for green/sustainable (public) procurement[12] (e.g. Finland)	X	
G	Creation of a budget approach for national building stock[13] (e.g. climate protection plan 2050 in Germany)	X	
H	Definition of benchmarks for the environmental performance of existing buildings	X	
I	Definition of internal targets by the design team (experience-based approach in design)[14]		X
K	Target setting in client's brief[15]		X
K	Communication of the achievement of performance levels or performance classes to third parties[16]		X
L	Assessment and optimisation of design solutions during the design process[17]		X
M	Quantification of assumptions in early design phases/ steps[18]		X

[7] In different countries the introduction of legal requirements to limit the life cycle carbon footprint of buildings are discussed. This requires specific calculation and verification rules including absolute benchmarks. Currently, the question arises of how to deal with different types of buildings and types of use.

[8] Various countries are discussing the introduction of funding programs, which often consist of financial support for the carbon sequestration in the construction (stored carbon), for the achievement of a carbon footprint target, or for the creation of "carbon neutral" buildings.

[9] Standards are discussed, developed or revised in various countries, which contain requirement levels for the carbon footprint or the non-renewable primary energy consumption.

[10] Different providers/organizations prepare or further develop environmental performance assessment systems. For individual criteria/indicators there is a need for assessment standards (performance level).

[11] In Europe, the principles are currently being processed, which should lead to favourable financing conditions for buildings (new construction, purchase, refurbishment) that contribute to sustainable development. Specific requirements for the energy or environmental performance are discussed.

[12] Institutional and in particular public clients increasingly formulate requirements for the environmental performance of buildings – in principle, minimum requirements or target values –to be met.

[13] In various countries work is being done on sector targets for the construction sector. Among other things, it indicates how much CO2 or GHG may still be emitted in a given period or at a given date. This corresponds to a target value.

[14] Benchmarks can be defined for early design stages by the design team that can be different than the ones provided in official requirements duet to the lack of data.

[15] In early design stages, specific project goals should be defined. To do so, requirements from legislation, building codes, standards or funding programs, assessment standards from certification systems or other target values are used.

[16] In various countries, instruments such as the energy performance certificate EPC are used to signal the achievement of performance levels or the classification in performance classes.

[17] During the design process, calculated values can be compared with relative or absolute benchmarks or performance levels to assess and optimize individual design variants.

[18] In early design phases, compliance with benchmarks can be assumed as an assumption. Thus, benchmarks can serve as input for other considerations. (For example, the assumption of a level of energy performance may be the input to estimating energy costs).

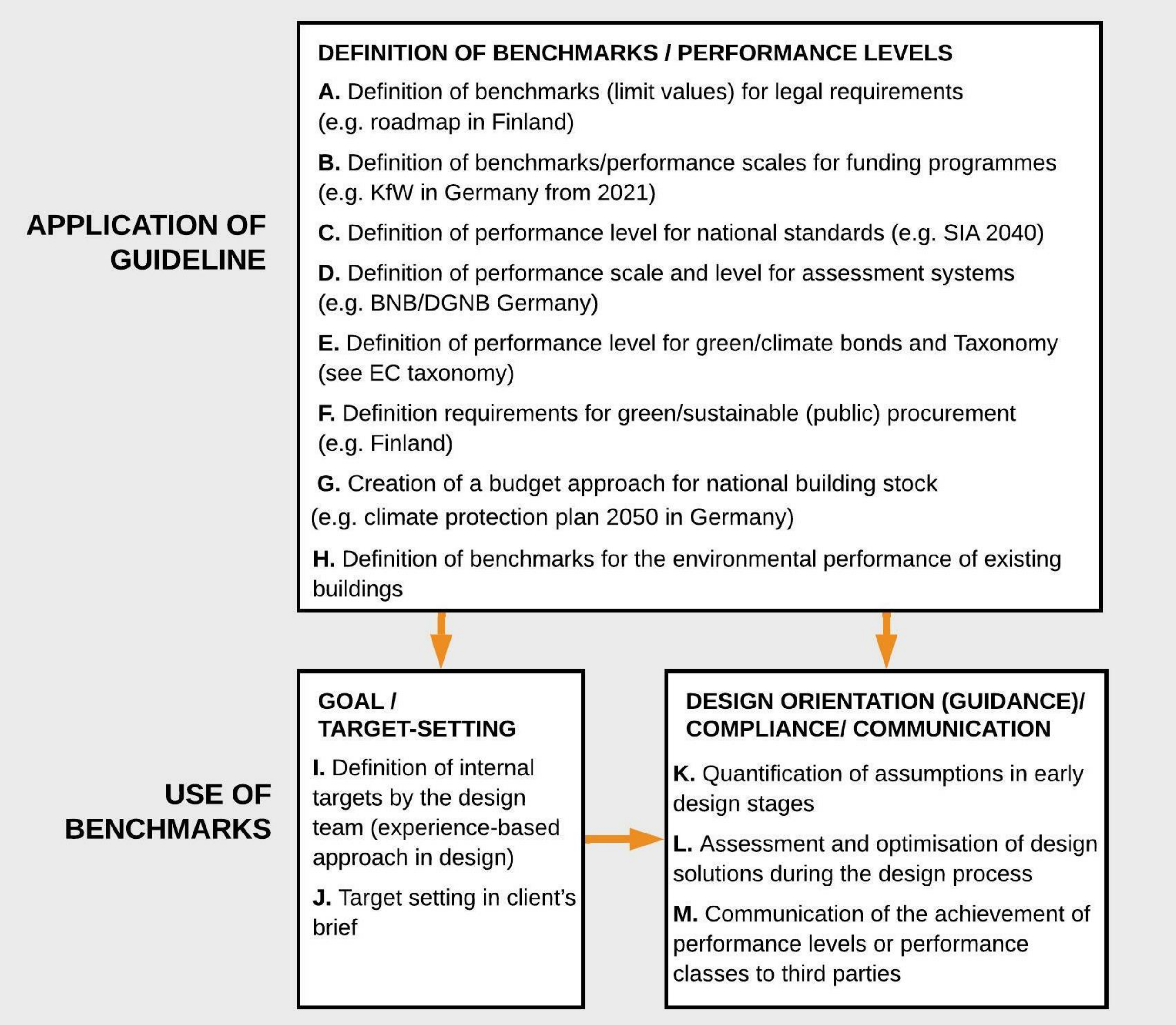


Figure 1.8: Application cases of this report and use cases of benchmarks. Note: The activities mentioned in the figure relate to the design of new construction and refurbishment projects for individual buildings. They can be transferred analogously to activities in the context of national, regional or institutional building stocks.

1.5 Purpose and Objectives of this Report

This report focuses on methodological issues related to the determination and development of benchmarks to support the assessment and presentation/communication of the life cycle-related environmental performance of buildings. It interprets, complements and enlarges the content of **ISO 21678:2020** *Sustainability in buildings and civil engineering works — Indicators and benchmarks — Principles, requirements and guidelines* in an effort to make it more manageable. The purpose of this report is to provide the foundations to responsible actors for further developing their specific methods to create life cycle related benchmarks for the non-renewable primary energy demand/consumption, GHG emissions and further environmental impacts of buildings and to increase the mainstreaming of practice globally.

This guideline covers:

– General principles and recommendations for the development of benchmarks and target values based on a bottom-up approach (technical and economic feasibility) and a top-down approach (science-based targets to define a safe operating space inside planetary boundaries)
– General principles and recommendations for the application and interpretation of benchmarks
– General principles and recommendations for the documentation and communication of benchmarks
– Recommendations for terms, definitions, system boundary and offsetting rules to provide transparency regarding absolute zero or net zero GHG emission benchmarks (climate neutral buildings).

The specific objectives of this report are to:

– clarify methodological questions with respect to the development of benchmarks to aid low carbon and low environmental impacts for construction, operation and end of life.
– provide a consistent and transparent basis for a reporting structure for environmental benchmarks in line with international standards
– contribute to the interpretation and supplementation of international standards to improve their applicability and support their dissemination
– promote long-term and life cycle-based thinking, by encouraging the early consideration of likely future environmental impacts regarding maintenance, repair and replacement as well as of durability and adaptability of building components and the building as a whole
– contribute to the overall efforts of national governments and standard makers to guide construction and real estate industry on how to respond to climate change and other mega trends like depletion of natural resources

1.6 How to use this Report

This guideline is aimed at people and institutions who are involved in the development and refinement of benchmarks. Both an overview of the methodological issues to be considered and assistance in the form of rules (i.e. shall) and recommendations (i.e. should) for action are given. The rules and recommendations for action are a result of the work of IEA EBC Annex 72 and are based on intensive opinion-forming and coordination processes among the researchers representing the project's 25 participating countries.

A rule is understood here as a suggestion for what must be done as a minimum for the further development of benchmarks. A recommendation, on the other hand, provides guidance that, when followed, should improve the procedure of developing and/or using benchmarks. Therefore, the former has a more binding character than the latter. Recommendations were formulated in particular when there were several options for action and there was no unanimity among A72 experts for a rule. In some cases, corresponding passages are marked as majority statements.

Except for Sections 2 and Section 3 which provide some basics and overview of existing benchmarking systems, each subsection of Sections 4-6 addresses a specific question and contains

- an introduction to the sub-topic and problem
- harmonized rules, if necessary, references to specific options to act in the context of concrete application cases
- recommendations for action for benchmark developers and benchmark users

This report is supplemented by two background report(s) for which links are provided in the relevant subsections. These two background reports cover the following topics in more detail:

- *Documentation and analysis of existing LCA-based benchmarks for buildings in selected countries* (Rasmussen, Trigaux, Balouktsi, et al., 2023)
- *Rules for assessment and declaration of buildings with net-zero GHG-emissions: an international survey* (Satola et al., 2023)

2. Types, Hierarchies and Sources of Benchmarks

2.1 Types of Benchmarks

2.1.1 Building-type specific versus universal benchmarks

In the past and present, all environmental performance requirements have been tailored to specific types of buildings with regard to their function. Since databases, calculation rules, assessment rules and benchmarks form an inseparable unit, most existing benchmarks are applicable to specific types of buildings. Typical applications are residential buildings, office buildings, educational buildings, etc. See also the A72 background report by Rasmussen et al. (2022). In most cases building-type specific benchmarks are applicable to all buildings within a building type and are not further specified (e.g. acc. to number of floors, intensity of use, etc.), except for residential buildings which may be further specified in selected cases, such as single-family or multi-family. Therefore, the advantages and disadvantages of a stronger differentiation within a type/use of building should be discussed. If a further differentiation is made for building groups (e.g. single-family house versus multifamily residential building, low rise versus high-rise building, etc.), a comparison should be made with the overall goals for the building stock. This requires a model for the national building stock.

In general, this raises the question of the underlying 'justice model' according to which a goal for an entire stock is shared among the individual buildings of the stock. For example, if an overall carbon budget is available for the entire national building stock from today until a certain future year, is this be distributed equally to buildings regardless of their type and particular site conditions (among others)? For example, a building may be constructed on a site containing very challenging soil conditions that requires deep foundations. This may be associated with high embodied impacts, even if the building is of low carbon design above ground. Therefore, is a higher budget allowance granted (or not) to buildings with difficult site conditions or otherwise higher life cycle impacts that can be justified (e.g., there is a new approach by the Danish BUILD institute to calculate a potential allowance of exceedance of the Danish limit value for problematic building cases[19])? In a pure justice-based effort for budget sharing, all additional impacts caused by building- and location-specific peculiarities are compensated for by the building design itself (no allowances are granted).

With the demand for climate-neutral buildings or building stocks by 2050 (e.g. Germany (BBSR & BBR, 2021) and Europe (EC 2018), or even 2030 (e.g. Architecture 2030 challenge (2021)), a universal requirement/uniform goal for all kind of buildings irrespective of their function is being formulated for the first time. However, the verification of compliance must continue to be adapted to the specific type of building as well as to regional and climatic, cultural and socio-political characteristics. For example, a "net zero" level for selected criteria can be achieved and proven differently for residential buildings than office buildings. A corresponding benchmark can therefore only be interpreted correctly if the system boundary, calculation and verification rules are known. Corresponding rules must be formulated for this.

Regarding universal benchmarks, a distinction is made here between:
– universal in relation to a certain building type (climate-neutral office building)
– universal independent of the building type (climate-neutral building)
– universal in the meaning of globally acceptable
This topic is dealt with in more detail, including the provision of guidance, under Section 5.

[19] the report "CO2 requirements and special building requirements" can currently only be found in Danish. For more information, see: https://www.lcabyg.dk/en/publications/

2.1.2 Benchmarks for new buildings and/or refurbished buildings

The design of new buildings and the preparation of refurbishment projects are typical tasks for designers based of the brief of their clients. It can be assumed that the rate of refurbishment will increase in selected regions (e.g. (EC, 2020). It is therefore necessary not only to formulate the benchmark requirements in the context of new building projects, but also to consider the refurbishment cases.

In principle, identical requirement levels should be achieved for new building and refurbishment projects, as it is important to meet the functional and technical requirements that are necessary for the upcoming use stage or that have been agreed with the client. However, the starting situations are different. The continued use of existing building fabric in the event of renovation/refurbishment leads to advantages and disadvantages. On the one hand, it may limit the range of possible technical and functional solutions; on the other hand, by continuing to use existing building parts, it can conserve resources, contribute to the preservation of cultural values or reduce the current amount of waste. These unique attributes can be considered by formulating identical requirements with regard to their life cycle or the remaining useful life, however, partial parameters for an embodied or operational part, in particular for primary energy, non-renewable or for GHG emissions differ. Compromises in the operational share can be compensated for by conserving resources as a result of the continued use of the existing building fabric. Such life cycle-based benchmarks fit both new buildings and refurbishments, while providing the possibility of compensation between the operational and embodied part, which can be seen e.g. in German sustainability assessment systems (BNB, DGNB and BNK) as well as design tools such as PLEIADES ACV EQUER.

Other benchmarking systems follow a different approach and distinguish between new buildings and refurbished buildings (e.g. see Table 2.1, the Swiss benchmarks for 2000-Watt-Society buildings according to the technical bulletin SIA 2040). Empirical evidence and feasibility studies in preparation of the Swiss standard SIA 2040 showed that life cycle-based benchmark values for refurbished buildings may even be stricter than those for new buildings because technical low energy/low impact solutions are available to lower the use stage impacts (the embodied impacts being distinctly lower anyhow).

When making relevant specifications, however, it should be borne in mind that somewhat less strict (in the sense of easier to achieve) requirements for the values to be achieved in the use stage can motivate builders/investors to decide in favor of refurbishment. A system of different binding benchmarks (requirements) for refurbishments and for new buildings (possibly weaker compared to new buildings) but the same demanding (non-binding) target values is proposed. In the future, requirements in the direction of net zero GHG emission buildings will apply to both new construction and refurbishment projects - see also Section 5.

2.1.3 Binding benchmarks versus non-binding guide values

When designing a new building or refurbishment measures for an existing one, it can be helpful to use non-binding **guide values** in addition to binding requirements. These values are not seen as benchmarks in the strict sense but rather as orientation/guide values for design improvement and optimisation since they usually constitute typical magnitudes. A typical example is the use of guide values for embodied and operational emissions with otherwise binding requirements for reducing GHG emissions in the life cycle of buildings (e.g. this is the approach followed by SIA 2040:2017, also shown in Table 2.1).

Non-binding guide values for embodied impacts can also be derived for individual building parts (components/elements) as a further level of granularity to provide direct support to designers in the early design stages (see example in Figure 2.1). Such level of granularity has not been investigated in the Annex 72 cases of existing benchmarks (see A72 background report by Rasmussen et al. (2023), although there are few examples in research literature (Hollberg et al., 2019; Marsh et al., 2018).

Table 2.1: Breakdown of binding values (target value) and non-binding values (guide value) for new residential buildings and conversions (aka refurbishments) acc. to the technical bulletin SIA 2040 (SIA, 2017). Note: mobility is usually not included in the benchmarking attempts of countries, Switzerland is an exception. Therefore, the last row is highlighted as most important.

Residential	Primary energy, non-renewable (kWh/m^2_{HFA}* year)		Greenhouse gas emissions (kg/m^2_{HFA}*year)	
	New building	Refurbish-ment	New building	Refurbish-ment
Guide value construction	30	20	9,0	5,0
Guide value operation	60	70	3,0	5,0
Guide value mobility	30	30	4,0	4,0
Target value	120		16,0	14,0
Additional requirement construction + operation	**90**		**12,0**	**10,0**

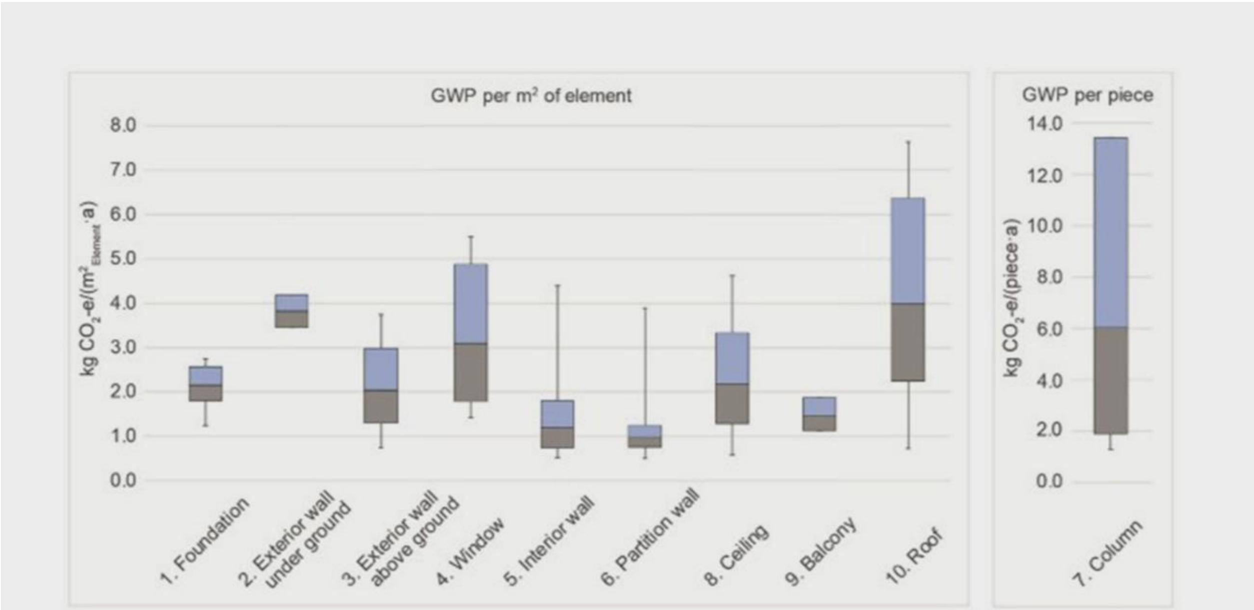


Figure 2.1: Variability of different elements per m^2 of element (1-6) and variability for the columns per piece (7) based on Hollberg et al. (2019)

2.2 Hierarchy of Requirement Levels

Benchmarks can be organized either in terms of an absolute or a relative requirement value or in the form of different requirement or performance levels or performance classes. Often, systems of performance levels (see definition in section 2.1) are developed and used (i.e. systems introducing more than one performance level) - in the sense of a **performance assessment scale**. A performance assessment scale can be designed (linear, logarithmic, with jumps, etc.) and subdivided in various ways. The minimum subdivision recommended in ISO 21678:2020 standard is into limit, reference and target values. A performance assessment scale can only be used in conjunction with concrete calculation and assessment rules (guideline/framework).

There are two options for a visual representation of benchmarks and target values as specific performance levels in a performance scale. Both are linked by the principle of showing the positive direction of performance (i.e. in which direction it will be better to move).

a) Representation according to the hierarchy of the requirement levels

In this representation, the minimum (weakest) requirement levels expressed via the limit value are shown at the bottom of the assessment scale, while the goals (i.e. strongest requirement levels) at the top of it, regardless of whether the limit value is the highest or lowest acceptable value (or the target value the highest or lowest desirable value) according to the particularities of the measurement specification and the indicator – see Figure 2.2. This way of representation is in compliance with ISO 21678. As earlier mentioned, it is always useful to have a distinction between short-, medium- and long-term goals and ISO 21678 recommends that assessment systems contain these in parallel (e.g. target value I - short term; target value II - medium/long term).

b) Representation according to the specific values

The specific benchmarks are given here on a scale with specific values. In this case, the positive direction of action consists in reducing the values. For example, for the indicator GHG emissions illustrated in Figure 2.2 the positive direction of performance is decreasing in value from top to bottom. On the other hand, If the indicator would have been the share of building products that can be recycled at the end of life, the positive direction of performance would have to be shown in the form of increasing values from bottom to top.

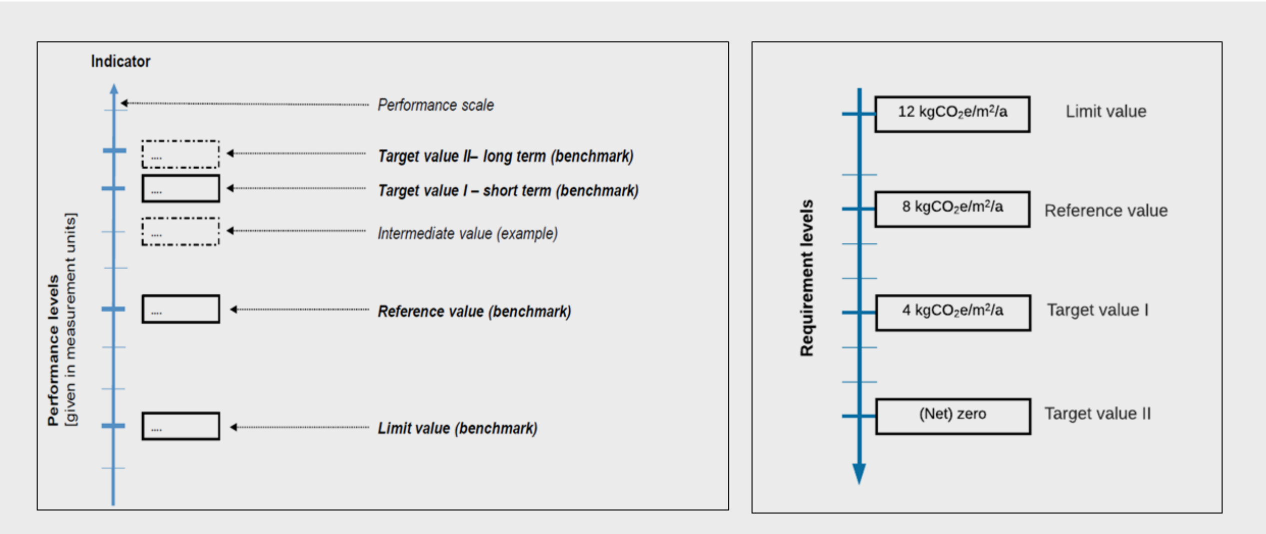


Figure 2.2 Left side: Example of a requirement-based performance assessment scale with limit, reference and target values as a minimum recommendation by Annex 72 and in compliance with ISO 21678 (Adapted from ISO 2020). Note: There may be a set of reference values (not a single value) which can correspond to classes from A to G in a label (see also Section 6.2). Right side: A value-based performance assessment scale (values are indicative).

It becomes clear that with a representation according to b) the desired direction of the indicator influences the representation. The representation according to a) thus proves to be a more robust and generally applicable variant.

2.3 Sources of Information for the Development of Benchmarks

Examples of the different sources of information for the different types of benchmarks are provided in Table 2.2. It becomes clear that, in particular, the interpretation of limit and reference values and thus also the way they are derived from different sources results from the specific application context - see also cases I) to III).

Table 2.2: Sources of information as a basis for derivation of different types of benchmarks (partly based on ISO 21678)

	Hierarchy levels			
Source of information	Limit value	Reference	Target value I	Target value II
Statistics	X	X	X	
Surveys having an adequate sample size	X	X	X	
Theoretical calculation	X	X	X	(x)
Legal and regulatory requirements (with performance levels)*****	X	X	(x)	
National standards (with performance levels)*	X	X	X	
Demonstration projects		X	X	
Policy objective			X	X
Planetary boundaries/ science-based targets			(x)	X

*Notice that the values obtained from the two sources of information can be based on statistics, surveys, policy objectives, etc.

2.3.1 Sources for limit values / basic requirements

Limit values in the sense of minimum requirements are, in most cases, set by regulations or defined in national standards. Those define minimum upper or lower values for different aspects of performance.

Limit values may be certain percentile values or may be based on the calculation of cost-optimal levels, economic and technical feasibility, or some combination of both. These shall be based on a comprehensive assessment that covers the methods of assessment, assessment results and assessment of the local relevance of the results.

Effective implementation of legal/regulatory minimum or maximum environmental values requires that such values are based on a knowledge of:

- the current performance of existing or new buildings that belong to the same type of building that is the object of consideration;
- the technical feasibility of the limit value;
- the economic and social feasibility of the limit value.

Upper and lower limit values for buildings and other types of construction works shall be based on reliable and transparent information about the current performance and the feasibility of these values. The minimum information needed in the development of limit values shall be locally relevant statistical information or other collected information or assessed/calculated information. In the process of establishing limit values the source of any databases, methods and tools needed in the design, construction and operation of buildings or other types of construction works, by those who are responsible for meeting the limit value, shall be provided or identified. Life cycle-based limit values can differ between, new buildings and refurbishment buildings. In the case of existing buildings, requirements and targets usually only exist as partial values for the operational part but benchmarks may exist on life cycle impacts (e.g. A to G label in French assessments, Swiss SIA 2040).

2.3.2 Sources for reference values

Reference values are often used in the rating scales of sustainability certification systems. They often arise from national or international collaboration by different stakeholders (such as owners, investors, designers, contractors, building authorities and researchers).

Reference values may be based on:
- local relevant statistical information about the performance of building type or other type of construction work;
- local surveys based on representative samples of the performance of building type or other type of construction work;
- theoretical assessment of a building type or other type of construction work (e.g. reference building);
- demonstration projects.

A reference value may also be identical to a limit value. For example, if any new building or other type of construction work needs to fulfil a minimum/maximum legal requirement or national standard, this is also a reference value.

The development of reference values based on economic or technical optima shall be based on a comprehensive assessment. Information about optima shall cover the description of methods of assessment as well as of local boundary conditions taken into account (legislation, price levels, availability of technology and products, local construction methods). The scale shall be based on a good understanding, as a result of statistics, calculations or specific and adequate surveys of the performance of the building under study.

2.3.3 Sources for target values

It has been discussed already under Section 1.2.2. In addition, best in class values can also be used. Best practice indicates the local best practice performance level of building types or other types of construction works types. The development of benchmarks using a best practice approach shall be based on an adequate understanding and knowledge of the technical and economic preconditions that enable their achievement. When information about best-practice-based target values is made available, the technical and economic feasibility and the local relevance of the values shall also be given.

3. Existing Approaches and Challenges

3.1 Overview of Existing Approaches in Selected Countries

To understand the different points of diversity among existing benchmarks and benchmark systems, a collection of cases of existing benchmarks has been provided by country representatives as part of the IEA EBC Annex 72 project and presented in a A72 background report by Rasmussen et al. (2023). Table 3.1 and Table 3.2 provide a summary of their differences in relation to their background (i.e. Different benchmarks exist in parallel within defined regions for laws, funding programs, assessment systems or voluntary commitments), calculation base, scope, as well as in relation to their structure and approach (benchmark types and hierarchies as earlier described, bottom-up vs top-down approach). At the same time, Figure 3.1 provides the spread of the reported values focusing on the GHG emissions indicator as an example. The following key points arise from the analyses:

- **Benchmarks are mostly used for academic purposes and based on bottom-up approaches.** Only a few of the existing benchmark systems represent certification systems, voluntary standards and regulation, and only one system includes top-down target values.
- **Even though several systems include target values for GHG emissions, the majority of the reported values are reference values**, reflecting the current state-of-art, although target values are crucial pointers for the building industry and should be applied broadly.
- **Eco-efficiency focus is reflected in otherwise varying reference units**. The reported benchmarks are typically based on an eco-efficiency point-of-view, where results are assessed per m2 building area. Only one case applies an end-user perspective where a per-capita expression is used.
- **Definitions of m^2 vary notably between the cases, presumably reflecting the existing regulation on energy efficiency, but not described in detail**. Adding to this is a more general inconsistency about what type of floor areas should be included when accounting for floor area. This contributes to the difficulties of comparing values from different benchmark systems.
- **There are great differences in physical and life cycle scope and related assumptions**, but they can be difficult to report in unambiguous ways. Particularly, there is a lack of clarity about what is included for operational energy use (e.g. only building-related operation or also plug-loads?) and which elements of the building are included/excluded for the inventory. Standardisation may be on the way for both topics, but currently it is not documented in a harmonised way. Additionally, each benchmark system relies on a set of calculation rules and assumptions, e.g. concerning service life of components that are context specific, and that can hinder to report and interpret in unambiguous ways.
- **Benchmarks are reported at different level of granularity**, and special cases of additional functions may challenge development and use. Granularity refers to key parameters such as building type, project type, life cycle and inventory detailing. The Annex cases vary mostly when it comes to granularity of building type and less when it comes to inventory detailing. Special cases of additional functions (e.g. parking basement) and location-specific conditions (e.g. extra soil stabilisation) can be addressed via granularity, but can challenge benchmarks development and may call for exception rules or attention in other parts of the planning process.
- **The mapped values of embodied GHG emissions as well as for full life cycle (related to the same type of m^2 and RSP) indicate that limit-, reference, and target values for residential buildings overall are slightly lower than for non-residential buildings**. This pattern is comparable to not only previous reviews of such benchmarks for buildings (Trigaux et al., 2021). It is further observed that full life cycle GHG emission values from all Annex 72 cases (approximately 5-90 kg CO2e/m2/year) have a larger span than embodied GHG emission values (approximately 1-12 kg CO2e/m2/y).

Table 3.1: Basic characteristics of the Annex 72 benchmark cases. Life cycle stages per module as defined by EN 15978. Scope of building elements included defined as (S) structure; (F) foundation; (I) internal elements; (B) building services (Source: Rasmussen, Trigaux, Alsema, et al. (2022)). A0 module is described by Belgian method as "pre-construction".

Case	Based on	Background	Reference unit	m^2 specification	RSP	Life cycle scope	Building scope	Broad application scope
AU	Typical building in varying climate zones	Academic purpose	Impacts/m^2/year	Internal floor area including garage	50	A1-A5, B2, B4, B6$^{1-2}$, C1-C4	SFIB	New build.
BE	Statistics based on 35 archetypes	Research project on environmental benchmarks	Impacts/m^2/year	Heated floor Area	60	A0-A5, B2, B4, B6$^{1-3}$, B8, C1-C4	SFIB	New build.
CA	Statistics based on 10 buildings	Research pilot project	Impacts/m^2	Gross Internal Floor Area	60	A1-A5, B2, B4, C1-C4	SFI	New build.
CH	Derived top-down based on '2000-watt-society goals' and verified/tested against feasibility with statistics based on real buildings	SIA Technical bulletin 2040 SIA energy efficiency path	Impacts/m^2/year	Energy Reference Floor Area	60	A1-A3, B4, B6$^{1-2}$, C1-C4	SFIB	New build. + Refurb build. (separate)
CZ	Embodied: Statistics based on 200 buildings Operational: Statistics based on archetypes in 400 variations	SBToolCZ	Impacts/m^2/year	Gross Internal Floor Area	50	A1-A3, B6^{1}	SFI	New build.
DE1	Statistics based on 19 real buildings	BNK certification for small residential buildings	Impacts/m^2/year	Gross Internal Floor Area (NRF)	50	A1-A5, B1-B5, B6^{1}, C3-C4	SFIB	All build.
DE2	Statistics based on 100+ real buildings*	DGNB certification system 2018	Impacts/m^2/year	NRF	50	A1-A3, B2, B4, B6^{1}, C3-C4, D	SFIB	All build.
DE3	Statistics based on archetypes in 150 variations	BNB assessment system for sustainable building 2015	Impacts/m^2/year	NRF	50	A1-A3, B2, B4, B6^{1}, C3-C4	SFIB	New build.
DE4	Statistics based on archetypes in 50 variations	QNG quality label for sustainable buildings 2021	Impacts/m^2/year	NRF	50	A1-A3, B4, B6^{1+3}, C3-C4, D	SFIB	New build.
DK	Statistics based on 60 real buildings	Academic purpose. Study specific (resembles the DGNB-DK approach)	Impacts/m^2/year	Gross Floor Area	50	A1-A3, B4, B6^{1}, C3-C4	SFIB	New build.
ES	Statistics based on 7 real buildings	Academic purpose	Impacts/m^2	Gross Internal Floor Area	50	A1-A5, C1-C4	SFIB	New build.
FR	Statistics based on archetypes in 20.000+ variations	Equer, www.izuba.fr	Impacts/m^2/year	Net Internal Floor Area	100 50	A1-A5, B4, B6$^{1-3}$, B7, C1-C4, D	SFIB	All build.
HU	Statistics based on archetypes in 6000 variations	Academic purpose	Impacts/m^2/year	Heated Internal Floor Area	50	A1-A5, B3, B4, B6^{1}, C1-C4	SFIB	New build.
NL	Statistics based on 5 residential archetypes Statistics based on 5 real office buildings	Milieu Prestatie Gebouwen	€/m^2	Gross Internal Floor Area	75 50	A1-A5, B1-B5, C1-C4	SFIB	New build.
NO	Statistics based on 129 real buildings	ZEN Case: GHG emission requirements for material use in buildings	Impacts/m^2/year	Heated Floor Area	60	A1-A3, B4, B8	varies	New build. + Refurb build. (separate)
NZ	Statistics based on 66 real buildings	Whole-building whole-of-life framework/ LCAQuick	Impacts/m^2/year Impacts/occupant	Treated Floor Area Gross Floor Area Net lettable floor area	90 60	A1-A5, B2, B4, B6$^{1-3}$, B7, C1-	SFIB	New build.
SE	Statistics based on 68 real buildings	Research work for national authorities	Impacts/m^2	Gross floor area Heated floor area	n/a	A1-A5	SFIB	New build.

* bonus for climate neutral building status

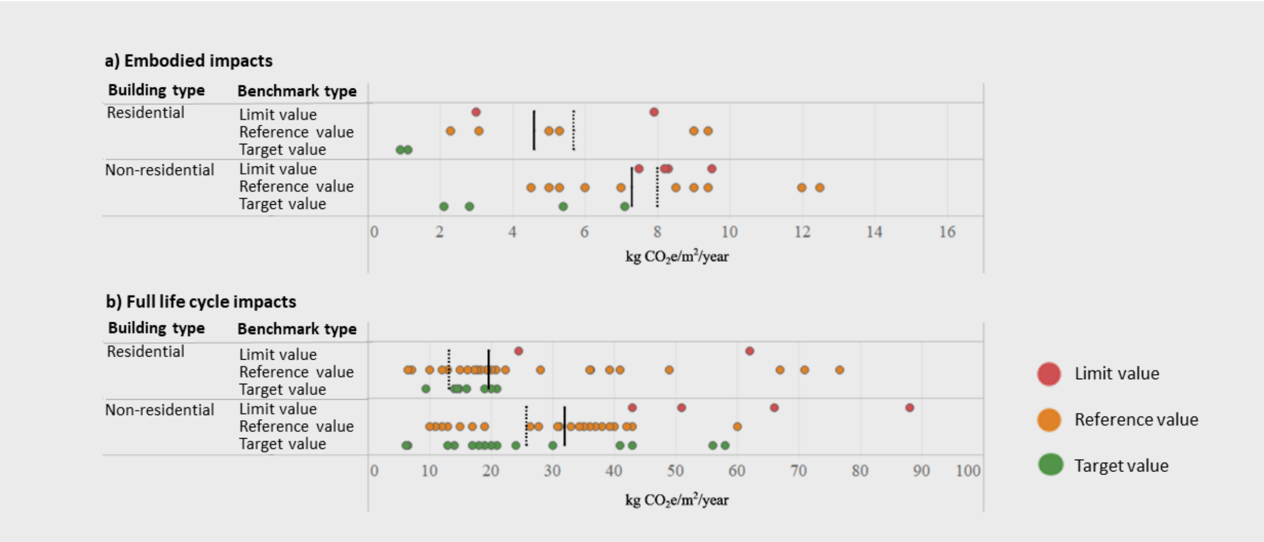


Figure 3.1: GHG emission values reported from the Annex 72 benchmark cases for embodied (a) and full life cycle (b) impacts. Median benchmark values across limit-, reference- and target values marked by a horizontal line. Median benchmark values from the benchmark review study of Trigaux et al. (2021) marked by dashed horizontal lines for comparison. (Source: Rasmussen, Trigaux, Alsema, et al. (2022)). Note: a more extensive versions of the figures can be found in the A72 background report by Rasmussen et al. (2022), showing for each country and for GWP and PEnren.

What can be expected in the background report on selected documented examples of benchmark systems from different countries by Rasmussen et al. (2023)?

1. It includes contributions from 14 countries to document details of specific LCA-based benchmark systems. The contributions were collected on a basis of a common template as well as workshops and discussions from the Annex 72 expert meetings were used to further refine data and explain background of methodological choices.
2. It shows and analyses the variations in methodological settings seen in the benchmark examples to provide a gross list of points-of-attention for benchmark development.
3. It provides a number of arguments for specific methodological choices necessary when designing benchmark systems.

3.2 Recent Developments in the Development and Application of Benchmarks in Selected Countries

The landscape of building LCA initiatives is changing at a fast pace, as more and more countries deal with climate change mitigation plans and climate change acts on a national regulatory level. Although not all initiatives impose the use of benchmarks as well as target and limit values, there seems to be a movement towards more tangible and quantifiable measures against which to evalute building designs. Initiatives without limit and target values have in several cases also been seen to act as predecessors to more binding requirements. In the following, examples of recent developments concerning the use of benchmarks, limit and target values are described, based on different accounts from Annex 72 international experts in mid-2022. The examples do not aim at providing an exhaustive overview of all initiatives internationally, but serve to highlight the types of development seen currently among the different types of benchmark developers. Details about the current initiatives from the specific countries can be found in the Annex 72 background report about existing benchmarks (Rasmussen, Trigaux, Balouktsi, et al., 2023).

3.2.1 Policy, regulation and law makers

National level: In 2012, the Netherlands introduced the first version of a mandatory declaration scheme for the environmental life cycle performance of new buildings, called MPG. Almost a decade passed before a range of other countries then followed suit on the regulatory level, adopting nationally adapted methods for the calculation of, primarily, life cycle GHG emissions from the construction of new buildings. By 2022 France, Sweden and Norway have regulation in place for climate declaration of buildings, and New Zealand, Denmark and Finland have method and regulation ready for implementation in the nearby future, either for public procurement or for national regulation. Of the mentioned countries, Netherlands, France and Denmark have limit values in place for the regulation. The remaining countries with regulation in place or preparation, all have research studies proposing benchmarks and/or limit values. These have not yet moved to the mandatory level in regulation but may in current or revised format become part of the regulation within few years.

In several other countries, the introduction into regulation is currently being discussed or negotiated for national level implementation, e.g. in Switzerland, Belgium and the UK. At the same time, softer measures promoting and guiding life cycle considerations of buildings, are put forward by national building or environmental authorities in other countries, e.g. Spain, Austria and Slovenia. As a preparation for legal requirements Germany is using benchmarks to limit the GHG-emissions in the life cycle of buildings as a requirement in a national funding programme since 2021. There are new solutions in place in relation to how to deal with BIPV and user-related energy demand in calculation rules and benchmarking.

Regional level: There are several international examples of regional or city scale initiatives to ensure the life cycle based evaluations of building. This is seen both as public procurement requirements involving the use of specific LCA-based benchmarks or certifications systems, e.g. in the Northern Jutland Region in Denmark, or as local requirements for new development projects, e.g. Greater London Authority and others in the UK.

3.2.2 Developers and providers of sustainability assessment systems

Sustainability assessment systems that include LCA-benchmarking are typically developed and/or promoted by green building councils or building institutes, e.g. in New Zealand, Austria, Spain, Belgium, Germany and others. However, also industry associations representing civil engineers or architects have, in many cases, successfully marketed methods and benchmarks for voluntary use in the national setting. Examples are the SIA 2040 in Switzerland and the RIBA guidance from the UK.

Worth noting from the side of industry associations is also that in several countries, broad networking initiatives are promoting initiatives for fast-track actions with stricter requirements than the ones in place by regulation. Examples of these are the fossil-free roadmap developed by Swedish actors, or the so-called Gideon’s Tribe in the Netherlands, aiming at speeding up green transition measures.

3.3 Identified Challenges and Sources of Misunderstanding

The following challenges can currently be identified when dealing with existing benchmarks from literature, third parties or other sources (Table 3.3). Section 4 and Section 5 are attempting to provide rules and recommendations to address as many as possible.

Table 3.3: Current challenges in relation to the interpretation and use of existing benchmarks.

Problem(s)	Implication(s)	Discussed in:
A. Missing explanations of the measurement and/or reference unit	The choice of suitable reference units has a major influence on the interpretability and comparability of benchmarks and assessment results; individual reference units have advantages and disadvantages. A clear declaration of the unit(s) used (and their definitions as background information) is a minimum requirement, perhaps in combination with rules of adaptation of benchmarks to different units	Section 4.1 "Reference Units"
B. Missing detailed information on the functional equivalent (called functional unit in LCA method) and system boundary of the object of assessment	Benchmarks usually apply to a specific object of assessment resulting in a need for its precise description.	Section 4.1 "Reference Units" Section 4.3 "Granularity of Benchmarks for Building Types/ Subtypes" Section 4.6 "Requirements for Individual Buildings Versus Groups of Buildings"
C. Only lifecycle-related benchmarks are given, without a disaggregation into partial values as hard and soft (i.e. only for guidance) benchmarks	Having in place benchmarks for the full life cycle allows global optimisation which is according to life cycle thinking. However, without guide values for individual shares (embodied and operational), building solutions may occur which are not optimised on both sides. GHG emissions in the future are less certain compared to upfront GHG emissions.	Section 4.4 "Granularity of benchmarks for life cycle modules: Overall versus partial values"
D. Lack of reference to specific calculation and assessment rules	Benchmarks form a "unit" with calculation and assessment rules. They may not be applicable in combination with calculation results based on other methods.	All sections
E. Missing information on temporal and territorial validity	Benchmarks usually apply only within narrowly defined boundaries. Lack of well-defined temporal and territorial validity can lead to misapplication.	Section 4.2 "Temporal and Territorial Validity"
F. Missing references to other assumptions and boundary conditions	Benchmarks are usually used in connection with deterministic models. It is important to match assumptions and boundary conditions.	Section 4.7 "Issues Particular to the Derivation of Bottom-up Benchmarks" Section 4.8 "Issues Particular to the Derivation of Top-down Benchmarks"

G.	**Lack of information on the type of LCA database applied for the derivation of benchmarks**	Using one or the other tool and database involves the risk of significant differences between single materials as well as whole assessment results, depending on the data and tool used. Hence, if the use of several tools and databases are allowed within a benchmark system, larger variations in values can be expected.	Section 4.2 "Temporal and Territorial Validity"
H.	**Provision of benchmarks only for a limited number of indicators**	A limited selection of indicators covered in a benchmark may cause burden shifting to other environmental areas (not covered).	Section 4.5 "Benchmark Systems with Multiple Indicators"
I.	**Lack of information on the characteristics and details of the building sample(s) behind the bottom-up benchmarks.**	If details of the method used to develop a benchmark are not known, it is difficult to check its significance and representativeness.	Section 4.7 "Issues Particular to the Derivation of Bottom-up Benchmarks"
J.	**Limited examples of top-down approaches in the development of target values, and especially science-based ones.**	In response to the urgency of climate mitigation action, it is desirable that more benchmark systems integrate the top-down approach, potentially along-side a bottom-up approach to establishing reference values. Furthermore, there is a need to implement target values based on planetary boundaries and remaining GHG emission budgets to a much larger degree to curb GHG emissions from the building and construction activities.	Section 4.8 "Issues Particular to the Derivation of Top-down Benchmarks"
K.	**Lack of transparency behind universal benchmarks such as net zero GHG emissions**	Variations behind what constitutes '(net) zero GHG-emission' exist. A common language and framework are needed to define the most important aspects behind this top-down target and increase the credibility of such claims.	Section 5 "(Net) Zero GHG Emission as Target Value: Definitions, Calculation and Offset Rules"

The identified problems result in minimum requirements for the documentation and communication of benchmarks. Benchmarks must be checked in each case to determine whether they are suitable for the specific application and the assessment task. Suggestions for a detailed description of benchmarks can be found in Section 6.

4. Rules and Recommendations for the Development of Benchmarks

This section provides rules and recommendations for ***benchmark developers*** (e.g. policy, regulation and law makers, national standardisation bodies, sustainability assessment system developers/providers, etc.) with respect to specific methodological issues surrounding the development of life cycle-oriented environmental benchmark. Where necessary and relevant, recommendations for ***benchmark users*** (e.g. clients, designers/architects and engineers, valuation professionals, etc.) are also provided that describe how benchmarks should be used to avoid misapplications. Particularly, Sections 4.1-6 handle general issues – concerning both bottom-up and top-down derived benchmarks – while Sections 4.7 and 4.8 handle special challenges for each approach, respectively.
"Net zero" is seen as a special type of benchmark, therefore it is treated separately in Section 5, while further rules and recommendations on the communication of all types of benchmarks are provided in Section 6.

4.1 Reference Units

4.1.1 General

A selection of suitable reference units can significantly improve the use and interpretation of LCA results and benchmarks. Most environmental benchmarks are given in impacts/(m²*year) (Table 3.1). Typical problems and/or questions arising when choosing reference units are presented in A72 report by Lützkendorf et al. (2022) and A72 background report by Rasmussen et al. (2023). and summarized below:

4.1.2 Reference areas

There are different types of floor areas based on which performance results can be normalized to express the benchmark values (see Figure 4.1). Therefore, at the risk of oversimplification, when benchmarks are given per one square meter (m²) without further specification, uncertainty of actual benchmark fulfillment can be as much as 55 per cent if one considers a typical ratio of gross floor area (GFA) to heated/conditioned floor area (HFA) of building types with large common spaces, e.g. multi-family buildings, offices or schools (VDI 2013, p.18).

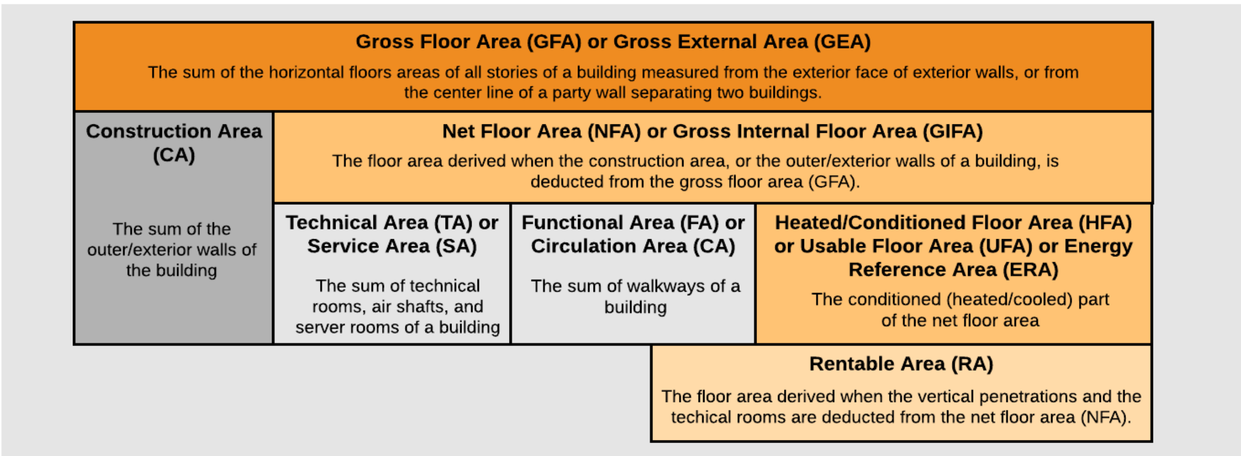


Figure 4.1: Overview of international and regional standards with terms and definitions regarding area and space measurement as part of building geometry (own illustration)

Even when naming the type of surface area, standards on calculating the different types of floor area vary across countries, especially when it comes to the inclusions/exclusions of staircases, balconies and garages among others. An overview of subjects for diverging approaches among the definitions of floor areas is shown in Table 4.1. Many countries have national standards for measurement of surface areas and volumes of buildings, such as DIN 277 in Germany (net floor area), TEK17 and NS 3940 in Norway (usable area) and NEN 2580 in the Netherlands (net internal area). Although there are some international and regional standards aiming at harmonization of terms and definitions (Table 4.2), there is no consistency between them, both in terms of their scope and applied terminology. Therefore, when it comes to talking about net floor area, rentable area, circulation area, or any other spaces, no standard is better than the other. The most important thing to remember is to always clarify terminology and measurement standards upfront.

Table 4.1: Subjects for diverging approaches among the definitions of floor areas. Based on the Annex 72 benchmark cases and (Dario Trabucco & William Douglas Miranda, 2019).

General measuring	Inclusion /exclusion of		
	Internal elements	External elements	Underground
Inside of walls	Internal walls	Terraces	Semi-heated basement
Outside of walls	Shafts/Plateaus	Balconies	Non-heated basement
Centre of walls	Technical rooms	Secondary buildings (sheds, garages)	

Table 4.2: Overview of international and regional standards with terms and definitions regarding area and space measurement as part of building geometry

Standard	Full title	Geographical scope
ISO 9836:2017	Performance standards in building — Definition and calculation of area and space indicators	World
IPMS Office Buildings (2014)	International Property Measurement Standards: Office Buildings	World
IPMS Residential Buildings (2016)	International Property Measurement Standards: Residential Buildings	World
IPMS Industrial Buildings (2018)	International Property Measurement Standards: Industrial Buildings	World
IPMS Retail Buildings (2019)	International Property Measurement Standards: Retail Buildings	World
RICS (2015; 2018)	Code of measuring practice, 6th edition	World
EN 15221-6:2011	EN 15221-6 – Facility Management - Part 6: Area and Space Measurement in Facility Management	Europe
TEGoVA European Valuation Standards (EVS) (2016)	European Code of Measurement	Europe
CLGE euREAL (2012)	Measurement Code for The Floor Area of Buildings	Europe
ASTM (2016)	ASTM Standard Practice for Building Floor Area Measurement for Facility Management	North America

Often, there is the argument of whether to use GFA or HFA as a reference unit for embodied impacts due to the convenience of the latter since the operational energy relates to this area anyway. Further, normalising impacts from a building over the HFA is more closely related to the user perspective as this is where the human activities take place whereas non-conditioned spaces are for parking, storage etc. In this line of argument, additional m^2s in non-conditioned spaces serve a somewhat secondary function but should nevertheless be accounted for by the conditioned area used as a proxy for the user. On the other hand, using the

GFA as a reference unit may be seen as more closely tied to the inventory of materials used in the whole building. This underlines the importance of considering the inventory scope carefully in light of the reference unit chosen for normalising impacts per m^2. The inclusion of large un-conditioned spaces, e.g. basements, have been seen to generate inconveniently large differences across projects, which makes it difficult to evaluate them within the same levels of performance per m^2.

It becomes clear that the introduction of life cycle-based benchmarks means that different approaches that are widespread in practice must be combined with one another. While benchmarks on energy performance traditionally refer to building areas that are directly related to use, benchmarks for construction costs and embodied impacts were and are often given in various reference areas, but mostly for gross floor areas. It would make sense to bring these two "cultures" together in such a way that several traditionally used reference areas are used in parallel.

While it is important to highlight that only one reference unit is always chosen as the official one when a project's level of fulfilment against a benchmark must be demonstrated, for informational purposes, several reference areas can be applied in parallel. If several benchmarks with selected reference areas are given in parallel, the risk of confusion is reduced and the interpretability for building practitioners is improved. Plausibility checks can be carried out using characteristic values for area ratios from the literature.

4.1.3 Use-specific reference units

For exploratory purposes, it may be useful to additionally search for alternative reference units for selected types of buildings to normalize benchmarks. Examples are 'per occupant' for residential buildings and 'per workstation' or 'hours of use' for office buildings. A list of examples can be found in (Häkkinen et al., 2012). The use of this type of reference units can be seen in the German standard VDI 3807 "Characteristic Value of Building Energy Consumption", where e.g. heating energy consumption reference values in health care buildings are expressed "per authorised bed". However, this end-use perspective is discussed more in research literature rather than being followed by actual benchmarks (see A72 background report by Rasmussen et al. (2023)). The use of at least two reference units provides a broader picture of building performance and supports effective environmental optimization efforts from different perspectives – the eco-efficiency perspective and the end-user perspective.

4.1.4 Building-component related reference units

Sometimes the object of assessment may not be the entire building but individual building components or parts for which guide values may be provided as a form of non-binding benchmarks (see Section 4.3). For such partial values, reference units such as GFA, NFA or EFA would not be useful/sensible/appropriate. Different reference units would be needed such as m^2 wall or other parts of the envelope, kW (in the case of heating system) or m of linear components.

4.1.5 Annualised versus non-annualised benchmark values

Following the tradition of operational energy benchmarks which are in place in most countries for many years now, most benchmark developers prefer to express life cycle-based benchmarks on a per-year-basis. Annualisation of results is typically achieved by dividing by a reference study period (RSP). However, it is important to remember that life cycle GHG emissions and impacts are not distributed evenly across the chosen number of years. A significant embodied 'carbon spike' related to the production of building materials and the construction of the building occurs in the year of construction (year 1), while smaller 'spikes' occur in the years of larger replacements and another spike with the end-of-life treatment in the final year.

This raises an important question. In the life cycle of a building, future operational and embodied emissions and environmental impacts (impacts from stages B1-7, C1-4) can still be influenced, for example, through the decarbonisation of energy supply as well as other types of technical progress (see Lützkendorf et al.

(2022)). This does not apply to the initial embodied impacts, which inevitably take up part of the remaining budget. Consequently, a solution can be to limit the initial embodied part (A1-5) with an additional 'non-annualised' benchmark in addition to the annualised requirements for the RSP.

It should be highlighted that time-dependent reference units can consider the entire reference study period or only parts of it. Benchmarks in the sense of target values as part of a step-by-step plan or reduction path can also relate to shorter reference study periods, as it may be assumed, for example, that after a certain date (net) zero impact is achieved.

4.1.6 Conclusions and guidance

The choice of suitable reference units (e.g. reference areas and reference time period) has a major influence on the interpretability of benchmarks and assessment results. A clear declaration of the unit(s) used (and their definitions) is a minimum requirement. Individual reference units have advantages and disadvantages, are traditionally used by specific target groups and are already determined in the surface area determination on the occasion of building applications or rental contracts as well as in the context of costing. It is useful to examine the applicability and effects of several reference units when defining binding legal requirements or assessment criteria. After choosing the most appropriate one, additional alternative reference values in the form of secondary requirements are possible and sensible and should be checked in each case.

The following rules (Table 4.3) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

Table 4.3: Rules for the choice and description of the reference unit(s) of a benchmark value.

ISSUE(S)		RULE(S)
How to choose reference unit(s)?	1.	Reference units shall be chosen with care and analysed with regard to their advantages and disadvantages. For **binding benchmarks** in view of legislation and certification: choose one core reference unit and apply it on all building types or choose one core reference unit per building type based on the specific type of use.
	2.	For **guide values/non-binding benchmarks**: Use several reference units in parallel to simultaneously cover different perspectives. Examples of building-specific reference units are (suitable for considering the efficiency of the structural solution – see also Figure 4.1): – … / functional equivalent – … / m² gross floor area – … / m² net floor area – … / m² heated floor area (alias: energy reference area / conditioned area) – … / m³ Examples of use-specific reference units are: – … / capita (resident, user, …) – … / h of use – … / number of workstations (e.g. office and academic buildings) – … / number of beds (e.g. hospitals and hotels) – … / number of spectator seats (e.g. sport facilities)
	3.	Special care shall be taken in selecting, describing and interpreting the time parameter in reference units. Examples are – … / year of planned service life or RSP (average) – Non-annualised values (total) – A combination: non-annualised values for EMBODIED + annualized values for OPERATIONAL (embodied values can be non-annualised EMBODIED upfront

+ non-annualised EMBODIED in the year(s) of replacement + non annualised end of life treatments)

How to describe the reference unit(s)?	4.	The applied reference units shall be adequately described, documented and indicated. Especially in the case of area-based reference units (e.g. gross floor area (GFA), net floor area (NFA), etc.), the type of floor area applied must be specified in detail, preferably with reference to a standard or other definition. A corresponding abbreviation must be added to the specification of the reference unit, e.g. m² NGF.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. Apply different reference units during the development of a (national) benchmark system to identify and finally introduce the best suited one per building type for checking and demonstrating the fulfilment of legal binding requirements, assessment systems and funding programmes in the final communication. All the effects and side effects of choosing a core reference unit should be checked on the basis of examples.
b. As a background information and to make the link to top-down limits derived from planetary boundaries, apply use-specific reference units and provide use-specific metrics (for example, m² usable area/ inhabitant). These are also useful for capturing changes in the number of users, along with the changes captured in the building floor area through area-based reference units. Please note that for final communication always one fixed core reference unit shall be applied as per rule 1.
c. To deal with the time aspect, present benchmarks for the upfront part in both a) “investment” in year 1 and b) per year.
d. Select the following reference units for different soft and hard benchmarks:
   - A1-5 impact (without accounting for biogenic carbon fixation in the case of GHG emissions but accounting for the fossil carbon released during end of life of fossil carbon containing materials such as plastics (legacy))/ GFA
   - B6 (B6.1, B6.2, B6.3) impact/ NFA and year
   - A1-C4 (dynamic for B & C) impact/ GFA and NFA and year
   - Biogenic carbon stored/ GFA

Benchmark users (application / use cases: H-J, see Table 1.2)

e. Adhere in the assessment at least to the reference unit prescribed by the benchmark developer
f. Using more than one reference unit on a voluntary basis is possible if there is a clear reason to do so (e.g. to ensure continuity with older projects) or to check the impact of the type of reference unit on the benchmark(s) or to allow a cross reference to a personal budget.

4.2 Temporal and Territorial Validity

4.2.1 General

Benchmarks are subject to temporal dynamics and must be constantly revised and brought into line with the latest state of the art, changing environmental & economic boundary conditions and/or results of political target setting. Possible reasons for a necessary revision or further development are shown in Table 4.4.

Table 4.4: Reasons why benchmarks shall be subject to periodic revisions

Reasons for periodical revision	TOP DOWN-derived benchmarks	BOTTOM UP-derived benchmarks
Evolving scientific knowledge (e.g. on the speed of climate change or the remaining GHG emissions budget)	X	
Evolving policy objectives (with consequences for setting target values)	X	
New products and solutions affecting technical and / or economic feasibility		X
Changing boundary conditions (including climate data)	(X)*+	X
Changing statutory minimum requirements (with consequences for setting limit values)		X
Changing data bases (changes in indicators, characterization factors and LCI database version or even change of database)	(X)+	X

* this does not influence the life cycle-based budget of a building but its shares of embodied and operational parts.
\+ not applicable in the case of "zero"

It should be noted that there can also be one-time changes applied to benchmarks that do not necessarily imply the need for periodic updates, like the choice to transition from static to dynamic approaches.

Along with the revision itself, it is important to keep track on development of the boundary conditions used as inputs to definitions of benchmarks. For instance: if a target value is based on top-down approach using a national share of the global carbon budget based on population and sectorial share of buildings, then the benchmark developer shall keep track on those inputs, in particular on the development of the global budget. Consequently, there is a need to limit/define the temporal validity of benchmarks.

Benchmarks can only be used within a known context, which is mainly defined by the use/application case, the applied calculation and assessment rules and the applied databases. There are regional/territorial as well as institutional differences. Consequently, there is a need to define spatial/territorial validity. The scope of application is not always bound by national borders. Larger scales like regions (such as Europe[20]), or smaller scales like cities (such as London[21]) may be feasible. In selected cases, the development and use of benchmarks in the context of international certification systems and international agreements (among others) is possible, while others are only available and can be used under local funding programs.

The introduction of a universal benchmark like 'net zero GHG emission' creates something special. The net zero GHG emission benchmark itself is the target value all over the world (i.e. definition of a specific geographic validity is not applicable), but the actual calculation and verification rules are country-/region-specific. Since benchmarks and calculation rules form a unit, when declaring benchmarks, it must be ensured that the

[20] See future results of the project: https://www.laudesfoundation.org/latest/press/2021/cramboll. Additionally, see: https://www.oneclicklca.com/eu-embodied-carbon-benchmarks/#:~:text=The%20Embodied%20Carbon%20Benchmarks%20for,industrial%2C%20office%20and%20residential%20multifamily.
[21] See: https://www.london.gov.uk/sites/default/files/wlc_guidance_consultation_version_oct_2020.pdf

modelling and assessment methodologies and LCI data are the same for benchmarks and the assessments compared against the benchmarks.

4.2.2 Conclusions and guidance

Along the declaration of the calculation choices behind benchmarks, it is also important to ensure transparency in relation to for which geographical scope and time period they are representative of. This information must be freely and publicly available unless it is clearly visible in the context of the reference to the benchmark. In terms of temporal validity, it is possible to limit it until the next foreseeable big change in state-of-the-art, socio-economic conditions, or science or according to a step-by-step plan.

The following rules (Table 4.5) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

Table 4.5: Rules for updating benchmark values

ISSUE(S)	RULE(S)
How to ensure that benchmarks do not become outdated?	1. Bottom-up benchmarks shall be periodically reviewed and revised if needed (i.e. to bring them into line with the latest state of the art in relation to data, economic and social situation and scenarios available if these cause large changes). The same applies to top-down benchmarks (i.e. to bring them into line with the latest state of the art in research/science).
	2. The territorial/geographic (e.g. global, regional, country or province level) and temporal (e.g. up to 2025, up to 2030, etc.) boundaries of benchmarks' validity shall be defined, documented and communicated.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. For bottom-up derived benchmarks a recommended frequency for review and revision (i.e. re-calculate/adjust) to capture changes in the economic and technical feasibility is every 5 years. On the other hand, that frequent updates are not that important for top-down derived benchmarks.
b. If one or more of the boundary conditions/inputs changes by more than 10%, it is advised to revise your benchmarks even earlier than the predefined expiration year.
c. If possible, develop and communicate a forecast of the next generation of benchmarks to allow a long-term preparation for new requirements. In the case of a benchmark system, this can be the target value II (see Figure xx). One solution is a timetable with a "path".

Benchmark users (application / use cases: H-J, see Table 1.2)

d. Always indicate the source of the benchmark used, including checking and documenting their geographic and temporal validity
e. Always ensure that the methodology and LCA data used to quantify the environmental impacts of the building under assessment complies with the one underlying the benchmark values.
f. To be ahead of the competition and already capture today future target path tightening, in addition to legal binding benchmarks, use voluntary target values and budgets. In some cases, such targets are a forecast of next generation legal binding requirements.

4.3 Granularity of Benchmarks Across Different Dimensions

4.3.1 General

Deciding on the level of granularity of the developed benchmarks regarding building characteristics and building life cycle is a critical part of benchmarking process. Figure 4.2 shows examples of different levels of granularity (vertical axis) that can be specified with benchmarks or guide values across most likely object parameters (horizontal axis). Figure 4.2 may be expanded in both directions, i.e. specifying granularity at an even finer level of detail and/or specifying more object parameters such as climatic conditions or heating supplying source (e.g. see (Lasvaux et al., 2017)). In general, the higher the granularity of a benchmark (system) is, the higher the sophistication is but also the more complex the process of achievement is. The granularity of benchmarks depends among other aspects on the granularity of the information involved in deriving them. The question arises: What is the optimum level of granularity so that benchmarking processes remain simple, but without losing important information?

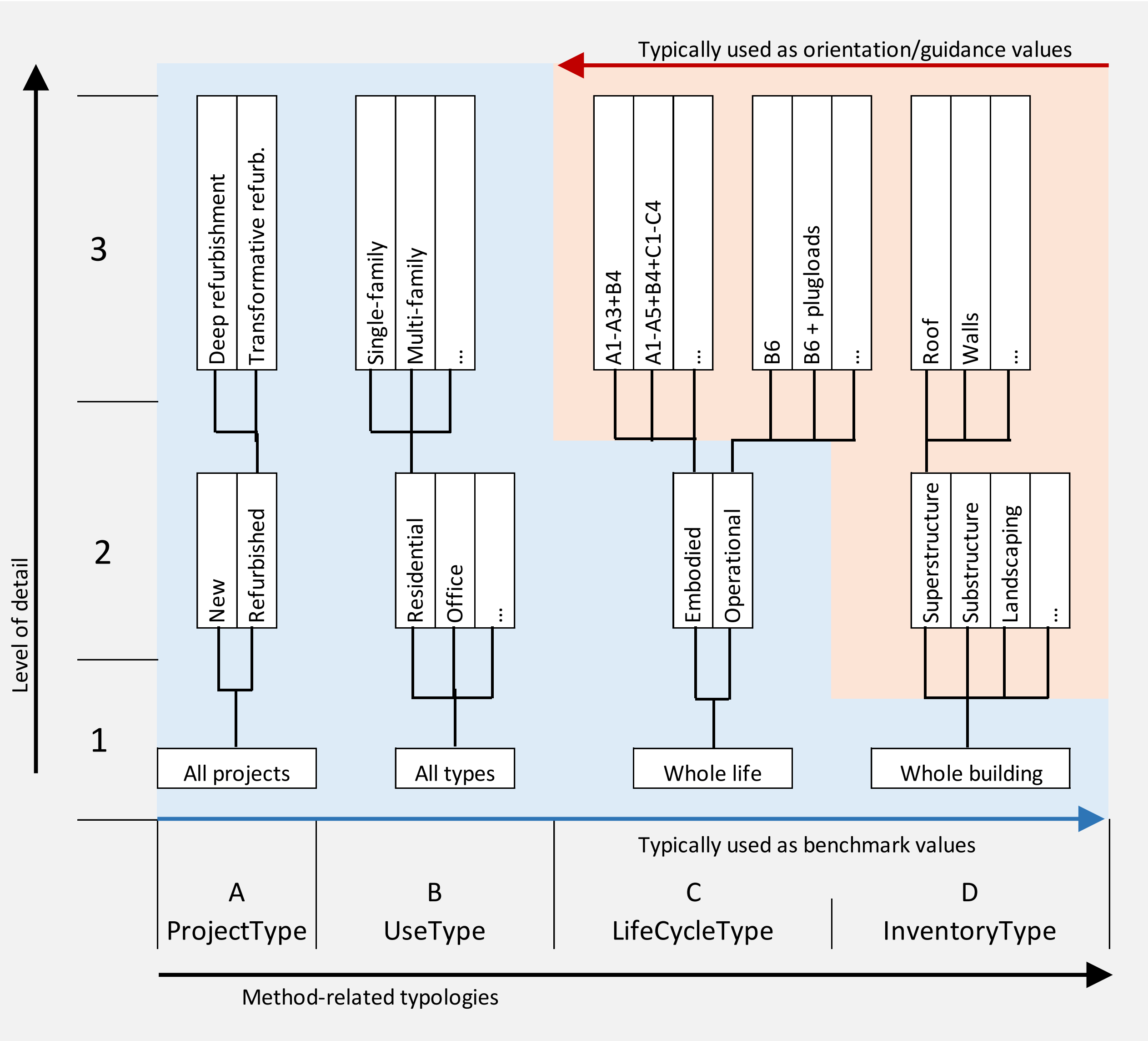


Figure 4.2: Framework for categorizing granularity of benchmarks. Note: the “blue” part covers the levels of granularity usually found in official benchmark values, while the “orange” part covers the levels of granularity usually only offered as guide values (Rasmussen et al., 2023).

In relation to ProjectType (parameter A, Figure 4.2), the most usual case is to have benchmarks for either new buildings or refurbishments (level A2), however, there are cases a benchmark is considered to fit new buildings as well as refurbishments (level A1). The usual approach to granularity for UseType (parameter B) is to provide different benchmarks per broad building type (see A72 background report by Rasmussen et al. (2023). Further specifications within building types are only seen in some systems in the category of residential buildings, distinguishing single-family from multi-family buildings. In other cases, there are specific requirements for buildings in social housing programmes in combination with a sufficiency strategy (limitation of m²/occupant). Only few benchmark systems further report benchmark values for “all building types” in one group. This is based on background analyses indicating that there is no statistical difference between the benchmarks of the different building types (Wiik et al., 2020; Zimmermann et al., 2020). However, this could also be a matter of the sample types and sizes used in these specific derivations. For example, it can be the case that the average impact/m² value of a sample of high-rise residential buildings (e.g. above 20 storeys) are closer to the average value of office buildings than that of single family houses. Therefore, a sample with a majority of residential buildings being high-rise may not reveal derivations. Such examinations are useful as background information.

Benchmarks can also be distinguished according to what extent relate to the complete building or selected parts and/or the complete life cycle or individual stages, i.e. parameter C and D (Figure 4.2). The extremes here range from capturing the complete building in its complete life cycle (level C1/D1) to benchmarks for the A1-3 of windows (C3/D3), for example. This choice is often influenced by the purpose/ use case – whether the purpose is to formulate an overall requirement on performance which allows a compensation between individual shares or to specify sub goals with a binding character. Most existing benchmarks adopt the former extreme (high aggregation), but a considerable trend towards adopting a level C2 of granularity is observed (Rasmussen, Trigaux, Balouktsi, et al., 2023). Finally, granularity for parameter D has not been sufficiently explored within benchmark systems so far (D1 level is dominant).

It should be noted that the life cycle of buildings is divided into modules based on ISO 21931 (in Europe also based on EN 15643 and EN 15978-1) and follow the alternative modular approach shown in A72 report by Lützkendorf et al. (2022). Therefore, it is important to clearly state which modules are included in a benchmark, as well as which assumptions and scenarios have been considered (as background information). Most possible benchmark cases are classified in Table 4.6. Furthermore, further note that partial demands can be of binding or non-binding nature depending on the national context. In the case of binding partial values, it should be ensured that impacts are not displaced in time (e.g. decreasing embodied impacts related to life cycle stage A may increase embodied impacts related to life cycle stage B with modules B2-B4 and/or operational impacts related to B6.1 – possibly leading to increased total impacts).

In individual countries some of the reasons given for using benchmarks for A1-A5 in/for the building are:

- Urgency to focus on emissions that take place today
- Emissions possible to verify with real values (material quantities) directly post-handover.

Table 4.6: Typology of benchmarks including different possibilities of partial or whole life cycle values. Note: the black 'X' denotes the minimum scope for using the proposed terms while the red 'X' denotes the possible inclusions in each scope depending on the national context (e.g. availability of data, specific activities being considered negligible, etc.). Which system boundaries are considered in real benchmark cases is provided Table 3.1.

Possible system boundary name for life cycle-based values	Production and construction			Use (incl. operation, repair and replacement)										End of life				Beyond life cycle
	A1-3	A4	A5	B1	B2	B3	B4	B5	B6.1	B6.2	B6.3	B7	B8[22]	C1	C2	C3	C4	D
Whole life cycle I	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Whole life cycle II	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Whole life cycle II, including D[23]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Limited life cycle	X	X	X	X	X	X	X	X	X	X								
Possible system boundary name for partial values																		
Partial value, embodied, upfront	X	X	X															
Partial value, embodied, invest., total	X	X	X	X	X	X	X	X										
Partial value, embodied, total	X	X	X	X	X	X	X	X						X	X	X	X	
Partial value, operational, building-related (regulated)									X									
Partial value, operational, building-related, complete									X	X								
Partial value, operational, complete									X	X	X	X	X					

[22] It should be noted that in the standards this module is seen as voluntary at the moment.

[23] It should be noted that in only a few benchmarking systems (the French regulation and DGNB in Germany) module D is added to A-C modules. This system boundary is provided here to also cover these cases, although this is not generally recommended by the standards. In any case, the standards' prescriptions are more focused in the calculation of environmental performance result and its reporting which involved reporting module D separately. While a country may provide D results separately from A-C results when reporting, in the assessment itself, a country may decide to sum all values together.

4.3.2 Summary of granularity options for building (sub-)types (granularity type B)

The question to be solved here is closely related to the "fairness model" pursued in each case in the development of benchmarks or the allocation of shares from the remaining budget to acceptable environmental pollution and GHG emissions. Table 4.7 provides the existing possibilities in principle and indicates an order of preference.

Table 4.7: Overview of possible granularity options for building types including a discussion on risks

Code	Possibilities	Notes
A	Benchmarks are given for a very limited number of building types. These apply regardless of the specific situation in the individual case.	Special situations can be: difficult subsoil conditions, more intensive use, special climatic conditions at the location, etc. The special features must be compensated for by making additional efforts in designing and constructing the building in order to comply with the benchmarks. Here lies the risk of additional work for the client or of obtaining a poorer rating in the context of a sustainability assessment for instance. For an alternative solution see C2.
B.1	Benchmarks are highly differentiated into a system of sub-categories within building types - e.g. single-family house (SFH)/multi-family house (MFH), small MFH/large MFH, high-rise building/low-rise building.	This option counteracts to a just and equal sharing of remaining environmental budgets. However, it follows a different "justice model". It is much more difficult for smaller buildings to meet benchmarks. As a counter-argument, it can be stated that such an unwanted increase in single-family homes can be hindered by stricter benchmarks.
B.2	Benchmarks are given for 'zones of use' (comparable to the cost key values).	This option is suitable for non-residential mixed-use buildings
C.1	An individual benchmark is determined for each project to adapt to very particular situations (e.g.….) using a reference building method.	This is a particularly useful approach for very specific and singular building projects/types with specific functional requirements such as a sports stadium that can affect the performance level.
C.2	A system of surcharges (margins) is being developed and published that can adapt the benchmark to special situations, e.g. difficult subsoil conditions.	It is a matter of question whether there is a public/state interest in such surcharges to compensate for an "injustice" – i.e. developers accepting additional expenses through no fault of their own (e.g. difficult building ground).

4.3.3 Summary of granularity options for life cycle modules

In several countries, it is now discussed whether and to what extent it makes sense to limit the upfront (initial) embodied part (A1-A5) with binding benchmarks focusing on that. The pros/cons and chances/risks for such benchmarks (binding or non-binding) are discussed below:

a. (A1-A3): has the disadvantage that the replacement and end-of-life impacts are not considered. The end-of-life treatment of materials which are burnt in waste incineration plants (fossil-based plastics and renewable materials such as wood or straw) may cause significant impacts. Furthermore, the negligence of replacement investments can lead to unfavorable design decisions when weighing up measures on the building envelope and the core building services. The advantage is that one focuses on emissions that can be influenced today and are not subject to future uncertainty. (A1-A5) has the same disadvantages with (A1-A3) but additional advantages, see (d).
b. (A1-A3) + (C3-C4): has the disadvantage, as with (a), replacements are neglected

c. (A1-A3) + B4 + (C3-C4) is no longer focuses on upfront embodied part but considers also embodied impacts that emerge during the use and EoL stage.
d. Many systems neglect the transport (A4/C2) and construction/deconstruction processes (A5/C1). The advantage for including A4 is an additional motivation for using locally available products, while the advantage for including A5 is saving energy on the construction site. Prefabricated solutions can only be compared to a benchmark when A1-A5 (cradle to handover) is the minimum system boundary.

One option is to use additional benchmarks for A1-A3 or A1-A5 as an additional side requirement to life cycle-related benchmarks.

Regarding Module D (in Europe the former module D is now called D1): according to the standards (i.e. ISO 21931-1, EN 15643, EN 15978) it shall not be combined with other modules and shall always be reported separately. Since standards are not mandatory, in some countries results of module D are combined with results of modules A-C in the national methods. Separate benchmarks for module D are under discussion among experts and in some countries.

4.3.4 Summary of granularity options for building parts (granularity type D)

Although not seen in current benchmarking systems, examples of granularity levels in terms of building parts and elements are seen in research literature (Hollberg et al., 2019; Marsh et al., 2018). However, two specific cases have stirred some interest in the development of benchmarks for individual parts of the building. These concern the potential granularity of building elements in the case of large substructures and in the case of high levels of technical equipment.

The main challenge about large substructures, is the fact, that an otherwise low-impact building design above-ground may be situated in a location where soil conditions necessitate large, stabilizing substructures. Locations with high levels of seismic activity is a case in itself, where extra care (and materials) must become part of the building design. Hence, benchmarks from regions with high seismic activities are not comparable with benchmarks from regions with low seismic activities. However, also in areas with low seismic activities, large differences occur, depending on the exact location. Soft soils and water-front locations are examples of conditions where building projects may find it impossible to comply with the set emission reduction targets, due to the need for large amounts of stabilising materials (see also A72 background report by Rasmussen et al. (2023) for a more detailed discussion). For example, One Click LCA Ltd (2020) in the process of developing benchmarks for Finland found that the impact of unfavourable foundation and parking scenarios is an increase of 12-20% in the building carbon footprint, while a soil stabilisation could cause a building carbon footprint increase of even more than 50%, depending on the building type. Generating reference values for stabilisation may prove difficult because conditions vary between plots. Additionally, the separate functions in a building will often overlap in the physical structure of the building. For instance, the heated floor area extends to part of the basement, or the underground parking construction also serves to stabilize the structure. That is why one approach is to exclude foundations and parking structures from the applied scope (e.g. One Click LCA Ltd (2020), and perhaps address this issue at a district or city planning level. With this approach, soil conditions can be considered already when decisions are made about which type of buildings to develop.

The main challenge about building technology is that it can be a large amount of the building' embodied impacts, i.e. it can be anywhere between 15-50 % of the total embodied carbon depending on the building type among others (e.g. see (The Carbon Leadership Forum, 2019), despite a low impact design for the building structure. Several organisations are now planning to generate reference values and targets particularly for electrical, mechanical and plumbing (MEP) services (e.g. CIBSE[24]), and default values are already used in different methods and design tools such as SIA 2040, 2032.

[24] See: https://www.cibse.org/knowledge-research/knowledge-portal/tm65-1-embodied-carbon-in-building-services-residential-heating

4.3.5 Conclusions and guidance

Establishing a "granularity" of benchmarks should be preceded by a detailed discussion of policy goals and the underlying "fairness model". Benchmarks for broad building types consciously accept the difficulties of fulfilling them in special cases. Reference building methods can have a demotivating effect on the search for the most favorable solution since they contain pre-determinations for individual design parameters. Different "justice approaches" have been tested and used so far. This problem will tend to be alleviated by a transition towards net-zero. Uniform benchmarks for broad building types are already pointing more strongly in this direction. Furthermore, the overarching goal must be to develop and use legal binding benchmarks that cover the complete building and its whole life cycle. The necessity and possibility of introducing sub-benchmarks with a binding effect needs further examination by the initiators of sustainability assessment systems as well as policy makers and legislators. In any case, to support the design process, it can also be helpful to develop guide values for individual building parts and/or life cycle stages.

The following rules (Table 4.8) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

Table 4.8: Rules for the level of granularity of benchmarks with respect to different parameters

ISSUE(S)		RULE(S)
What shall be the level of granularity of benchmarks with respect to building types?	1.	For building-related benchmarks of all kinds, it shall be declared for which type of building and pattern of use they apply. The description of the type of building and its use is in principle identical to the description of the functional equivalent of the object of assessment according to ISO 21678. For more rules and recommendations on the topic of functional equivalent see A72 report by Lützkendorf et al. (2022), Section 4.1.2.
	2.	The derivation of individual benchmark values for individual categories within the same building type (e.g. low-rise and high-rise residential buildings) shall be examined for scientific purposes and related information shall be provided as background information.
… with respect to life cycle stages?	3.	For each benchmark it shall be stated which life cycle stages and modules were taken into account during its development, based on the system of modules according to ISO 21931-1 or EN 15978-1. In the case of module B6, its details (B6.1 building-related, regulated; B6.2 building-related, non-regulated, B6.3 user-related) shall be shown.
	4.	For module B1, it shall be shown whether it has been taken into account and what exactly includes.
	5.	For module B8, it shall be shown whether it has been taken into account and what exactly includes.
	6.	For modules D1 and D2, it shall be clearly stated whether they have been reported and taken into account separately according to the standards (if at all). If a national method requires a summary of modules A-D, this shall (1) be clearly communicated (2) be justified and (3) it shall be shown how double counting can be avoided.
	7.	All explanations must be freely accessible
	8.	In the case of benchmarks for upfront impacts, it must be clarified how biogenic and fossil carbon embodied in the building is handled.
… with respect to building parts?	9.	Guide values (i.e. non-binding values) shall be given for at least the building-related part and building services/technology-related part to support early design steps.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. Keep the benchmark system as simple as possible, avoiding high levels of granularity. Particularly set one benchmark per building type for legislation or certification schemes.
b. Define bottom-up benchmarks for types of uses and do not differentiate in an extended way, unless specific research explorations with adequate sample size show large variations between sub-categories of building types.
c. In case of top-down benchmarks, if differentiations for building types is desired, ensure that the overall impacts of the entire building stock are well below the reduction path.
d. In the case of complex, lifecycle-related benchmarks, these should be in addition divided into binding partial demands or non-binding guide values. Particularly, require (1) binding life cycle values and (2) binding embodied upfront values (A1-3/5), with the precondition that carbon sequestration is not subtracted from the latter but reported as additional information and the end-of-life emissions of embodied fossil carbon are accounted for. All the rest provided values can be non-binding partial values as guide values to support the design process.
e. In general, a minimum subdivision into (1) embodied, upfront, (2) embodied recurrent, (3) operational and (4) EoL, is recommended for guide values. Alternatively (1) + (4) can be combined in a 'joint' value as the materials used determine their production as well as their end-of-life impacts. These values serve only as a rough guide as the final goal is global optimisation. The respective system boundary, modelling choices, and data bases applied for each partial guide value must be defined.
f. In methods where module D1 is mandatorily reported as additional information, develop approaches for its benchmarking taking care of the far future nature of such potentially avoided impacts and test them in research projects.

Benchmark users (application / use cases: H-J, see Table 1.2)

g. Make sure that you apply the rules and data prescribed by the benchmark system and check whether the benchmark to be used fits the building under examination.
h. If data for calculating specific modules are not in place, guide values provided by a benchmark system can be used as a proxy

4.4 Benchmark Systems with Multiple Indicators

4.4.1 General

Questions are raised about how to deal with a set of indicators, both in terms of (1) developing benchmarks for different indicators, (2) supporting multi-criteria decision-making through a partial or full aggregation (among others). As shown in the A72 background report by Rasmussen et al. (2023), multiple indicators are applied in most of approaches, and few systems report categories outside the scope of the EN 15804:2012 and EN 15978:2012 standards. A focus on GHG emissions and, to a lesser degree, nonrenewable primary energy (PEnr) is also observed. The basic benchmark model for a set of indicators is described in Figure 4.3.

What should be noted here is that the individual topics and goals such as conservation of resources and climate protection will not always be able to lead to "balanced" performance levels. In addition to synergy effects (e.g. if a building complies with the GHG emission benchmark it also typically complies with PE non-ren. too), target conflicts may also arise. For example, the change to wood construction for embodied energy/CO_2 reasons is not unlimited; wood growth is maximized as well on earth. The definition of few critical indicators is necessary, and a starting point can be the absolute ceilings provided by the planetary boundaries.

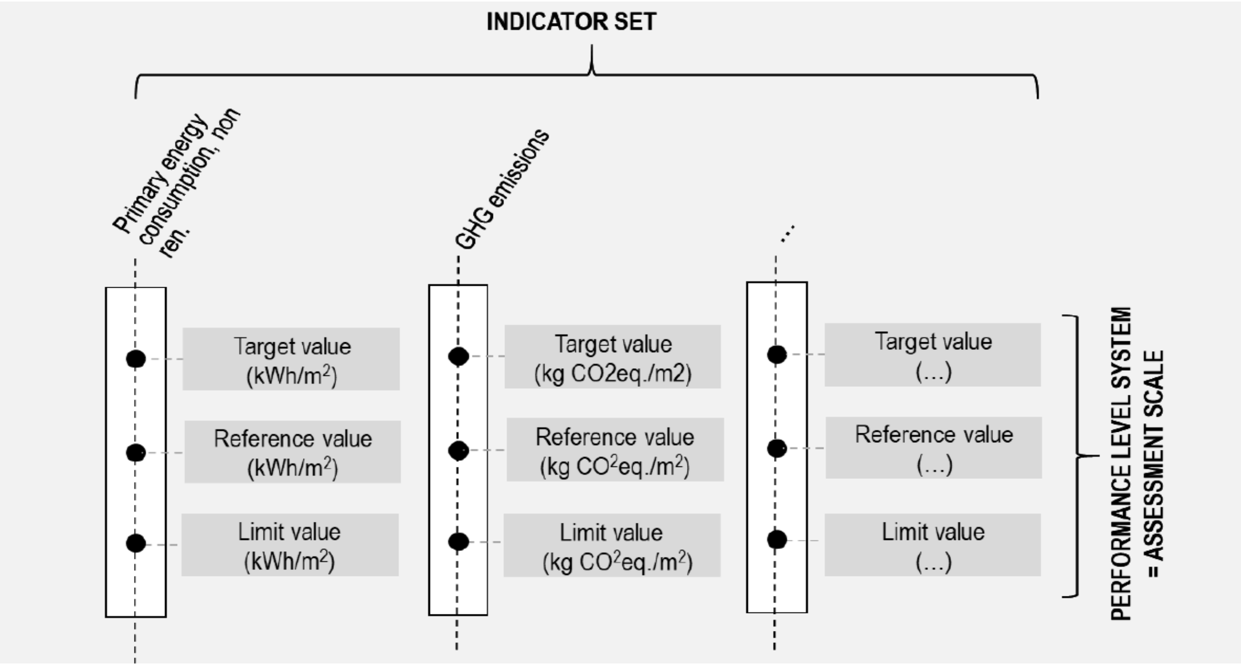


Figure 4.3: Concept of system of benchmarks for multiple indicators

In some countries like Belgium, The Netherlands and Switzerland, benchmarks based on a fully aggregated (single score) environmental indicator were developed, see e.g. Tschümperlin and Frischknecht (2018), Tschümperlin et al. (2016) and Wyss et al. (2015), as well as the descriptions of the Dutch[25] and Belgian[26] methods.

Apart from the official benchmarks per indicator and the need to fulfill them, it is important to note that a performance-based benchmark system may also be supplemented with side requirements such as requirements for the use of the solar potential at the location, use of recycled products, avoidance of products that cause F-gas emissions, etc. Furthermore, it is also increasingly discussed whether minimum limit values are needed for the biogenic carbon content of buildings (limit values in kg $C_{biogenic}/m^2$) to ensure that the amount

[25] See:https://milieudatabase.nl/milieuprestatie/milieuprestatieberekening/
[26] See: Lam. W. C. and Trigaux, D. (2021). "Environmental profile of buildings" (pg. 35-37), available at: www.totem-building.be

of biogenic carbon in the current building stock is not reduced or rather increased, or whether the focus should not be on the increase of use of wood per se and follow a double strategy, i.e. reduce fossil-based GHG emissions while asking for the use of products with low life cycle based greenhouse gas emissions in general (not just wood).

4.4.2 Conclusions and guidance

Several benchmarking systems focus exclusively on GHG emissions, while others include benchmarks for an expanded set of indicators. Going beyond GHG emissions is necessary for avoiding burden-shifting. Rules (Table 4.9) and recommendations are provided below.

Table 4.9: Rules for the creation of benchmark systems with multiple indicators

ISSUE(S)		RULE(S)
How to deal with providing benchmarks for multiple indicators?	1.	The benchmark system shall be created in such a way that it allows identify opposing tendencies and conflicting goals among topics. It shall be clear whether all benchmarks shall be achieved in parallel or benchmarks are seen as independent performance levels, with some being mandatorily fulfilled while others can be of a 'do not significantly harm' level.
	2.	Side requirements shall supplement the main indicators where necessary.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. Develop or advance environmental benchmarks in such a way that performance levels and target values are available for all essential environmental areas of protection and protection goals. As a minimum, this applies to benchmarks for assessing the carbon footprint in the life cycle of buildings, as well as benchmarks addressing nuclear waste, biodiversity losses caused by land use, and respiratory effects due to fine particles in order to avoid displacement of pollution[27].

b. Have a non-compensatory system of benchmarks (e.g. over fulfilment in acidification shall not compensate for an overshoot GHG emissions) for the most critical indicators to avoid shifting burdens.

c. In the case of individual construction projects, building owners and institutions of all kinds are free to formulate more extensive/ stricter target values for environmental performance. These are to be contractually agreed.

d. Consider introducing benchmarks for biogenic carbon content in buildings (biogenic carbon content as additional information acc. to the standard EN 15643:2021) taking local availability, building tradition and suitability into consideration. Define the benchmark in a way that it helps to maintain, preferably increase the amount of biogenic carbon content in buildings and in the built environment in general. If not possible to have such a benchmark on a single building level, consider such a benchmark at the "building stock" level. It should be expressed in kg $C_{biogenic}$ /m^2 and kept separately from a carbon footprint benchmark[28].

Benchmark users (application / use cases: H-J, see Table 1.2)

e. Designers/consultants should inform clients of the existence of legal requirements and voluntary benchmarks (in the context of quality marks and sustainability assessment systems) and support them in their compliance/selection.

[27] Some authors of this report additionally recommend to introduce a single score environmental benchmark, which is used side by side to the greenhouse gas emissions benchmark and ideally is supported by the competent national authority.
[28] It is important to note that biogenic carbon stored in buildings is seen as temporal storage, unless it is legally ensured that the stored carbon is not released at end of life of the building.

4.5 Requirements for Individual Buildings Versus Groups of Buildings

4.5.1 General

From the perspective of the overall environment, it is not important whether a single building meets a benchmark as long as the overall building stock meets this benchmark on average. For this reason, in some countries, benchmarks exist for groups of buildings or the building stock rather than individual buildings. Applying benchmarks to an entire group of building to conclude whether targets can be fulfilled or not provides the advantage that one is able to make exceptions for really specific building cases (e.g. historic buildings) that may exceed the benchmarks, if other buildings in the group can overfulfil. In relation to what constitutes a group of buildings it is useful to make a distinction between (see also Habert et al. 2020):

- National or regional building stock
- Institutional building stock / building portfolio (of a company)
- City
- District/Neighbourhood[29]
- Group of buildings under development of one building ownership

For example, in Switzerland, the 2000-Watt-society benchmarks are defined for sites (German: "Areal"), where the benchmark applies to a group of buildings in which some may exceed the individual benchmarks, whereas others overfulfil. The City of Zurich already applies the 2000-Watt Society targets to the public building stock and makes exceptions for specific building cases if other buildings can compensate by overfulfillment (Frischknecht et al., 2019). An important question related to the application of benchmarks, and especially target values, for a group of buildings is whether they should be based on the current state of the building stock or also consider its future evolution.

4.5.2 Conclusions and guidance

The following rules (Table 4.10) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

Table 4.10: Rules for the development of benchmarks and target values in applications beyond a single building

ISSUE(S)		RULE(S)
Benchmarks for individual buildings, "Areale" or a building stock of a municipality?	1.	For benchmarks in the sense of their (target) application, a distinction must be made as to whether they apply to every single building (possibly a type of building and pattern of use) or if compensation for a below-average level is permitted for a building within a group of buildings by achieving above-average target achievement for another building.
	2.	In the second case, verifiable facts shall be defined as justification for exceptions and a target achievement in the stock ("group consumption"/ "group emissions") must be checked.
	3.	If there are benchmarks for the entire building stock in place, such values are also possible to be derived for districts, cities, companies, regions and countries.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

Benchmarks for groups of buildings should consider that the group is made up of new and existing buildings. It is a target value for the development of the existing stock which can lead to the fact that new buildings added to the stock need to contribute disproportionately to the achievement of the target.

[29] This can also include brownfield districts being developed and converted from mere industry sites to mixed uses with a mixture of refurbishing/converting existing buildings and new constructions.

4.6 Issues Particular to Bottom-up Derivation of Benchmarks

4.6.1 General

Most benchmarks found in the literature and in the different national assessment methods are bottom-up benchmarks derived from assessing a number of buildings. These buildings can be:

– existing buildings collected in a larger database (e.g. see Simonen et al. (2017));
– a virtual building dataset, e.g. a buildings' sample extracted using a (random or not) parameter selection (e.g. see the Hungarian approach as described in Rasmussen, Trigaux, Balouktsi, et al. (2023);
– statistically-based archetypes, representative of the building stock (e.g.Lavagna et al. (2018)).
– archetypes which have been derived in much simpler ways than "statistically-based" or assuring that they are "representative of the building stock";
– archetypes complemented by parametric variation in order to expand the sample.

Samples of (real or virtual) buildings can be statistically evaluated to derive limit, reference or target values, which can be (and usually are) represented by the values shown in Table 4.11.

Conventional' practice (also known as 'business as usual') is assumed to be given by the mean, modal or median value of the environmental performance of the buildings, while typically 'best practice' is assumed to be given by the values of the environmental performance that are achieved by only 10% or 25% of the buildings (i.e. 10 and 25 percentile). Different percentiles are used by different methods, depending on the population of the building cases and how ambitious a benchmark system is aspired to be (e.g. in Germany 25% and 75% are used for target and limit values (see BNB system), while in Norway 5% and 75% (Wiik et al., 2020), respectively).

One fact which cannot be too strongly emphasized is that the values resulting from such a statistical exercise highly depend on the type, function, age and quality of the "basic population" comprising the sample of buildings. For example, if the sample includes primarily new buildings complying with the latest national building code in a country, the derived benchmarks will be lower (i.e. stricter) compared to a sample also including old buildings. Additionally, there is still no consensus on what constitutes an "adequate" number of cases so that to derive representative values. The size of the sample is crucial for generalization.

On the other hand, the approach of reference buildings is usually based on compliance with the latest national requirements of technical and functional quality. The values derived are typically interpreted as reference values, and percentage increases and reductions can be used to work out limit and target values. In the case of archetypes, a building case may quite accurately represent the archetypical, or the 'most common', type of building and be used as a baseline. However, environmental impacts from materials as well as energy use can vary notably depending on the exact design choice, hence diverging considerably from the results of the defined archetype. As seen from the Annex 72 cases in Section 3.1 (see also Rasmussen, Trigaux, Balouktsi, et al. (2023) and Rasmussen, Trigaux, Alsema, et al. (2022)), several of the archetypical approaches further diversify the samples by varying important parameters such as climate zone and material use. The possibility of controlling the variation, e.g. concerning climate zones, can be seen as an explicit advantage of the archetypical model approach. In contrast, it is more difficult to control the variations of a sample of real buildings. However, the use of real buildings for benchmark derivation could ensure a more accurate representation of reality.

In both the case of real buildings and archetypes, target values can also be derived from theoretical values, in particular technical and economic optimum values. The problem is that these values change with time and technological progress.

Table 4.11: Type of statistical information and relevance for each type of benchmark value (limit, reference, target), including pros and cons. Note: 'X' indicates the relevance of the source or type of information for different kinds of benchmarks.

Type of statistical information	Limit value	Reference value	Target value	Comment	Pros and Cons
Mean value		X		sum of all the values divided by the number of values	**Pros:** The best if one wants to take into account all values **Cons:** Sensitive to extreme values, especially when the sample size is small
Modal value		X		value that appears most often	**Pros:** Less sensitive to extreme values **Cons:** There can be no value, or in contrary two or more values that share the highest frequency.
Median value		X		lies in the middle when the values are ordered (=50 percentile =2nd quarter)	**Pros**: Less sensitive to extreme values **Cons:** It is less representative
10 percentile[30]	X	X		10% of lowest values on a scale from high to low values, i.e. the best low-carbon buildings	**Pros:** Appropriate for setting stricter requirements **Cons:** Inappropriate for small datasets
25 percentile	X	X		25% of lowest values on a scale from high to low values, i.e. the best low-carbon buildings	**Pros:** Less sensitive to extreme values **Cons:** can fluctuate more than a smaller percentile year to year
75 percentile		X	X	75% of lowest values on a scale from high to low values, i.e. the best low-carbon buildings	**Pros**: Less sensitive to extreme values **Cons**: can fluctuate more than a larger percentile year to year
90 percentile		X	X	90% of lowest values on a scale from high to low values, i.e. the best low-carbon buildings	**Pros: -** **Cons:** Inappropriate for small datasets

4.6.2 Conclusions and guidance

The two main sources to derive benchmarks based on a bottom-up approach are the use of archetypical buildings (based on building models) and the use of real building cases. Each of these sources have pros and cons in terms of being representative.

The following rules (Table 4.12) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

[30] There are countries even using a stricter percentile, e.g. 5th percentile, but this presupposes a very large sample of buildings which is usually not the case in the development of bottom-up benchmarks.

Table 4.12: Rules for the derivation of bottom-up benchmarks on the basis of real buildings or building models

ISSUE(S)		RULE(S)
How to derive bottom-up based target values?	1.	If the size of the dataset allows it, the 10th percentile (indicating the value below which the ten % best low-carbon buildings are) shall be applied to derive the target values at the minimum. Stricter percentiles can be also applied. The strictest the bottom-up derived target value is, the easiest will be to later shift to medium-term to long-term top-down derived targets.
How and when to use arche-types as a ba-sis?	2.	It shall be demonstrated that the archetypes really represent large building stocks. Representativity shall include technological and geographical representativity at the minimum.
	3.	If the sample of the real buildings is not sufficient for generalisation, the approach that shall be followed is either to add virtual buildings to the sample to increase its size or to apply the archetype method.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. Use the bottom-up approach to check the feasibility of (strict) top-down benchmark values. The sample of buildings assessed in such a bottom-up approach should be new advanced ones, certainly not the average of to-day's building fleet.

Benchmark users (application / use cases: H-J, see Table 1.2)

b. When a sample is available, verify how it has been determined and if the functional equivalent of the evaluated building corresponds to the functional equivalent of the sample buildings.

4.7 Issues Particular to Top-down Derivation of Budget-based «Intermediate Targets» on the Way to Net Zero

4.7.1 General

In recent years, the intensified understanding of climate change being a survival issue for humanity has led to more far-reaching efforts. To stay within the planetary boundaries (as shown in Section 1.2.2), solely focusing on marginal improvements is no longer sufficient. The question of how much more effort is really needed to stay within planetary boundaries can only be answered through the development of top-down benchmarks following a budget approach. For example, in the case of GHG emissions, such benchmarks can serve as intermediate targets on the way to (net) zero by 2050 the latest. This is the focus of this section.

Budget approaches rely on the determination of global remaining budgets for different environmental issues and are particularly important as they can clearly demonstrate the urgency of immediate actions. Starting from global budgets, it is also possible to determine budgets for individual countries and individual macro-economic sectors, areas of action or areas of need. There are several different approaches for downscaling a given remaining global environmental budget to single countries, areas of need, individuals (citizens) and individual companies. Figure 1.5 (Section 1.2.2) showed a scheme of the top-down process of breaking down particularly a global budget for GHG emissions to the country and sector/area of activity/area of need level. However, to support the design of new single buildings, or the refurbishment of existing single buildings, a further differentiation is necessary. Requirements to limit GHG emissions in the life cycle of a building are now a necessity. This can also be interpreted as a kind of budget. A non-binding subdivision of the budget into an embodied and an operational part can help in the design process design process using bottom-up information and data. It helps in the temporal allocation of emissions (if needed).

Figure 4.4 shows the different steps for carbon budget definition in more detail and shows the development up to the individual building and its life cycle stages with references to the operational and embodied part. Different decision choices are possible at every step allowing for different configurations. There is no strict ‘right’ or ‘wrong’ approach (i.e. configuration) that shall be applied, but the modelling choices depend on stakeholder’s viewpoint on framework assumptions as well as ethical questions.

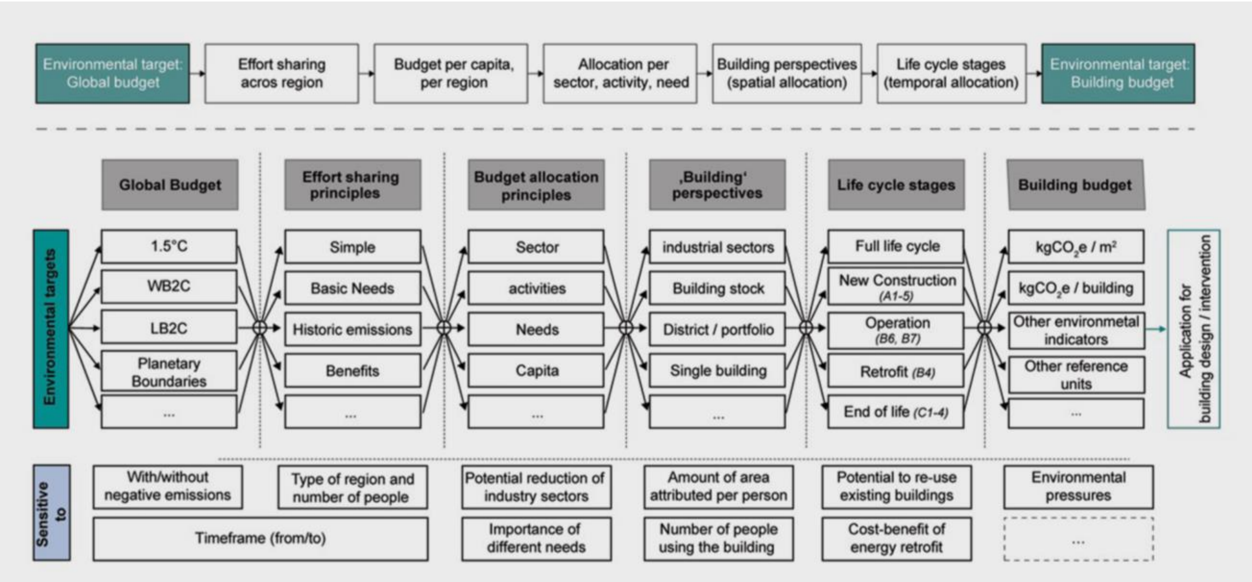


Figure 4.4: Decision tree for budget definition, showing the various steps and decisions to be taken and specified for definition of environmental budgets. Several aspects in this definition are sensitive to country specific characteristics (e.g. number of people, historic emissions, etc.) as well as sensitive to behavioural aspects (e.g. number of people using a building and area per person) (Taken from Habert et al. (2020)).

At the minimum, transparency is needed in relation to the system boundary and key hypotheses associated with a given building budget, such as:

- Choice of the remaining **global budget** and effort sharing principles across regions to get the **budget per capita or region** (Section 4.8.2)
- Choice of allocation principles **per sector/area of action/area of need** (Section 4.8.3)
- Allocation principles **per type/group of buildings** and **per single building or m^2** (Section 4.8.4)
- Sharing principles of building’s budget to **embodied and operational part** (Section 4.8.5)

The text in the following sections is primarily focused on the application of budget approach for the indicator of GHG emissions as the most prevalent example. Similar analyses for other environmental concerns as target values or budgets based on top-down approaches are of interest for all kinds of environmental impacts that are dealt with in Annex 72 and are mentioned when available.

Key topic-specific definitions

Carrying capacity: The maximum persistent impact that the environment can sustain without suffering perceived unacceptable impairment of the functional integrity of its natural systems or, in the case of non-renewable resource use, that corresponds to the rate at which renewable substitutes can be developed[31] (taken from: Bjørn et al., 2020). In general, the exact carrying capacity is not known due to natural variability and uncertain scientific knowledge about the nature of the environmental systems and their underlying mechanisms (Rockström et al., 2009), thus, in the planetary boundaries framework, the uncertainty about the exact carrying capacity is indicated by a lower and an upper limit.

Sharing principle: A principle used to assign a carrying capacity in the form of a 'budget' to an anthropogenic system or process. Similar terms are: Assignment principle, allocation principle, effort-sharing principle or approach (adapted from: Bjørn et al., 2020)

4.7.2 From Global Budgets to per Capita Budgets

Two important issues arise when it comes to translating global environmental budgets to per capita budgets:

- Which global budget to choose when there are many available (different sources, different scenarios)?
- How to share the remaining budgets to countries and their people (i.e. what effort-sharing principles to apply)?

It is important to note that such questions are typically asked on a national government level. Therefore, developers of benchmarks, particularly for buildings, use the per capita budgets defined by governments and do not derive such benchmarks themselves. However, they should understand the rationale behind the assumptions on which selected national budgets were derived and the potential uncertainties associated with current scientific models leading to a future revision of these budgets.

Per capita carbon budgets or personal carbon allowance (or better: budgets for GHG emissions or CO_2eq): The IPCC's scenario work has been important in establishing global carbon budgets. Based on IPCC's scientific evidence, policymakers have agreed to use 2°C target (temperature rise limit) as important objective for international climate policy (UNFCCC 2016), even though a 1.5°C target is now under consideration (IPCC 2018: 32). Based on these targets, progressive roadmaps have been drawn up to further concretise compatible emission levels at different times. Considering these two targets, their probability of achievement (50% or 66%), and the potential use of negative emissions by the end of the century different carbon budgets occur. A synthesis is presented in Table 4.13.

Table 4.13: Total remaining global carbon budget expressed in Gt CO2e (it includes all GHG emissions) for six different scenarios. The values are taken from IPCC AR6 (IPCC, 2021, pp-29): a well below 2°C scenario (WB2C), i.e. more than 66% below 2°C; a well below 1.7°C scenario (WB1.7C), i.e. more than 66% probability of 1.7°C; a target of 1.5°C (T1.5C), i.e. with 50% below 1.5°C.

Period (unit)	Scenarios					
	Without negative emissions			With negative emissions		
	T1.5C	WB1.7C	WB2C	T1.5C	WB1.7C	WB2C
2020-2050 ($GtCO_2$)	500	700	1150	1700	1900	2350
2050-2100 ($GtCO_2$)	Net zero	Net zero	Net zero	-1200	-1200	-1200

The allocation of all these budgets to countries and persons is often framed under the perspective of effort-sharing. Allocation mechanisms have been categorised based on the three equity principles of responsibility, capability and equality, and on their various combinations, as specified in IPCC AR5. This can result in various ways of distributing the remaining global budget to countries. This is not a science-driven choice, but one that represents an interplay and continuous discussion between ethics, justice, society and geophysics

[31] Non-renewable sources are finite, they may eventually run out, the society can still be functional if there are enough renewable substitutes

(Matthews et al. 2020). The most applied sharing approaches are the equal per capita (EPC) and contraction and convergence (CAC). In general, the choice of the effort-sharing approach plays a significant role, especially for highly industrialised countries (see Table 4.14, values taken from Steininger et al. (2020)). Especially, EPC approaches can lead to extreme outcomes for industrialised nations with negative remaining carbon budgets indicating that these have already been exploited. A country- specific example is shown in Figure 4.5.

Table 4.14: Example of ranges of per capita budget for different countries depending on the effort-sharing principle (adapted from Steininger et al. (2020))

Range of per capita budget for 2017-50) (t CO_2 per person) depending on the effort-sharing principle (different variations of EPC and CAC)	Countries						
	Austria	China	Germany	India	Russian Federation	Sweden	USA
	-28.7 to 127.2	23.2 to 137.5	-48.2 to 158.6	95 to 179.2	-41.8 to 209.7	1.8 to 140.5	-234.7 to 287.8

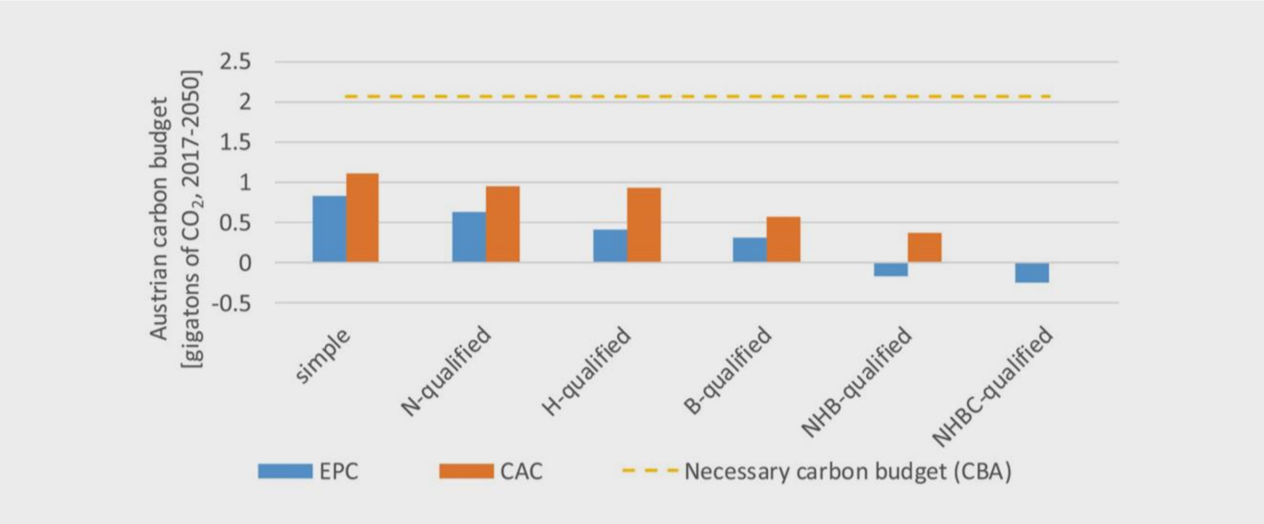


Figure 4.5: National carbon budget for Austria following different global allocation mechanisms, applying a global carbon budget (GCB) of 700 Gt CO2, for 2017–50, and a necessary carbon budget under consumption-based accounting (CBA). Note: 'N-qualified' denotes a needs-based sufficiency threshold; 'H-qualified' denotes responsibility for historical emissions starting from 1995; 'B-qualified' denotes accounting for the inherited benefits from historical emissions; 'C-qualified' a constraint on countries' capacity to reduce emissions. Source: Steininger et al. (2020).

Per capita budgets for other environmental concerns: Compared to the increasing attempts to scale down global carbon budgets to country level on a per capita basis, such attempts for other impacts have not been many. Some examples are: in addition to greenhouse gas footprint, Switzerland has 2015 estimates for biodiversity footprint and eutrophication footprint among others, which have been compared to thresholds based on planetary boundaries (see Figure 4.6, taken from (Frischknecht et al. (2018)). A more detailed view on biodiversity footprint and the related threshold is shown in Figure 4.7.

The planetary boundary of the biodiversity footprint was established as follows: From 500 to 800 AD a first phase of large scale clearcutting of forests took place in Europe. About 1500 years before the publication of Steffen et al. (2015) the biodiversity in Europe was nearly free from human interventions and influences. Applying a natural extinction rate of 10 species per million species per year during 1500 years leads to a threshold value of 15'000 species lost per million species, i.e. 1.5 %. Distributing this loss to the world population results in a per capita threshold value of 2.0 Piko-PDF·a. In 2015 the per capita biodiversity footprint of Switzerland was 7.4 Piko-PDF·a which exceeds the threshold value by 270 % (need for reduction by 73 %).

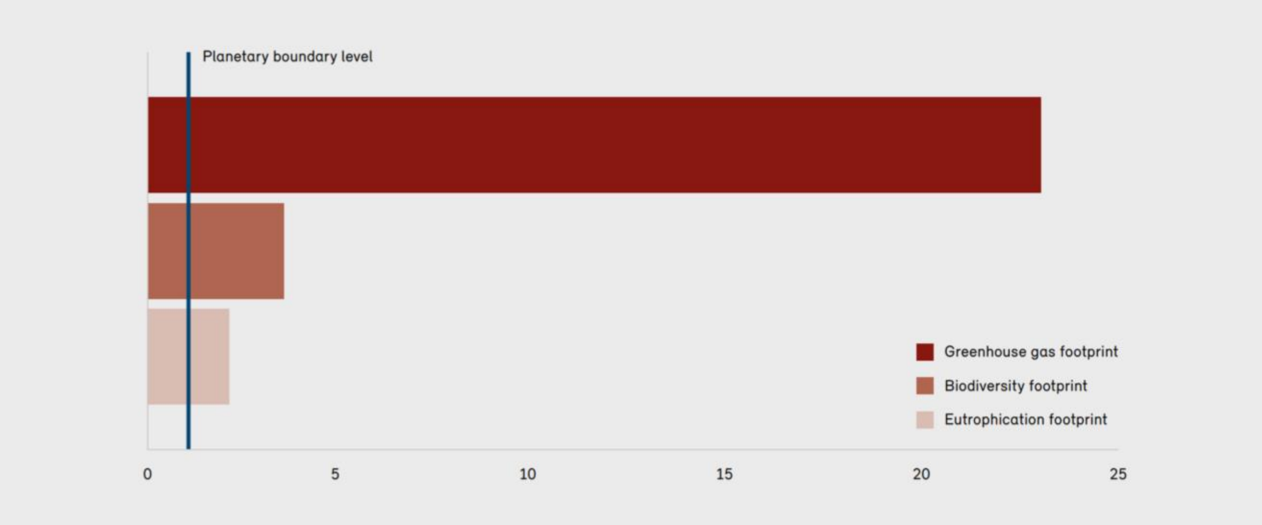


Figure 4.6: 2015 footprints of Swiss consumption per capita in comparison to the threshold value based on the planetary boundaries. Note: Greenhouse gas, biodiversity and eutrophication footprint of Swiss consumption per capita in 2015, are expressed as a multiple of the threshold value (planetary boundary level) of the corresponding environmental indicator (Source: Frischknecht et al. (2018)).

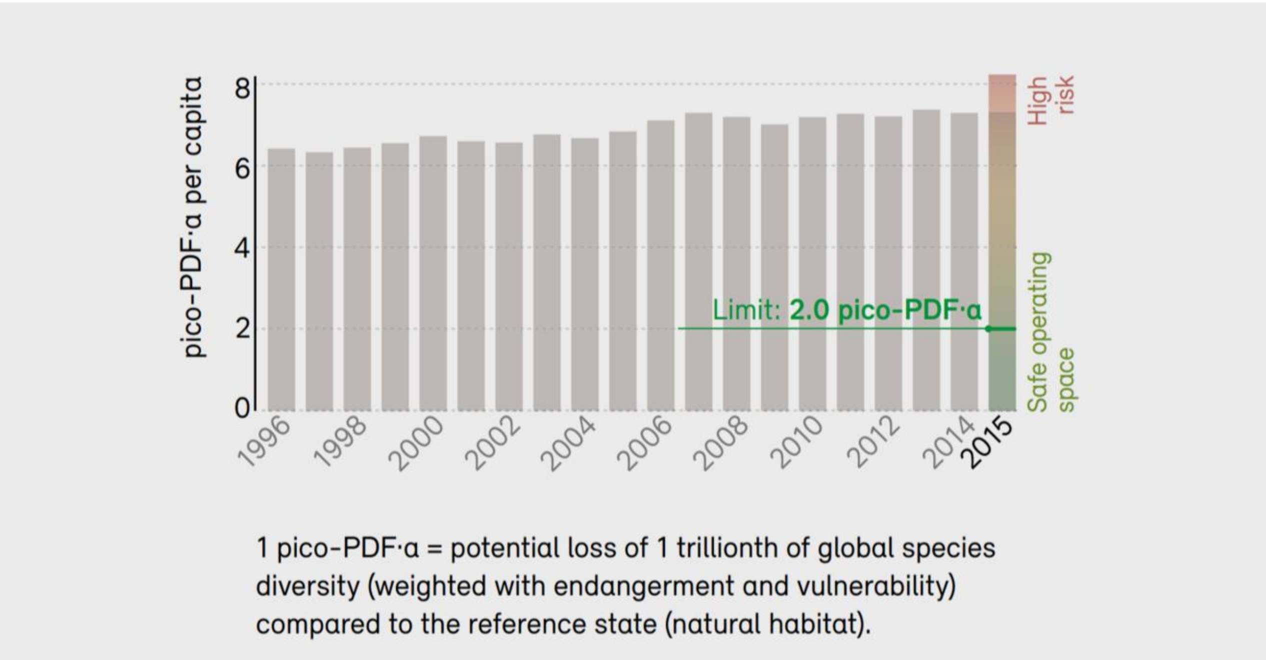


Figure 4.7: represents a 20 years' time series of biodiversity damage footprint of Switzerland with links to planetary boundary derived targets for Switzerland. Note 1: The per capita footprint has increased by 14% within 20 years (especially abroad) and the limits of the safe operating space are exceeded by nearly four times (Source: FOEN (2018))

An example of derived budgets for material resources can be found in Germany as part of the RESCUE project of the German Environment Agency (UBA) (Günther, Lehmann, Lorenz, et al., 2019; Günther, Lehmann, Nuss, et al., 2019). Particularly, this project explores the nexus between climate protection and associated resource requirements. Using six scenarios, different development paths are explored on how to reduce future resource use and greenhouse-gas emissions in Germany to achieve "a resource-efficient and greenhouse-gas (GHG) neutral Germany until 2050", leading to the derivation of total **raw material consumption** budgets, as well as per capita budgets (Figure 4.8). These budgets are not based on planetary boundaries but levels of consumption of fossil energy and materials derived from climate change targets.

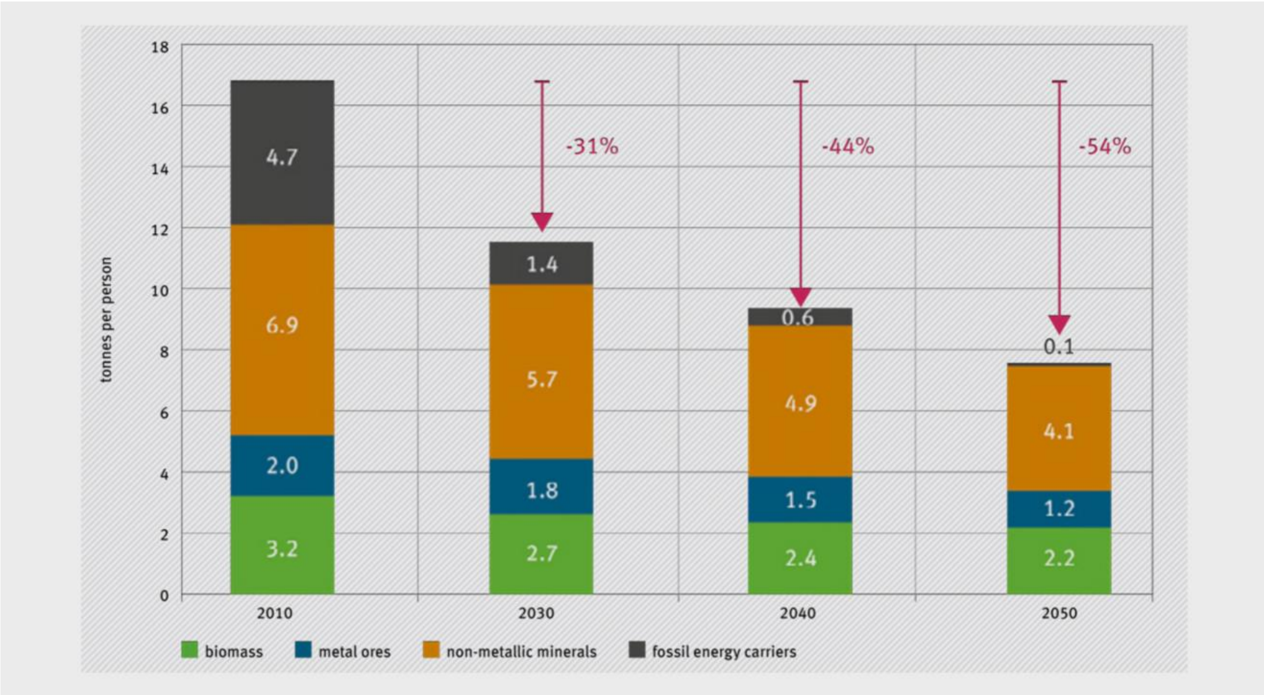


Figure 4.8: Per capita raw material consumption by raw materials category in Germany (absolute and percentage change) for the GreenEe scenario. Note: the report examines different green scenarios in Germany. The GreenEe scenarios stand for "Energy efficiency" and focus on the implementation of energy efficiency measures across all sectors Source: Günther, Lehmann, Lorenz, et al. (2019).

4.7.3 From country or per capita budgets to budgets for economic sectors and areas of activities

The purpose of this guideline is to discuss how to derive target values precisely for construction projects on the basis of a budget. Having allocated the global carbon budget to individual nations, as discussed above, national budgets can be assigned to individual sectors or areas of activity wifthin countries, particularly to activities associated with the construction and operation buildings. The question is thus what proportion of the total country budget or per capita budget should be allocated to the construction and real estate sector or other objects of assessment?

Sectoral carbon budget: Sectoral distribution and reduction ambitions particularly for GHG emissions occur in a few national climate road maps. For example, Germany's Climate Action Plan 2050 (German Federal Government, 2018) stipulates a two third emission reduction for buildings (called here "building sector" and covers direct energy related emissions only) by 2030 compared to 1990, which in 2030 corresponds to 13% of the total German greenhouse gas emissions. This roadmap also provides a 'budget' in ton CO_2e based on these targeted reductions. However, in 2021 the Climate Action Law was amended to align with new EU targets and speed up efforts to reach the goal of greenhouse gas neutrality five years earlier (by 2045). This also included introducing smaller emission budgets in all sectors, and new and tougher annual reduction targets for the 2030s (Table 4.15). However, for 'buildings the budgets only represent the direct emissions related with the energy used for their operation. Currently, there is no target or budget in place for the embodied part. For 2045 the target is a climate-neutral national building stock – again, only for the operational part with direct emissions. In general, sectoral divisions are not always clear in detail and it can therefore be difficult to understand what the sectoral goals and statistics in different sources stand for. In the current political discussion in Germany, it is assumed that its purely sectoral allocation must be supplemented by cross-sectoral considerations. For example, "embodied emissions" are assigned to the industry sector, but the demand for the type and quantity of construction products is influenced by the construction and building sector.

A complex analysis for the environmental footprint of Swiss real estate service sector to deduce necessary reductions for both the use and supply chains of buildings, while respecting planetary boundaries was conducted by Frischknecht et al. (2020). This is part of a larger study which provides a detailed cross-sectoral view on different Swiss industries, not only the real estate service industry, where the **GHG emissions and other environmental impacts** caused by each sector and its supply chains are quantified to identify environmental hotspots (for details see: Alig et al. (2019) and Nathani et al. (2019)). Figure 4.9 shows the results for the real estate service sector. Particularly for GHG emissions the target corresponds to the remaining global carbon budget for a likely below 2°C temperature increase scenario (which is the least strict scenario). Similar data are available for Germany (BBSR & BBR, 2020).

The environmental footprints of industry sectors assessed in both studies include the supply chains and thus activities and emissions occurring all over the world. That is why environmental benchmarks were defined on a global level using global reduction needs.

Such studies provide the basis for a better understanding of a cross-sectoral share and thus the influence of the construction and building sector in national GHG emissions. Among other things, a budget for the national building stock can be derived from this.

Like the allocation of global budgets to countries, the allocation of a budget to sectors or areas of activity does not follow scientific principles. One may choose to either maintain the size of the previous proportions of the sectors/industries and set identical specifications for a percentage reduction within the sector as a more simplified approach and following the grandfathering principle[32] (Swiss example of the time series of environmental footprints of Swiss consumption) or to look for the options with the most favorable ratio of cost and benefit - e.g. CO_2 avoidance/abatement/mitigation costs.

Table 4.15: Permissible annual emission budgets per sector/area of activity according to the amended German Climate Action Law (May 2021). Sectoral budgets from 2030 onwards will be placed in 2024.

Annual emission budgets in millions of tonCO_2eq	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Energy	280		257								108
Industry	186	182	177	172	165	157	149	140	132	125	118
Buildings*	118	113	108	102	97	92	87	82	77	72	67
Transport	150	145	139	134	128	123	117	112	105	96	85
Agriculture	70	68	67	66	65	63	62	61	59	57	56
Waste and others	9	9	8	8	7	7	6	6	5	5	4

* direct emissions only

[32] allocation of future impact allowances based on current impact shares, i.e. continuation of status quo in terms of shares.

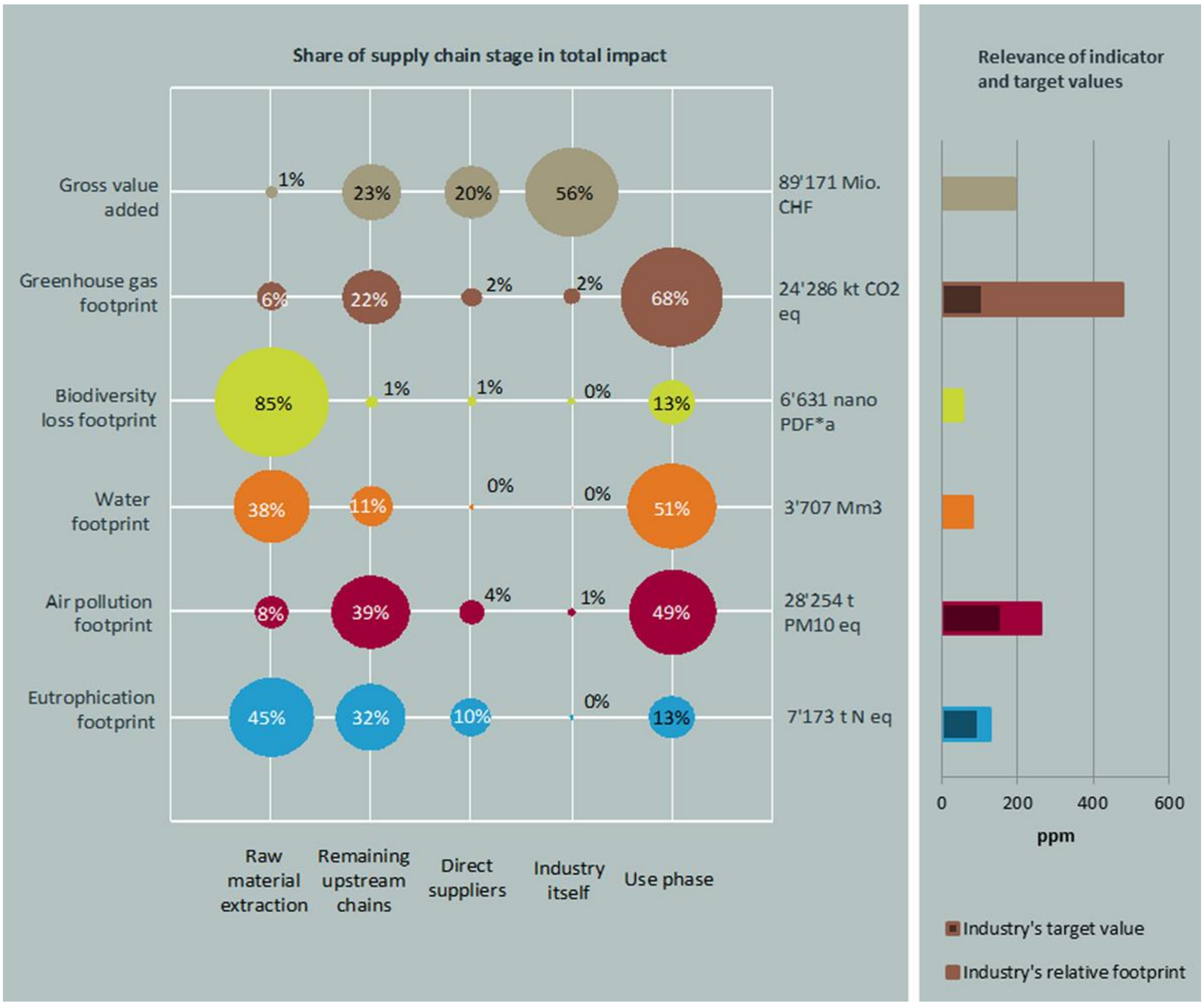


Figure 4.9: Environmental footprints caused by the Swiss real estate sector in 2008 by supply chain stages, share of the industry in global gross production value and global environmental footprints, as well as the reduction necessary to comply with the planetary boundaries. The greenhouse gas (GHG) footprint target is an intermediate value; the final target value is net zero. The bars on the right-hand side show the reduction necessary to comply with the planetary boundaries. Source: Nathani et al. (2019). Note: ppm (parts per million): the values show the share of the industry sector under assessment on the world total gross value added and environmental footprints. Example: the Swiss real estate sector including its supply chains contributes 200 ppm, i.e. 0.02 % to the global gross value added.

4.7.4 Allocation of budgets to single buildings

In general, it is possible to reach a budget per building or per m² by multiplying the personal building related part of the individual carbon allowance of a respective country (m²/capita) by the planned number of building occupants. This allowance can be the current average space available per occupant based on statistics or it can reflect sufficiency strategies existing in some countries to reduce the floor area per resident. This practically means: When converting a per capita budget to a per floor area budget, a smaller area (m²) per capita leads to an increased environmental budget per area (m²).

Carbon budgets per m²: Several studies have derived carbon budgets per m² which can be used in the respective countries as intermediate targets (e.g. 2030 targets) until reaching a reduction to zero by 2050 latest. For example, in a study of six Danish single-family housing designs, Andersen et al. (2020) investigated the transgression of carrying capacity and planetary boundaries allocated to a dwelling. According to Bjørn and Hauschild (2015) the concepts of carrying capacity and planetary boundaries are closely related, although planetary boundaries is a more precautionary approach and sets a lower environmental boundary than the carrying capacity; the planetary boundary represents the lower limit of the zone of uncertainty and the carrying capacity an average in the zone of uncertainty (Figure 4.10). For both approaches, the study explored six different sharing principles (SP) to establish the per-dwelling 'allowed' carbon emissions in a life cycle perspective. The sharing principles combinations occur by utilising both egalitarian (i.e. equal per capita), utilitarian (i.e. final consumption expenditure) and acquired rights-based (e.g. grandfathering) approaches (Table 4.16).

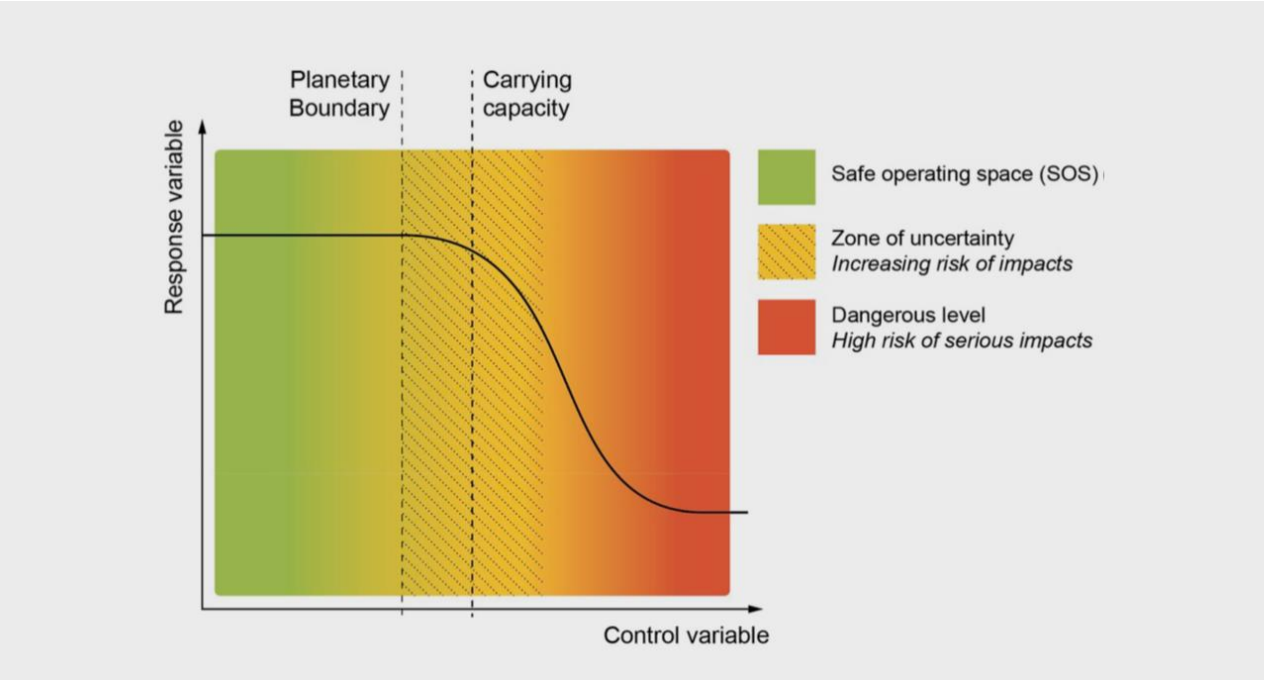


Figure 4.10: The concept of Planetary Boundaries and carrying capacity framework for global Earth System processes. The green zone marks the safe operating space, the yellow zone the uncertainty and the red zone a high risk of critical change. The lines mark the Planetary Boundary located at the lower limit of the zone of uncertainty and the carrying capacity located as an average in the zone of uncertainty as defined by Bjørn and Hauschild (2015) (Source: Andersen et al., 2020)

Table 4.16: The assigned safe operating space (SOS) for greenhouse gas emissions and sharing principle to a single-family dwelling in Denmark considering Carrying Capacity approach, annual greenhouse gas emissions budget per dwelling. Note: Sharing principle 1 (egalitarian + time shared + final consumption expenditure); Sharing principle 2 (egalitarian + final consumption expenditure); Sharing principle 3 (egalitarian + grandfathering); Sharing principle 4 (grandfathering + energy); Sharing principle 5 (grandfathering + final consumption expenditure); and Sharing principle 6 (final consumption expenditure).

Impact	SP1	SP2	SP3	SP4	SP5	SP6
Climate change (kg CO_2eq./year)	1,01E+02	2,54E+02	1,61E+02	1,33E+03	5,58E+02	6,25E+02

Habert et al. (2020) used these per-dwelling carbon emissions of the carrying capacity within the six sharing principles to further subdivide into carbon budgets on a per-m^2 basis as well as for operational vs embodied budgets for Denmark[33]. The large variations – up to more than a factor 10 - between the budgets of the six sharing principles (see Table 4.17) shows how important the applied sharing principles are when determining the absolute carbon performance of a dwelling. However, regardless of the SP followed, the annual budget-based values occur are lower than the current target of 5 kgCO_2eq./m^2.year of the voluntary standard in Denmark (Figure 1.1). It is also important to highlight that all these values need to be reduced to '0' by 2050 latest.

[33] It can be assumed that the budget was shared between embodied and operational GHG emissions by using statistics of real buildings and considering the future energy mix for the operational part (as is the usual methodological choice in Denmark).

Table 4.17: Annual carbon budget per m² building (kg CO2 eq./m².yr) based on the carrying capacity approach for six different sharing principles (SP) (Habert et al. (2020), based on Andersen et al. (2020) who used the budgets from Ryberg et al. (2018). Note 1. Derived from results of a household living in a dwelling of 150 m² in Denmark (Andersen et al., 2020). Note 2. The sharing principles are given in the previous Table.

Type of budget	SP1	SP2	SP3	SP4	SP5	SP6
Operational budget ($kgCO_2eq./m^2.year$)	0.19	0.47	0.3	2.47	1.04	1.17
Embodied budget ($kgCO_2eq./m^2.year$)	0.48	1.22	0.77	6.36	2.68	3
Life-cycle budget ($kgCO_2eq./m^2.year$)	0.67	1.69	1.07	8.84	3.72	4.16

In addtion to the great variations occuring due to the choice of sharing principles, another difficulty with trying to align per capita emission targets at national or international level with building level targets is that, apart from residential buildings, it is often difficult to define the share of a per capita target for other building types. Usually, the process followed for other building types is to allocate the total national budget to the related sector (following one of the effort-sharing principles) and then convert this share to m².year based on the predicted gross floor area. Examples of such efforts for commercial buildings are presented by Hoxha et al. (2016), Russell-Smith et al. (2015) and more recently Bullen et al. (2021).

It is noteworthy that some of these studies have also led to the introduction of such budgets into practical LCA tools as a form of information for the time being (e.g. the New Zealand LCAQuick v3.4 tool as shown in Figure 4.11). An overview of examples of top-down targets per m² (and their carbon budget approach) primarily developed as part of research activities are shown in Habert et al. (2020). The overview shows the high sensitivity of hypothesis on the budget definition and the need for clarity in definition and consistency of approach. Consensus on process is needed to narrow this gap.

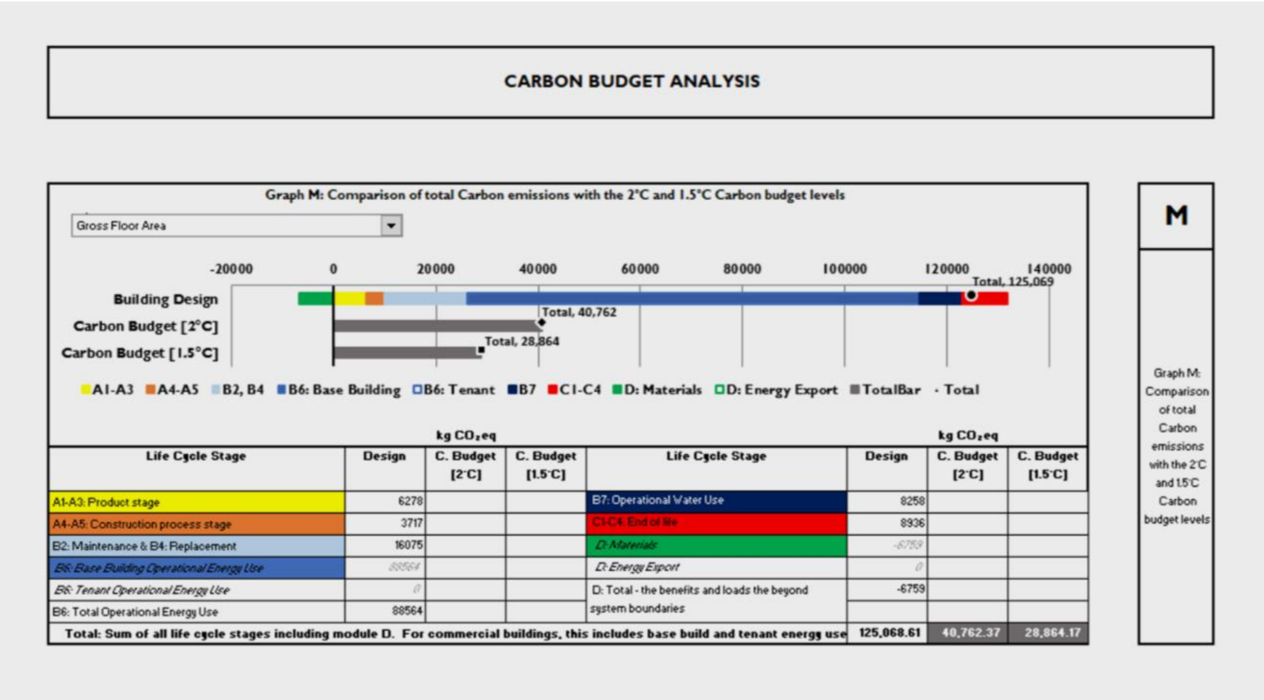


Figure 4.11: Screenshot of the carbon budget analysis worksheet in LCAQuick v3.4 (Dowdell et al., 2020).

Other budgets per m²: The study by Andersen et al. (2020) estimated the SOS also for other environmental indicators, in addtion to GHG emissions, as shown in Table 4.18. The starting point for this estimation is the method developed by Bjørn and Hauschild (2015). These values can be divided by 150 m² as done in Table 4.16 to get the budgets per m².

Table 4.18: The assigned safe operating space (SOS) for each impact category and sharing principle to a single-family dwelling in Denmark considering Carrying Capacity approach. This can be seen as an annual carbon budget.

Impact category	SP1	SP2	SP3	SP4	SP5	SP6
Ozone depletion [kg CFC-11 eq]	8,00E-03	2,01E-02	1,27E-02	1,05E-01	4,42E-02	4,95E-02
Photochemical ozone formation [kg NMVOC eq]	3,90E-01	9,81E-01	6,20E-01	5,12E+00	2,15E+00	2,41E+00
Acidification [molc H+ eq]	1,49E+01	3,74E+01	2,36E+01	1,95E+02	8,21E+01	9,19E+01
Terrestrial eutrophication [molc N eq]	9,10E+01	2,29E+02	1,45E+02	1,19E+03	5,03E+02	5,63E+02
Freshwater eutrophication [kg P eq]	8,61E-02	2,17E-01	1,37E-01	1,13E+00	4,76E-01	5,33E-01
Marine eutrophication [kg N eq]	2,97E+00	7,49E+00	4,73E+00	3,91E+01	1,64E+01	1,84E+01
Freshwater ecotoxicity [CTUe]	1,95E+03	4,90E+03	3,10E+03	2,56E+04	1,08E+04	1,21E+04
Land use [kg C deficit]	2,04E+03	5,13E+03	3,24E+03	2,68E+04	1,13E+04	1,26E+04
Water resource depletion [m^3 water eq]	1,02E+01	2,56E+01	1,62E+01	1,34E+02	5,63E+01	6,30E+01

Despite this example from literature, it should be noted that, in general, top-down targets for buildings, either derived from a budget approach or political priorities, are currently rarely observed. This is mainly due to lack of environmental models for certain impact categories or unquantified planetary and regional boundaries for some Earth-system processes (Bullen et al., 2021). However, good practice implies the inclusion of as many impact categories and in extension top-down targets as possible to minimize the risk of 'burden shifting' (Section 4.5).

4.7.5 Allocation of budgets to different parts of the life cycle

To assist designers in identifying hotspots, remaining budgets for GHG emissions (and other impacts) need to also be divided into life cycle stages, or broadly operational and embodied GHG emission budgets. Again, this is a process subject to many assumptions and future scenarios on the development of the building stock (m^2 of new constructions, new replacement constructions, refurbishments), the operational fuel and electricity consumption of the building stock as well as the development of their environmental footprints. For example, when it is assumed that the energy supply will be decarbonised by e.g. 2040, then a bigger proportion of the remaining budget may be allocated to the embodied part, especially the upfront one (since decarbonisation will also influence the carbon intensity of future material and products) compared to following a grandfathering approach where the budget is allocated in analogy to current average embodied/operational GHG emission share per building type.

In reality, the sharing of the budget to life cycle stages is a dynamic and complex process and it also has to do with the "curve" according to which the budget decreases.

4.7.6 Conclusions and guidance

The downscaling of global budgets to the building level so as to derive top-down targets in line with planetary boundaries requires a series of value and modeling choices such as: (1) the choice of the global budget/target itself as the starting point; (2) the choice of effort-sharing approach to allocate the global budget to a country and/or from national budgets to sectors; (3) the type of population used as a basis if an equal per capita sharing is chosen. Societal consensus is needed on the most appropriate choices subject to value judgement, given the diversity of stakeholder perspectives, especially the choices to which the result is more sensitive. For example, it has been shown that the choice of sharing principles can have an important impact on the assigned carrying capacity.

In any case, regardless of the decisions taken, it is important to communicate uncertainties and acknowledge that some uncertainties are difficult to reduce, in particular uncertainties due to (value) choices. Hence, care should be taken when interpreting assessment results based on comparisons with planetary-based or carrying capacity-based targets. Especially when budgets are based on future assigned carrying capacity, it is especially important to communicate any assumptions related to future global production and consumption.

The following rules (Table 4.18) and recommendations (gray box) are applicable to both new and refurbished buildings, as well as both binding and non-binding benchmarks.

Table 4.19: Rules for the derivation of top-down benchmarks (ideally) on the basis of planetary boundaries

ISSUE(S)	RULE(S)
How to deal with budget-based target values following a top-down approach?	Transparency shall be ensured along the different steps to define the operating budget. In particular, it is fundamental to declare what is the global target chosen, how this global budget is shared among countries and people, how this individual budget is then shared between economic sectors, area of actions and area of needs.

Recommendations for action

Benchmark developers (application / use cases: A-G, see Table 1.2)

a. Derive medium-term life cycle-based target values based on a top-down approach from science-based targets or planetary boundaries, insofar as these are available for selected areas of protection (concern) and protection goals. In other cases, they should be derived from political goals. General goals/specifications/limits for the areas of protection and protection goals are adapted to individual buildings using suitable methods and distribution principles (fair share).
b. Formulate top-down target values for the national building stock first.
c. Use a budget/capita of a country as a starting point. The allocation of parts of the budget to the construction and real estate sector, “area of activity” buildings and/or “area of need” housing is a distribution problem and the subject of macroeconomic considerations.
d. If top-down life cycle-based benchmarks for buildings and the building stock based on the remaining carbon budget are not already in place, these should be defined and used for orientation and information as a first step. A transition phase is needed for such requirements to become legally binding.
e. For residential buildings, define a socially acceptable “necessary living space” (measured in m^2) per capita.

4.8 Special Case: Issues Particular to Existing Buildings in Use

There are several reasons why establishing benchmarks for existing buildings in-use (in addition to benchmarks for new buildings and refurbishments) may be useful:

- Sustainability assessment in-use, sustainability reporting
- Building diagnosis before refurbishment planning, including determination of the baseline
- Success control (or recertification) after new construction and refurbishment, where benchmarks need to be adjusted to actual use.

In the use stage of buildings, the actual energy consumption can be measured and/or taken from bills. The resulting non-renewable primary energy use and the resulting GHG emissions can be determined from the consumption of final energy sources or grid-bound energy use using average or specific primary energy and emission factors. In some cases, specific primary energy and emission factors are part of the contract, in other cases they are specified in the invoices. It is possible to state other values per kWh of final energy (in Europe, for example, g radioactive waste/kWh electricity).

Energy consumption and GHG emissions can therefore be re-determined and re-assessed in the use stage. These values flow into the sustainability reporting of the institutions using the buildings and the sustainability assessment of buildings "in use". The corresponding results are part of the assessment of the real consumption compared to the designed energy performance of the building (also called «performance gap»). Real energy consumption and the GHG emissions derived from it are also assessed using benchmarks to demonstrate e.g. balanced GHG emissions under real conditions in the case of (net) zero operational GHG emission buildings.

Typical assessment standards include "classes" for energy consumption and GHG emissions during operation, and particularly module B6.1. There are discrepancies between the calculated energy demand and the measured energy consumption under real conditions. The reasons are (1) deviations in the intensity of use, (2) different user behavior than predicted, (3) an annual climate deviating from the typical one and (4) different system boundary for calculation and measurement. Therefore, it is a systematic problem. The previous calculations have concentrated on B6.1, but the electricity bills also include B6.2 and B6.3 in the case submetering is not applied. The problem can be reduced by extending the system boundary for determining the energy demand. ISO 16745-1:2017 points in this direction and introduces a corresponding typology for parameters with different system boundaries. Problem (1) can be reduced by adapting the target specifications for energy consumption to the real usage profile after commissioning. This must be repeated with every change of use. Problem (3) can be solved by correcting the weather in the sense of a conversion into values that represent average climatic conditions (temperature, sunshine hours).

When specifying values in time series, it must be specified whether (1) the type and intensity of use, (2) the type of energy supply, (3) primary energy and emission factors, (4) climate data and other boundary conditions have changed and thus are the cause for changed parameters from the ones used during the design.

5. (Net) Zero GHG Emission as Target Value: Definitions, Calculation and Offset Rules

The global budget of GHG emissions is 500 Gt to reach or remain below the 1.5 °C target with a likeliness of 50% (Table 4.12). This finite global budget translates to an annual net zero emission target by 2050 latest. The global target of reducing GHG emissions to a (net) zero level before 2050 to stay within the remaining global budget has given rise to various concepts and perspectives around the world regarding what it means to design, construct, and operate buildings that cause little or no GHG emissions. According to the latest science, this target should now shift to 2030[34]. This section provides guidance for benchmark developers who want to establish pathways to transition to a (net) zero built environment that is aligned with the 1.5-degree trajectory. The difference between 'net zero' targets and other top-down targets is that they require a consistent and globally effective set of balance and offset principles. A common language and framework are needed to define the most important aspects that describe what it means for a building to be '(net) zero GHG-emission'. Key aspects are presented in this section at a high-level. The details behind each aspect are extensive and thus not fully explored here. Where necessary reference to an associated background report as well as other documents are provided to explain the details. Particularly:

- Section 5.1 provides an overview of current pathways towards a (net) zero GHG emission built environment
- Section 5.2 aims at creating a common language within and across (net) zero GHG emission approaches in the context of buildings by proposing a system of terms and definitions.
- Section 5.3 handles special methodological decisions linked to these approaches
- Section 5.4 provides a summary of a survey carried out by Annex 72 about existing (net) zero GHG emission approaches
- Section 5.6 provides conclusions and guidance (rules and recommendations)

In the box below, a topic-specific glossary is provided to establish a common understanding of key terms used throughout Section 5.

[34] See pg. TS-9 in the latest IPCC report: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

Key topic-specific definitions

Potentially avoided emissions: Potentially avoided emissions are the net potential GHG emissions reduction caused by exporting renewable energy produced on-site beyond the building system boundary. This exported renewable energy potentially substitutes demand for fossil fuel derived energy outside the system boundary, e.g. as part of the national/regional grid mix. The determination of potentially avoided emissions requires the definition of a "what if" scenario.

Carbon/GHG emission offset: An offset is where a measure of reduction (direct or indirect) or removal of a GHG emission is used to compensate for or neutralise a CO_2 or other GHG emission that occurs elsewhere.

Carbon/GHG emission reduction offset: a measure which reduces emissions in a source outside the value chain of the entity. Emissions can be reduced by e.g. investing in energy efficiency retrofits and renovations of other buildings. A reference scenario is needed to determine the amount of emissions reduced.

Carbon/GHG emission removal offset: measures that removes CO_2 or other GHG emission from the atmosphere.

Negative emission technologies (NETs): NETs refer to all possible options for GHG emissions removal from the atmosphere. The following general categories can be assigned to NETs (EASAC, 2018): (1) Afforestation and reforestation; (2) Land management to increase and fix carbon in soils; (3) Bioenergy production with carbon capture and storage (BECCS); (4) Enhanced weathering; (5) Direct capture of CO_2 from ambient air with CO_2 storage (DACCS); (6) Ocean fertilisation to increase CO_2.
Note: In some countries like Australia and New Zealand wood landfilling is considered as a partly permanent carbon storage (see: A72 background report by Saade et al. (2023) for more information). However, landfilling wood (and other organic material) does not qualify as NET in the majority of countries as it bears the risk of anaerobic digestion, producing methane and thus potentially be a substantial source of GHG emissions. That is why landfilling organic material is forbidden by law in Europe.

Energy attribute certificate (EAC): A contractual instrument that represents information about the origin of the energy generated. Various energy attribute certificates exist in a variety of markets, e.g., guarantees of origin (GOs) in Europe, renewable energy certificates (RECs) in the United States and international certificates – such as I-RECs. Unbundled EACs (such as GO, REC and I-REC) are the ones that can be purchased separately from the purchase of the generation of electricity (IRENA, 2018).

5.1 General

Globally, a number of governmental organisations and NGOs as well as industry associations have created specific pathways towards a (net) zero GHG emission built environment (Table 5.1; see also Prasad et al. (2021) and Smith et al. (2022)). Commonalities exist among these pathways: they all recommend achieving (net) zero operational GHG emissions (sometimes covering only Scope 1, others both Scope 1 and 2[35]), at least for the new buildings, in the short-term and most of them require achieving in parallel significant reductions (40-65%) in embodied GHG emissions (typically Scope 3[2]). In the case of a net zero target in the whole life, some consider it feasible already for the medium-term (2040), while others see it as long-term target. Given the urgency of the climate crisis and the need for coordinated action, the EBC Annex 72 expert group, agreed that governments should introduce a road map to whole life net zero already by 2035, supported by binding and continuously lowered life cycle-based carbon footprint target values[36].

Reducing GHG emissions over the life cycle of buildings is not an isolated task. It is part of an overarching strategy to achieve climate neutrality (often also called carbon neutrality). Many countries have now defined goals by when they want to achieve climate neutrality. It is important to examine whether these goals are sufficient with respect to the budget still available for GHGs or whether they need tightening considering the dynamics of climate change so that to achieve an accelerated development towards climate neutrality. A respective sub-goal is a climate-neutral building stock. This makes it necessary to build or refurbish buildings in such a way that they either cause no GHG emissions or have a net zero or even positive balance of GHG emissions over the life cycle. This is a cross-sectoral task. While the design of buildings further reduces the energy use while attempting to not compromise the comfort level demanded by the client and user, it is the task of the energy sector to provide or supply energy from renewable sources (buildings can contribute to this, e.g. through building-integrated or on-site generated renewable energy) to build a decarbonised energy supply. On this basis, too, it is then the task of the energy sector to make low-carbon energy services available to the construction and real estate industry. The building developers, owners and/or tenants in turn must ask for and use these services. In addition, the industry sector, responsible to deliver construction products, must provide low carbon products to support a low carbon construction, maintenance and refurbishment of buildings. The importance of a cross-sectoral approach is not yet recognized in all countries.

Table 5.1: Key global pathways to reduce operational and embodied greenhouse gas emissions of the built environment close to net zero level (adapted and updated from Prasad et al. (2021). Note: OE denotes 'Operational GHG Emissions', EE denotes 'Embodied GHG Emissions'.

Initiative		Short-term (2030)	Medium-term (2040)	Long-term (2050)
EPBD recast proposal (EC, 2021)	**OE**	– All new public buildings are **zero-emission** (Scope 1) by 2027, while all new buildings by 2030.		zero-emission (Scope 1) building stock by 2050
	OE&EE	Calculation and communication of life-cycle GWP of new buildings as of 2030 in accordance with the Level(s) framework (for large buildings as of 2027)	-	-

[35] Scope 1: In situ emissions from burning fossil fuels or biomass, as well as refrigerant leaks (the later in some net zero schemes and pathways is assigned to operational GHG emissions, in others to embodied GHG emissions); Scope 2: in situ emissions in power plants and heating plants providing electricity and district heat used by the building; Scope 3: all other emissions in the supply chains, including the supply chains of fuels used in the building and in power and heating plants; see GHG Protocol

[36] See: https://www.buildingsandcities.org/insights/news/built-environment-planetary-boundaries.html

Architecture 2030 (AIA 2021)[37]	**OE**	**zero-net-carbon (ZNC)** (scope 1 & 2) for all new buildings and major renovations.	-	-
	EE	45% reduction by 2025 and 65% by 2030 (compared to 2020) in embodied carbon for all buildings, infrastructure, and associated materials	**Zero embodied carbon** (scope 3) for all buildings, infrastructure, and associated materials.	-
International Energy Agency (IEA, 2021)	**OE**	– All new buildings are **zero carbon ready**[38] – 20% of existing buildings retrofitted to be zero carbon ready	50% of existing buildings retrofitted to be **zero carbon ready**	More than 85% of buildings are **zero carbon ready**.
	EE	40% reduction per m^2 of new floor area (compared to 2020)		– 30% reduction in the use of energy-intensive materials per m^2. – 50% reduction in the use of cement and steel.[39] – 20% relative increase on average building lifetime. – 95% reduction in embodied carbon due to NZC
World Green Building Council (WGBC, 2021)	**OE**	**Net-zero operational carbon** (scope 1 & 2) for all new buildings.		**Net-zero operational carbon** (scope 1 & 2) for all buildings, including existing buildings.
	EE	40% reduction (assumingly compared to 2020) in embodied carbon for new buildings, infrastructures and renovations.		**Net-zero embodied carbon** (scope 3) for all new buildings, infrastructure and renovations.
World Economic Forum (WEF, 2021)	**OE&EE**	Reduce carbon footprint to 50% (compared to a representative year of business)		**Net-zero carbon footprint** by 2050 latest.

[37] https://architecture2030.org/accelerating-to-zero-by-2040/
[38] A zero-carbon-ready building is highly energy efficient and either uses renewable energy directly or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat. This means that a zero-carbon-ready building will become a zero-carbon building by 2050, without any further changes to the building or its equipment (IEA, 2021).
[39] Unclear whether these targets refer to new construction or also refurbishments (entire building stock).

5.2 Typology of (net) Zero GHG Emission Approaches

There are variations in the existing schemes in ways of thinking about (net) zero GHG emission buildings and how to achieve them and these will most likely continue to exist in the near future. These variations raise some important questions on how this concept is evolving. To foster transparency and, consequently, the credibility of current approaches, a system of main characteristics of definitions is proposed below. To make the differences visible, these characteristics are:

– Focus on CO_2 emissions, defined/selected GHG emissions or all GHG emissions
– Lifecycle stages and modules considered, including consideration (or not) of upstream emissions of operation (Section 5.2.1)
– Options and order of reduction and offsetting measures considered (Section 5.2.2)
– Type of balance or offset to handle residual GHG emissions (Section 5.2.3)

Differences in these characteristics determine whether net zero GHG emission targets are truly ambitious and contribute to deeply decarbonize the building stock, or whether they cause limited impact on the reduction of overall GEH emissions.

5.2.1 Typology regarding life cycle stages and modules considered

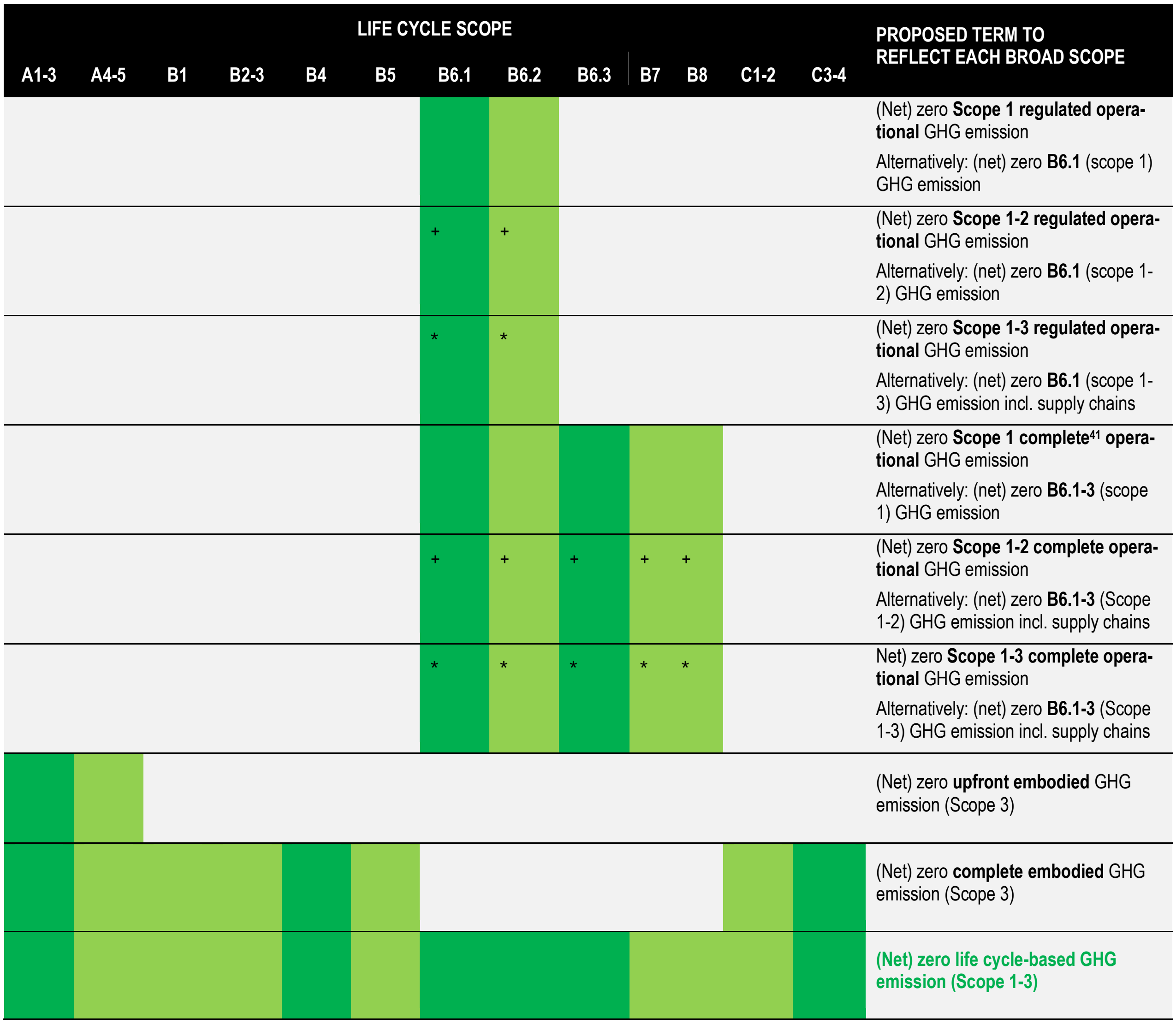
There is a variety of system boundaries in relation to included life cycle stages and information modules (see also Table 4.7) in the different net zero emission schemes and approaches (see the A72 background report by Satola et al. (2022)). Several definitions generally only include direct and indirect operational GHG emissions (Scope 1 and 2) and exclude the embodied emissions of the operational energy supply as well as the embodied GHG emissions of the building (Scope 3). Although at this stage embodied GHG emissions are only partly covered in current net zero commitments (Table 5.1), it remains a priority for the future. As a minimum, the improvement of the clarity of the terms and the transparency of what is represented by a 'zero' or 'net zero' statement is necessary.

Against this background, it is advisable to include both embodied and operational GHG emissions within the scope of 'net zero' definitions. Therefore, for this report 'net zero GHG emission' means 'net zero life cycle-based GHG emissions'. Where specifically 'net zero' refers to a system boundary other than the whole life, e.g. only operational GHG emissions or only upfront GHG emissions, this should be reflected in the term used. Figure 5.1 shows the proposed terms to be used to denote each possible broad scope included in a definition. It ranges from '(net) zero Scope 1 regulated operational GHG emission'[40], where "regulated" refers to module B6.1 following EN 15643 (depending on the country module B6.2 may also be included), to '(net) zero life cycle-based GHG emission'. Particularly, for the operational part, it is important to clarify whether Scope 2 and Scope 3 emissions are also accounted for, therefore Scope 1-3 becomes part of the terms. This is a simplified system of names intending an essential level of transparency; the provision of detailed system boundaries is always necessary, as possible variations within each naming exist. For example, standardized detailed lists of different types of energy uses to describe in more detail what is included in B6 and their categorization under different types of 'carbon metric' can also be found in ISO 16745.

Particular attention should be paid to whether a net zero GHG emissions definition covers only the energy-related GHG emissions or also the non-energy-related GHG emissions. For example, it important to make clear whether module B1 (which covers the GHG emissions arising during the useful life of a building from its components, e.g. the release of GHG from refrigerants or HFC blown insulation, i.e. exclusively non-

[40] Regulated operational energy use typically includes space heating and cooling, hot water, ventilation, pumps and sometimes also lighting. This means that with this term a significant part of Scope 1 emissions is covered (if gas is used for heating and hot water; refrigerant leaks are not covered as they are usually assigned to embodied impacts). If the use of off-site renewable energy is allowable then a part of Scope 2 emissions is also covered, i.e. '(net) zero Scope 1-2 regulated operational GHG emission' status. If the emissions indirectly associated with energy use are also included (upstream emissions of fuels and electricity supply) then also a small part of Scope 3 emissions are also covered, i.e. '(net) zero Scope 1-3 regulated operational GHG emission' status.

energy related emissions) is included in a definition and whether this is allocated to the operational or embodied GHG emissions (both concepts exist). In this report, these are considered as embodied GHG emissions as they are linked to specific products.



+ relevant for when purchased electricity, steam, heat and cooling are permitted in a net zero approach.

*the inclusion of the embodied impacts of energy supply (i.e. supply chains) is expressed in the emission factor

Figure 5.1: System of terms/names to denote the life cycle scope included in a net zero approach. Note: the dark green denotes the 'minimum' scope for using the proposed terms under an assessment standard, while the light green denotes the additional possible inclusions in each scope depending on the national context (e.g. availability of data, what is regulated in operation and what not, etc.). The life cycle model follows EN 15643:2021.

5.2.2 Options and order of reduction and offsetting measures

To achieve 'climate-neutral' buildings that fulfil the Paris Agreement requires that the GHG emissions caused during their life cycle needs to be (absolute) zero or net-zero (either balanced or offset). In many markets, climates and building typologies, achieving absolute zero operational GHG emissions is feasible without the use of any kind of offsets when only the direct GHG emissions (scope 1) are considered. It is possible to design and construct buildings to be highly energy efficient and exclusively powered by renewable energy sources (on-site), with no residual emissions, i.e. completely decarbonised operationally.

However, GHG emissions are possibly still emitted in the upstream and downstream supply chains of fuel supply and of technical systems generating renewable energies (production of materials, manufacturing and

[41] regulated + unregulated

maintenance of technical systems, end-of-life management) (Lützkendorf & Frischknecht, 2020). Thus, absolute zero operational incl. supply chains are difficult to practically achieve today, but possible in the future[42]. The same applies to the embodied GHG emissions of the building, as well as water supply and wastewater treatment emissions. There are studies that show in which direction the decarbonisation process in energy supply as well as the construction and real estate sector can be advanced and achieved (Alig et al., 2020) if the respective industries take the necessary actions and support the respective environmental policies.

Therefore, for the short- and medium-term one can only speak of "net zero" emission buildings, for which offsets represents an important element. This is the case for net zero GHG emissions in operation (including supply chain) as well as for net zero GHG emissions in the entire life cycle. At the moment, there is a shift in net zero discussions towards allowing offsets only for covering residual/unavoidable emissions (Scope 3 and Scope 1 associated with refrigerant leaks), in a transition period while all parts of the economy decarbonise, and not Scope 1 and Scope 2 emissions associated with operational energy use (LETI & CIBSE, 2022). In this context, today's (net) zero concepts should require to first pursue all options to reduce a building's GHG emissions to the greatest degree possible and then use offsets for any residual emissions to ultimately bring the emissions balance to net zero.

To this end, a recommended order of actions shall be part of a (net) zero approach, particularly in the following areas: energy efficiency, renewable energy (on- and off-site), embodied carbon, and carbon offsetting (WEF, 2021). Such an order is provided in Figure 5.2, which stresses that on the way to (net) zero a building first needs to:

– reduce its whole life carbon footprint by applying all possible design-related options, combining sufficiency and efficiency strategies first to target the demand side. Even after all sufficiency and efficiency measures are implemented, there will still be a demand for final energy to operate buildings. This should be covered by energy coming from renewable sources generated on-site as much as possible to also target the supply side (consistency strategy)[43,44].
– further reduce the whole carbon footprint by applying all possible low carbon procurement/supply-related options to cover the needs for operational energy that could not be covered by on-site renewables, and the need for specific construction products to construct and maintain the building.
– offset unavoidable emissions with investing in high-quality[45] removal or reduction offset projects. The typology related to the balancing and offsetting options shown in Figure 5.2 is described in more detail in the following Section.

The reasons behind this hierarchy is that buildings cannot be considered in isolation. For example, if a building's energy needs are met by on-site renewable energy production and storage (e.g. batteries), having in place ambitious operational efficiency targets helps limit the demand for renewable energy systems; this leads to reduced embodied GHG emissions for the on-site supply systems, or generated surplus energy which could contribute to a net zero energy system. In the case of embodied GHG emissions, having in place ambitious targets, reduces the need for offsets. At the moment, there is not sufficient amount of offsets available at a global scale, to keep emitting GHG emissions and purchasing offsets without first reducing emissions (LETI & CIBSE, 2022).

[42] In addition to emissions directly associated with energy use, there are also: (a) Well-to-Tank emissions (WTT) from the production, processing and delivery of a fuel, e.g. processing and transport of biomass, extraction and processing of gas; electricity is also subject to WTT emissions if generated using biomass, oil or gas; (b) emissions lost in lost in Transmission and Distribution (T&D) related to electricity. These are the so-called 'upstream GHG emissions' and are reflected in the emission factors used for each type of fuel.

[43] To properly maximise use of the on-site generation of renewable energy most complete scopes in the direction of including B6.3 and B8 should be favoured. Furthermore, self-use necessitates the use of temporary storage units in the building whose life cycle impacts need to be considered as part of the building's LCA.

[44] One could argue that on-site use of renewable energy (self-use) would encourage to implement batteries in each net zero building, which is less optimal than considering battery sizing on a district level. (Net) zero concepts shall make clear that self-use on a district level is preferred over self-use on individual building level when it comes to storage technology sizing. It is also important to note that environmental impacts of batteries are getting lower as well as there may be alternatives in future such as using waste batteries from cars (e.g. Cusenza et al., 2019).

[45] Additional, without unintended consequences, transparent, permanent (WEF, 2021)

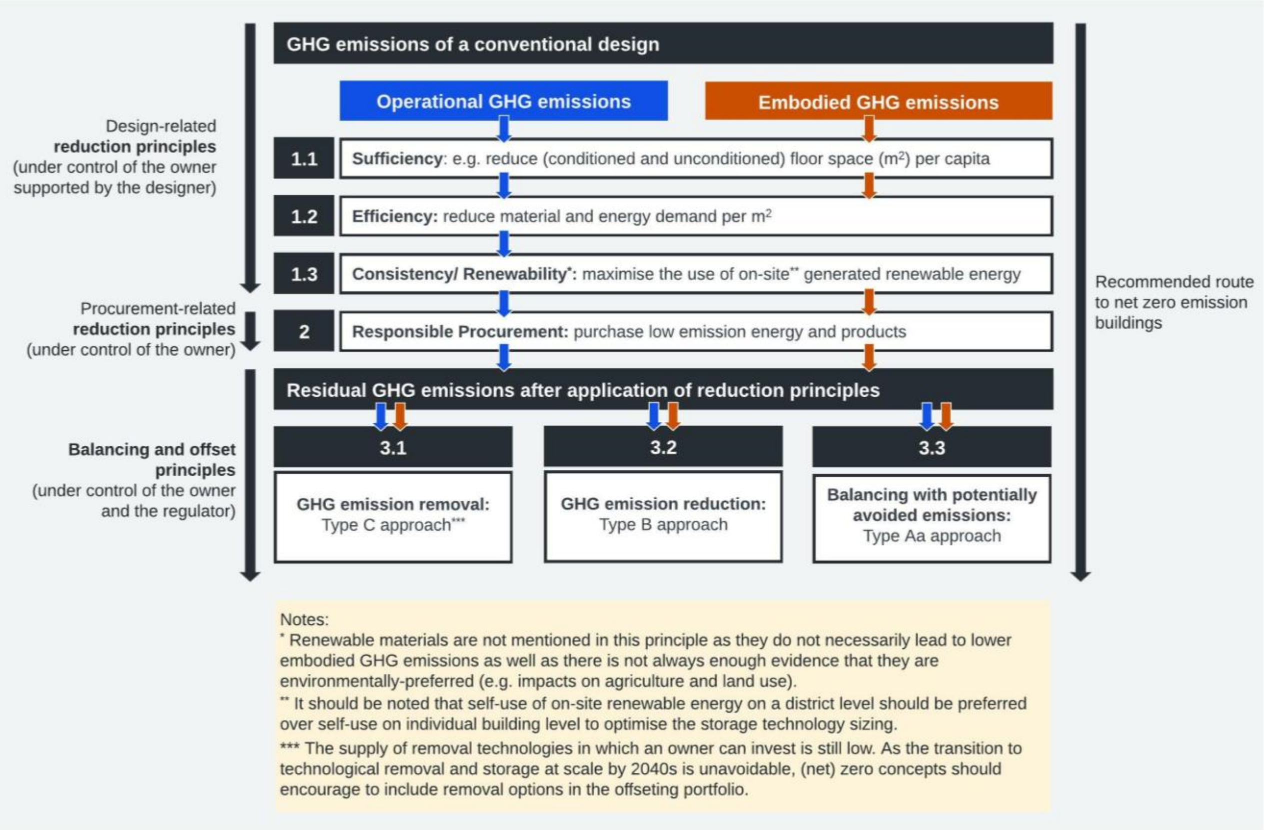


Figure 5.2: Recommended hierarchy of actions to (net) zero emission buildings. Note: the typology of approaches to tackle residual emissions (Type Aa, Type B, Type C) are described in detail in Section 5.2.3 and Table 5.2.

5.2.3 Typology regarding balance and offsetting approaches

Based on the various options existing for achieving a zero or net zero GHG emission building after its unbalanced life cycle carbon footprint has been reduced as much as possible in a first step, a typology is introduced below (Table 5.2). This system serves the purpose of grouping the different approaches and thus of enhancing transparency and facilitating understanding. It is suited for the assessment of operational or life-cycle-related GHG emissions. The classification in Table 5.2 consists of four broad categories of 'net-zero' (approaches A–C) and 'zero' (approach D):

- A: Net-balance approach
- B: Technical reduction
- C: Technical neutralisation
- D: Absolute zero

In **Approach A** 'net zero' is achieved via generation of renewable energy sources. If parts of the renewable energy produced on-site is exported to third parties, two further options are available:

- the potential benefits beyond the system boundary caused by exporting energy (a 'potentially avoided GHG emissions') and the associated embodied impacts are attributed to the building (**approach Aa** 'potentially avoided emissions') and therefore its GHG emissions and the potentially avoided GHG emissions elsewhere may balance.[46]
- the pro rata share of life cycle GHG emissions caused by on-site energy production is attributed to the exported energy (**approach Ab** 'allocation') and no potentially avoided emissions beyond the system boundary are attributed to the building. It will be possible to report potentially avoided emissions elsewhere as result from exported energy as additional information (this requires specific emission factors, which

[46] Theoretically, for methods choosing to add module D1 impacts to whole life impacts (though generally not recommended by the standards), approach Aa could also include module D1 aspects (recycling, re-use…), i.e. potentially avoiding impacts of new production of materials/products/components to achieve a balance, in addition to exported energy (module D2).

tend to decrease rapidly due to the decarbonisation of the energy supply). In this case 'net zero' is only achieved with additional measures (approaches B and C).

Approach Aa has been so far the most common as it allows to reach net zero operational GHG emission incl. supply chains or net zero GHG emission (in the whole life) without the need for carbon offsets (see also Section 5.4). In this case, exported energy is seen as a sort of 'offset credit'. However, exported energy potentially reduces the emissions elsewhere compared to an alternative energy generation or procurement scenario. There is currently a debate as to whether embodied and avoided impacts associated with exported energy shall be given for information only (e.g. in module D2 following latest developments in European standardisation in CEN TC 350 like EN 15643) or considered in the net zero balance. The latter involves the risk of double counting (1 x for the building and 1 x for the purchaser of the exported energy)[47]. The risk of double counting decreases when the building is part of a self-sufficient net zero GHG emission group of buildings or district/neighbourhood (i.e. no exported energy), therefore, part of a larger system following Approach Ab.

It becomes clear that while a net-zero-emission building may be reached with approach Aa, it is not the case with approach Ab, unless it is combined with some sort of offsetting (Approaches B and C, respectively). There are different types of carbon/GHG emission offset options. These can broadly be split into two categories: the ones that reduce emissions (compared to a reference scenario) and the ones that remove emissions. These are categorized separately under **Approach B** and **Approach C** in Table 5.2.

There are different types of reduction projects, not all of the same traceability. For example, for some type of projects the emission reduction is directly measurable and therefore real reductions are claimed and shared between the building at issue and the offset project (e.g. CCS equipment in coal power plants). Others are simply leading to potentially avoided emissions elsewhere (investments in renewable energy production plants), and therefore potential (i.e. scenario-based) reductions are claimed and shared between the building at issue and the offset project. Based on this consideration, Approach B is further distinguished between two categories: 'Technical reduction, direct' (**Ba**) and 'Technical reduction, indirect' (**Bb**).

An issue particularly with Approach B is that with an emission reduction outside the building's boundary (real or scenario-based), CO_2 is still being emitted by the building at issue. Therefore, on a global level, net-zero emissions cannot be reached with reductions only, but they can help to reach a maximum reduction of 50% of GHG emissions: per 1 tonne emission reduction, 1 tonne is still being emitted (by the entity purchasing the certificate or investing on a project). Furthermore, considering that the cheapest reduction potentials are likely located in emerging and developing economies, these countries may face high costs in future when it is their turn to reduce their GHG emissions (Lützkendorf & Frischknecht, 2020). Based on these considerations, the transition from reductions to removals becomes critical because even if the building sector would stop emitting GHG emissions right now, the quantity of emissions in the atmosphere is still vast to stop the warming trajectory.

[47] It can be argued that using a consequential LCA approach where potentially avoided emissions correspond to a marginal mix the risk of double-counting is minimized. This issue is further discussed in the A72 background report by Peuportier et al. (2023).

Table 5.2: System of approaches for net-zero and zero-emission building during operation or full life-cycle (adapted and modified from: Lützkendorf and Frischknecht (2020).

Code	Name	Description	Note
Aa	**Net-balance approach, potentially avoided emissions**	Embodied impacts of exported energy produced on-site, and its potentially avoided emissions, as part of the GHG-emission balance of the building	Risk of double counting, unless emissions equivalent to the amount of avoided emissions booked on the building are booked by the party using the exported energy. Approach Aa is a special case of Approach Bb as the investment is made on the building under assessment.
Ab	**Net-balance approach, allocation**	Embodied impacts of exported energy produced on-site and its potentially avoided emissions as additional information (either as part of module D2 of the building or the balance of exported energy)	Life cycle related net-zero GHG-emission buildings are reachable only with additional technical reduction or removal (offsets)
Ba	**Technical reduction, direct** (emission reduction within the project)	Investment in CO_2/GHG emission reduction projects by contributing to its initial financing and implementation, or purchase of corresponding CO_2/GHG emission certificates. Examples: carbon capture and storage (CCS) equipment in coal power plants, energy retrofit of existing buildings.	The emission reduction is directly measurable. The emission reduction is shared between the building at issue and the project, in which the technical reduction is realised. If claimed by the building, it shall not be claimed by the project.
Bb	**Technical reduction, indirect** (potential emission reduction occurs beyond the project)	Investment in projects, which lead to potential CO_2/GHG emission reductions elsewhere, by contributing to its initial financing and implementation, or purchase of corresponding CO_2/GHG emission certificates. Examples: investments in solar or wind power plants.	The emission reduction is determined indirectly using "what-if" scenarios. The potential emission reduction is shared between the building at issue and the project, in which the technical reduction is realised. If claimed by the building, it shall not be claimed by the project.
Ca	**Technical removal** NETs with potentially reversible permanence)	Investment in projects, which remove CO_2 from the atmosphere with potentially reversible performance, by contributing to its initial financing and implementation, or purchase of corresponding CO_2/GHG emission certificates. Examples: Biological fixation, achievable with afforestation, improved forest management; the storage of carbon in long-living buildings and wood products; the storage of carbon in the soil; and long-term underground storage of biogenic carbon	This approach allows to reach net zero GHG emissions buildings and contributes at the same time to the global net zero emissions goal. The viability of such measures is still questionable. For example, planting trees does not claim of taking care of them until they are grown up nor about the fate of the mature tree (afforestation may not be efficient in regions where there is a risk of fire).
Cb	**Technical removal** (NETs with stable permanence)	Investment in projects, which remove CO_2 from the atmosphere with stable performance, by contributing to its initial financing and implementation, or purchase of corresponding CO_2/GHG emission certificates. Examples: biogenic energy resources with carbon capture and storage (BECCS) or direct air capture with carbon separation and storage (DACCS)	This approach allows to reach net zero GHG emissions buildings and contributes at the same time to the global net zero emissions goal, but the long-term viability of such measures is still questionable.
D	**Absolute zero approach**	Use of construction materials and components with zero GHG emissions (including supply chain emissions), purchase of operational energy and water with zero GHG emissions (including supply chain emissions)	An absolute zero life-cycle-based GHG-emission status is currently not within reach for buildings and leads to the necessary inclusion of some kind of measures for GHG emission reductions and ways to balance such emissions in the strategy to achieve a (net) zero target.

In Approach C offsetting takes place with negative GHG-emissions achieved via NETs. Not all NETs are the same, therefore this approach has been further distinguished into two categories (**Ca** and **Cb**) based on the reversibility of the storage permanence (see Minx et al. (2018) for a more detailed analysis). It is important to note that, currently, most carbon offset projects available to invest in are either a type of emission reduction or a type of carbon removal with reversible permanence. These can provide additional social and environmental co-benefits that advance the UN Sustainable Development Goals as well as contributing to overall emissions reductions and sector decarbonisation (WEF, 2021). This makes them essential also for years to come. However, several organisations acknowledge the need to shift to more high-technology permanent carbon removal offsets, such as bioenergy with carbon capture storage (BECCS), which will require more investment and development in many cases. It is not only possible but also necessary for net zero GHG emission definitions to encourage investment in the research and development of these technologies as part of a carbon offsetting strategy.

The two typologies presented in Figure 5.1 and Table 5.2 can be combined to provide a flexible, transparent classification system for different approaches for a chosen emissions balance. The chosen combination would be representative of a net zero approach and can be used as background information (see Table 6.1).

5.3 Linkages of Net Zero Benchmarks to Key Methodological Decisions Beyond Considered Life Cycle Stages

Usually, there are LCA-related and LCI data-related methodological decisions that need to be specified in net zero GHG emission approaches. Net zero GHG emission is a type of benchmark and is linked to a specific method and related data. Selected decisions here described are:
- The allowable types of off-site renewable energy supply and which emission factors to use
- Validity of concept in the context of energy supply decarbonisation
- The timing of (net) zero achievement post-handover
- The proposed mechanisms for verification of real performance

5.3.1 Renewable energy procurement options and emission factors

Renewable energy procurement is a frequently used measure to reduce GHG emissions. Although there is a consensus that on-site renewable energy generation should take preference over remote renewable energy provision plants in order to respect restricted land availability and strengthen independence among others, this option may be able to only partially cover the building site's requirements due to legal, economic, structural or architectural restrictions. There are different options for renewable energy supply from off-site sources (see also the A72 background report by Peuportier et al. (2023)) but not all of them are of them same quality. This calls for an establishment of hierarchy where the maximisation of use of best quality options is sought after before choosing alternative options. There is an increasing consensus that the focus shall be on options that can demonstrate exclusivity and additionality, which are briefly defined as (WEF, 2021):
- **Exclusivity:** refers to when the energy procurement company has a guarantee that they exclusively own the energy generated. This is best guaranteed with direct purchase agreements or with bundled Energy attribute certificates (EACs), where physical electricity production and electricity quality are purchased from the same power plants.
- **Additionality:** refers to the idea that the renewable energy that a company procures would not have been created if it had not been specifically requested. Given that current renewable availability is not sufficient to achieve global net zero carbon targets by mid-century, let alone earlier, the role of real estate sector in creating additional renewable energy generation capacity is important and widely acknowledged.

The only options providing exclusivity and additionality are direct ownership of off-site renewables (with the precondition that it is also connected to a cancelled EAC), corporate or physical PPAs and high-quality green tariffs[48] (although for the latter it is sometimes difficult to prove its additionality). For the countries not providing these possibilities, there is the option of purchasing bundled international Renewable Energy Certificates (i-RECs). While in several net zero approaches standard or low-quality green tariffs as well as unbundled EACs are currently accepted, they are not considered best practice. Especially in the case of unbundled EACs, fossil or nuclear production may be artificially transformed into renewable electricity (a company could use electricity produced with coal or nuclear power but purchase Guarantees of Origin (GOs) of renewable electricity to claim that it uses renewable power). This is likely to lead to double counting of renewable electricity (e.g. building LCAs in Switzerland and Norway both claim (partly) Norwegian hydroelectric power) because GOs are a voluntary means of communication.

5.3.2 'Zero' or 'net zero' in the context of energy supply decarbonisation

In a changing context, where national grids are continuing to decarbonise, with various scenarios to achieve net zero by 2050 or earlier, a question is often whether for buildings not able to reach a 'net zero' status immediately, which can often be the case for existing buildings, the progress towards net zero shall also be acknowledged and standardised within approaches. There are now two new terms found in literature addressing this issue:

– the new term 'zero-carbon ready' buildings introduced by IEA in its roadmap for the global energy sector (IEA, 2021). These are the buildings defined as "highly energy efficient and either uses renewable energy directly, or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat. This means that a zero-carbon-ready building will become a zero-carbon building (*in operation according to the present authors' interpretation*) by 2050, without any further changes to the building or its equipment. (p. 144). In this respect, 'zero-carbon ready' can be interpreted as an intermediate step towards achieving the goal of (net) zero in operation. From this, benchmarks can be derived for the operational energy of buildings (see the draft for the EPBD in Europe and the Commentary by Lützkendorf and Frischknecht (2022). So far there is no definition for zero-carbon ready in the life cycle.
– The term 'net zero in progress' buildings introduced by LETI and CIBSE (2022). This status can be claimed by buildings that have done everything in their control at this point in time and have a committed plan in place with a time frame to meet all requirements (e.g. operation covered by 100% renewable sources). For example, such a status can be claimed by a building which has to (e.g. under planning requirements) be supplied by a non-Net- Zero-compliant energy network (e.g. which uses fossil fuels or is not efficient enough), but the network has a decarbonisation plan in place which will allow the building to be net zero in future. Post-handover this approach applies only to operational GHG emissions while for embodied emissions, net zero is in progress only in its 'as designed' status (pre-realisation).

Therefore, in such concepts a net zero figure is targeted for the future (within a certain timeframe) considering the effects of the decarbonisation of the electricity supply and/or district heating/cooling supply. The choice between the approaches (a) 'net zero GHG emission ready' and (b) 'net zero GHG emission' already after the first year of operation has consequences on the allowable energy sources within the context of a net zero GHG emission framework. The choice of (b) results in buildings that must use already today renewable energy sources to cover their energy needs, while (a) results in a building that may use energy supply sources which are not yet renewable but will be decarbonized over the next years or decade(s). Therefore, (b) leads to stricter definitions than choice (a). Both approaches (1) zero carbon ready and (2) net zero in progress initially correspond to a (binding) reduction strategy and are not direct benchmarks. However, specific benchmarks can be indirectly derived from them.

[48] This implies direct purchase contracts with specific renewable power plants or bundled EACs.

5.3.3 Consideration of timing of offsetting residual GHG emissions

In this report, what is understood by “timing” is the timespan over which the delivery of ‘net zero’ GHG emission performance should be possible. The time of occurrence of embodied GHG emissions differs from operational GHG emissions (Figure 5.3). In different approaches, the question often arises as to whether they should be offset:

a. **Annually** – regardless of on which point on time embodied GHG emissions occur, they can be offset on an annual basis together with operational emissions (one figure)
b. **Just-in-time** – embodied GHG emissions can be offset the time they occur or soon after.
c. **With a time-lag aligned with national or other goals** – embodied GHG emissions can be offset later than they occur, for example, close to the year a country is planning to become carbon neutral.

While from the perspective of a remaining emission budget from now till the medium-term future the question of timing is hardly relevant, choosing approach (b) allows offsetting to be based on verified calculations of actual activities that cause embodied GHG emissions rather than those predicted at design stage (see Section 5.3.4). Another question in relation to the timing of offsetting that occurs, especially in the case of offsetting via investment in removal offsets as per Approach Cb, but in projects that are not yet in place, whether the time of payment (with a guarantee of later removal) or the time of real GHG emission removal counts as the time of offsetting.

5.3.4 Verification of achievement of (net) zero GHG emissions post-handover

From the perspective of the environment, it is essential that (net) zero emission buildings are verified for their real performance. In this way, it can be seen as a process which demonstrates that a building's performance is being maintained at (net) zero emissions. Compared to the verification of achievement of other targets, what makes (net) zero targets different is that also the offsetting part of the balance needs to be verified.

For **operational GHG emissions** the usual case is to request verification after 12 months of measured energy use and renewable energy production data. A question the frameworks should ask is whether this is sufficient, or proofs shall be provided every year or at least regularly (e.g. every five years). Verifying the energy performance of a building is more complex than just measuring the consumption, which depends on climatic variation (the actual heating bill may be higher than estimated because of a colder year) and on occupants’ behaviour (the actual heating bill may be higher because of a high thermostat set point rather than because of a poor building performance). Appropriate protocols exist (e.g. International Performance Measurement and Verification Protocol). In addition, for a net zero operational GHG emissions status including the upstream emissions, the correct and appropriate amounts of GHG emissions reduced via technical reductions (Approach B) or eliminated via NETs (Approach C) to offset the upstream emissions need to be checked. Especially in the case of offsets via NETs a matter of question is whether GHG emissions count as ‘removed’, only once safely stored.

Concerning verification of **embodied GHG emissions** based on as-built conditions this can be done only for upfront emissions by recalculation using actual bills of quantities of construction products and equipment (for A1-3), as well as transport fuel bills and metered energy used for the actual on-site construction process (A4-5). On the other hand, the recurrent embodied GHG emissions associated with repair and replacements, as well as the end-of-life impacts cannot be verified with real values soon enough after the building completion. This means that if whole life (net) zero GHG emission status is declared after the first year of building operation, this will be always partly based on modelled data. Again, also in this case, the amounts of GHG emissions reduced via technical reductions (Approach B) or eliminated via NETs (Approach C) to offset embodied emissions need to be checked and approved. This leads to a need to incorporate a list of allowable and acceptable offset possibilities in a definition of net zero GHG emission buildings. Ideally, such lists should be provided by the national governments.

5.4 Existing Net Zero Definitions in National Assessment Approaches

In addition to the international commitments and roadmaps, there are various national building approaches in the form of certification schemes, assessment standards or frameworks (set of codified principles) to support buildings reaching net zero GHG emission target even today. The number of independent net zero approaches emerging with the aim of guiding this transition is greatly increasing, creating a confusing landscape for real estate industry (Smith et al., 2022). These approaches were identified through a survey conducted among EBC Annex 72 participants and selected external stakeholders. The general data related to key features were extracted and are presented in a A72 background report by (Satola et al. (2022). It is important to note that more than 2/3 of the existing analysed approaches have now shifted to a whole life net zero approach. A summary of key aspects is provided in Table 5.3 organising the information into two groups: how the operational GHG emissions are treated and how the embodied GHG emissions are treated.

Table 5.3: Summary of key findings about how selected aspects are treated within existing national 'net zero GHG emission' assessment approaches for buildings. Note: see background report for details. Where OE = operational GHG emissions; EE = embodied GHG emissions

Aspect		Summary/Conclusions from Survey
OE	**Life cycle scope**	– Most of the analysed approaches consider the complete scope of operational energy use modules (B6.1-3). Some countries consider them in the form of various ambition levels.[49] – In some frameworks, the regulated, building-related energy consumption module (B6.1) is still the single scope of operational impact assessment[50]. – All (so far) existing frameworks include only "chimney emissions" of electricity (scope 1, e.g. PV electricity with 0 g CO_2-eq/kWh), and therefore ignore the supply chain (scopes 2 and 3), however, in some whole life cycle frameworks EE from PV systems are included in the balance.
	GHG emission factor	– Average vs marginal vs hybrid: In most approaches, the average electricity principle of assessing the GHG emissions from the electricity mix is employed. However, there are some approaches using a marginal electricity mix approach or a hybrid one[51]. – Temporal evolution: several approaches start shifting towards a dynamic approach in the sense of considering the evolution of mix in the future[52]. This is particularly evident for approaches aiming for net zero during the building lifetime or up to a certain date and not on an annual basis (see the row on 'timing'). – Temporal resolution: Only one approach considers the hourly variation of emission factors from energy sources[53].
	Balance and/or Offsets	– All approaches allow a Type Aa (Table 5.2) balancing of operational GHG emissions, particularly focusing on on-site renewable energy generation (either building-integrated or within building site boundaries). – A significant number of approaches also allows off-site renewables supplied under a variety of contractual arrangements such as direct ownership, community ownership (net metering), power purchase agreement, etc.

[49] One example is the Australian Climate Active Carbon Neutral Standard for Buildings acc. to which carbon neutral claims can be made for "base building operations" (only B6.1-2) or "whole building operations" (Australian Government Initiative, 2019). Similar approaches exist in Norway (Fufa et al., 2016) and South Africa (Green Building Council South Africa, 2019).
[50] One example is Net Zero Carbon Buildings Framework Definition by (UKGBC, 2019).
[51] For an example of an approach using marginal GHG emission factors see EQUER tool (Frossard et al., 2020); For hybrid approaches where an average emission factor is used for estimating the GHG emissions from electricity use in the building, while a marginal emission factor is employed to determine potential environmental benefits from locally produced electricity exported to the grid see the Zero Carbon Standard by (CaGBC, 2020) and the NollCO$_2$ Certification by Sweden GBC (2020).
[52] Examples are the Carbon Neutral building framework by DGNB (2020), and several approaches from Northern countries (Fufa et al., 2016; Kuittinen, 2019; Local Roadmap Malmö 2030, 2021; Sweden Green Building Council, 2020)
[53] See EQUER tool (Frossard et al., 2020).

		– About half of approaches allow compensation with carbon credits in addition as in Type B (Table 5.2)[54]. – Prioritisation of on-site renewables is a principle in most approaches (but not in all of them).
	Verification of actual performance	– Most of approaches mandate the verification of net-zero operational performance of designed buildings using on-site metered data during the first year of building operation. – The UK GBC approach introduced a requirement for annual verification to increase robustness[55].
EE	**Life cycle scope**	– Some approaches only focus on upfront emissions[56]. However, most of them are trying to shift towards a complete scope (including replacements and end of life treatment) based on data availability. – The modules less covered in the different approaches are: refrigerants (B1) repair process (B3), demolition work (C1) and transport from the site to disposal/waste treatment facility (C2)
	GHG emission factor	– <u>Temporal evolution</u>: A static approach to the "time" factor in embodied GHG emissions assessment during the building lifespan is evident in most of analysed approaches, except: (a) the Swedish NollCO$_2$ scheme assumes zero end-of-life stage (C1-C4) GHG emissions due to the assumption of carbon neutrality taking into account the lifecycle of all activities up to 2050; (b) in the Norwegian approach the GHG emissions caused by the replacement of PV modules is assumed 50% reduced relative to product stage impact (A1-A3) as a rule of thumb based on continues improvement of new technologies and material use, as well as, prospective LCA studies.
	Balance and/or offsets	– Most approaches offset these emissions with economic compensation options, not specifying which type of projects (technical reduction (Ba, Bb) or technical removal (Ca, Cb), Table 5.2) or use a mixture of carbon offsets and exported energy credits, i.e. Type Aa. A specific type of offset project is only mentioned by the Local Roadmap Malmö which plans to neutralise residual embodied GHG emissions with carbon capture and storage projects (Type Ba). – some approaches use the exported renewable energy as credit to offset embodied GHG emissions (Type Aa) as the sole approach to (net) zero, despite the risk of double-counting[57].
	Verification of actual performance	– Verification of embodied GHG emissions calculation using actual bills of quantities of construction materials and products, as well as, metered energy used for the actual on-site construction process, is not common among the various approaches, but some examples exist[58].
	Timing	– Some approaches amortise embodied GHG emissions over the building service life and offset them on annual basis together with operational GHG emissions after building completion (e.g. CaGBC approach), others request to offset upfront emissions soon after completion (e.g. UKGBC approach).

[54] Examples are the Climate Active Carbon Neutral Standard for Buildings (Australian Government Initiative, 2019) and the Zero Carbon Standard by (CaGBC, 2020)
[55] See (UKGBC (2019)
[56] For example, see the guidance by the International Living Future Institute (2019).
[57] Examples are the Carbon Neutral building framework by DGNB (2020) and some approaches from Northern countries (Fufa et al., 2016; Kuittinen, 2019)
[58] E.g. the Carbon Neutral building framework by DGNB (2020) and the Zero Carbon Standard by (CaGBC, 2020).

What can be expected in the background report on an international survey of net zero GHG emission definitions by Satola et al. (2022)?

1. It includes contributions from different Annex 72 countries participants, to identify key national and international initiatives in relation to the definition of 'net zero GHG emission' buildings. The contributions were collected on a basis of a structured survey and a systematic review of information included in the different schemes.
2. Based on the survey, diversity was identified in the following thematic areas: (1) terms and definitions, (2) system boundaries for the recording and evaluation of greenhouse gas emissions, (3) calculation and evaluation rules, (4) balancing and offset options to demonstrate the net zero status.
3. Recommendations are provided as a means for improving transparency and traceability which should also be drawn up to maintain the credibility of the relevant statements.

5.5 Conclusions and Guidance

Large differences in key thematic areas in net zero GHG emission approaches complicate their comparison and makes the identification of truly ambitious approaches difficult. The diversity of approaches means that most probably no single one will satisfy all requirements, but convergence is necessary on a set of principles to provide a consistent framing of 'net zero' for all approaches. General rules (Table 5.4) and recommendations are offered to support the further development of the country-specific assessment approach or definition of net-carbon/emission buildings and increase target transparency with the aim of achieving greater credibility and ambition.

Table 5.4: Rules for setting better and more transparent net zero GHG emission targets

ISSUE(S)	RULE(S)
How to ensure transparency under the umbrella of various 'net zero' approaches?	1. The description of a (net) zero GHG emission benchmark in a framework, standard or roadmap shall provide the terms, system boundary, data bases, rules for calculation, emission balancing, emission offsetting via emission reduction or CO_2 removal and verification in a transparent and comprehensive manner. This information shall be public and freely accessible.
	2. In the case of net zero solutions, the two parts of the balance in the sense of +10/-10 kg CO_2eq./m²y or +50/-50 kg CO_2eq /m²y shall be requested to be indicated as part of the communication of the benchmark achievement. Therefore, the two sides of the balance shall be always provided separately. This is also in line with ISO 16475-1 (ISO 2017). The definition of type of balance and offsetting shall be requested.
What are the necessary side-requirements to prevent from choosing the low hanging fruit?	3. A clear priority 'order' of balance, reduction and removal solutions shall be provided.
	4. On-site renewable energy generation shall always be prioritized for covering the operational energy consumption (see also Figure 5.2).
	5. Off-site renewable energy generation with additionality and bundled EACs shall be prioritized over other off-site options (if at all allowed). Additionality principles shall be clearly stated, as well as a central list of suppliers providing additionality shall be collected and provided.

	6.	It shall be clearly stated how the potentially avoided emissions by third parties as a result of exported energy shall be handled[59,60].
	7.	Offsetting shall be limited to the most hard-to-reduce areas, such as Scope 3 emissions, to encourage a focus on emissions reduction. A list of allowable and acceptable offset possibilities in a definition of net zero GHG emission buildings shall be provided.
How to deal with the timing of balance and offset?	8.	For net zero operational emission, the balance shall be achieved on an annual basis. The same applies to the supply chain (up- and downstream) emissions of the operational part for which the offsets shall be realised and disclosed annually.
	9.	For net zero embodied (or just upfront) emission, the offsets shall be realised at practical completion or within the first three years after completion. In general, GHG emissions shall be offset when (or soon enough after) emitted.
How to verify the benchmark fulfilment at post construction?	10.	Operational part: The real performance assessment of declared net zero GHG emissions buildings for the operational part during use stage shall be mandatorily verified during building operation by on site energy monitoring system. The verification shall be realised on annual basis and not only the first year of operation.
	11.	Embodied part: the material quantities in the embodied emissions calculations shall be verified via the bill of materials "as built".
	12.	The GHG emission offsets purchased or invested in shall be verified and compared against the carbon footprint of the building.

Recommendations for action

Benchmark developers incl. policy makers (application / use cases: A-G, see Table 1.2)

a. Ask by legislation for life cycle-based net zero GHG emission buildings by 2035; start with binding benchmarks in 2025, which are then lowered to net zero by 2035. Net zero can be target value II in the transition period to 2035. Such a roadmap should be also accompanied by a binding definition and description of net zero GHG emission building.

b. To make the description of the 'net zero' approach transparent, use the related parts of Table 6.1 (Section 6.1). Moreover, as far as possible, adopt the suggestions made here for classification in a typology (Figure 5.1 and Table 5.2).

c. To compensate for residual/unavoidable GHG emissions (after all reduction possibilities on the building itself have been exercised), prioritise carbon removal offsets over reduction offsets over balancing approaches via avoided GHG emissions to the extent possible. Therefore, Option C should be preferred over Option B and Aa (see Table 5.2).[61]

d. If feasible provide the partial results showing both parts of the balance, i.e. the carbon footprint of the building and the amount and kind of offset emissions (potentially avoided emissions, technical reduction, technical removal) Use of GHG emission factors of energy sources of the highest resolution possible and available by the specific energy provider.

Benchmark users (application / use cases: H-J, see Table 1.2)

e. When designing and assessing a net zero GHG emissions building, refer to a publicly available definition and make the key aspects of the approach followed explicit in any communication.

[59] Whether or not exported energy should give rise for potentially avoided emissions and for their accounting on the building depends on the national context and preferences. That is why no guidance is given on the role and accountability of exported energy in the greenhouse gas balance of the building under assessment.

[60] The majority of the present authors consider that there is a risk of double-counting in the consideration of potentially avoided emissions by third parties in a building's balance, which should be avoided. Information about exported energy can be documented in module D2 dealing with exported utilities.

[61] Minority statement of some authors: BIPV has an immediate effect by avoiding impacts of standard production whereas options C and B solutions are quite unsure.

6. Rules and Recommendations: Transparency and Interpretability of Benchmarks

This section deals with how to ensure transparency and validity in the development and communication of all benchmarks used to assess the environmental performance of buildings. Transparency means to address and document all methodological issues as well as assessment results in open, comprehensive and understandable presentation formats. Validity means to document enough evidence to be able to identify whether the benchmark fits the purpose of assessment. These principles need to be examined in two types of communication:

– Communication of supporting information (B2B) (Section 6.1)
– Communication of the benchmark achievement to third parties (B2C) (Section 6.2)

6.1 Documentation and Communication of Supporting Information

To overcome the problems described in Section 3.2 and ensure transparency and interpretability of benchmarks used during design as reaction to client's brief, in an assessment system, funding program or law (or even research study), it is necessary to provide detailed, comprehensive and freely accessible (to users) supporting information that describe benchmarks. Table 6.1 can be used for such a purpose. It was adapted and modified from ISO 21678:2020 (Section 5.2 and Tables in Appendix A in the standard) in a way that:

1. more details can be in general provided (e.g. row B.04 "Assumptions, defaults, and choices" in the standard is divided into several parts in Table 6.1);
2. supporting information for top-down "budget-based" and "net zero" benchmarks can also be reported (rows B.05 and B.06-09 in light and darker orange are relevant for these concepts);
3. a special place for source and type of information for top-down budget-oriented approaches is provided in row C.03.

It should be noted that when a benchmarking system with limit, reference and target values is **fully bottom-up derived** from the same sample of buildings, then the filling-in of one template of supporting information is sufficient, indicating all the types of levels in A.02 and respective statistical values in C.02. All highlighted rows are then excluded.

For a **combination of top-down and bottom-up** benchmarks, i.e. when a benchmark system also includes target values derived from a top-down approach, rows B.05-09 and C.03 become relevant, depending on whether the benchmarks are budget-based or net zero. It is useful to fill in two different templates for bottom-up and top-down approaches.

Table 6.1: Checklist for the documentation and communication of benchmarks. Note: Rows A.03 + A.04 cover the functional equivalent description; Row B.05 is only relevant for budget-based benchmarks, while B.06-09 are only relevant for net zero benchmarks.

PART A	**Basic information**	**Example**
A.01	Name of the indicator	*Greenhouse gas (GHG) emissions*
A.02	Level(s) in the benchmark system	*Target value*
A.03	Type of building (function and new, refurbished or in-use)	*Office buildings, New construction*
A.04	More detailed specification if applicable (period and pattern of use)	*Period and pattern of use 5 days/week, 10 hours/day*
A.05	Reference unit	*(kg CO_2eq./m^2) x year* *m^2 based on Gross Internal Floor Area* *'year' based on the number of years defined in the reference study period (RSP)*
A.06	Region/Climate zone of validity	*Germany/ Climate zone III*
A.07	Period of validity	*From 2020 to 2025*
PART B	**System boundaries and methods**	**Example**
B.01	Explanation of methods and data bases	*Following the calculation rules of standard XX* *Data base: Ökobaudat 2017a for construction products, energy services and transport services*
B.02	Building elements/ parts covered (i.e. building model completeness)	*All building elements and services*
B.03.a	Life cycle stages covered (i.e. life cycle model completeness based on the modular structure in EN 15978:2021)	*A1-C4*
B.03.b	Parts of operational energy use covered in detail (B6.1, B6.2 & B6.3)	*B6.1 (heating, cooling, ventilation, hot water supply, lighting)*
B.04.a	Assumptions, defaults, and choices for A4-5 (if covered)	*Average transport distance of 100 km*
B.04.b	Assumptions, defaults, and choices for B1 (if covered)	*e.g. F-gases ignored or included or there are specific rules for selection of products in place*
B.04.c	Assumptions, defaults, and choices for B2-3 (if covered)	*based on date for single processes based on maintenance plan or default values*
B.04.d	Assumptions, defaults, and choices for B4-5 (if covered)	*Reference study period 50 years* *25 years assumed service life for windows, PV panels, etc.* *No technological progress considered (e.g. in relation to future production efficiency of products, etc.)*
B.04.e	Assumptions, defaults, and choices for B6.1	*Average, national annual supply electricity mix (static)*
B.04.f	Assumptions, defaults, and choices for B6.2-3 (if covered)	*Average, national annual supply electricity mix (static)*
B.04.g	Assumptions, defaults, and choices for B7 (if covered)	*average or specific data for LCA for water supply and wastewater treatment*
B.04.h	Assumptions, defaults, and choices for B8 (if covered)	*scenarios for mobility of users*

B.04.i	Assumptions, defaults, and choices for C1-2 (if covered)	*based on process related data or default values*
B.04.j	Assumptions, defaults, and choices for C3-4 (if covered)	*Taking into account current average situation*
B.04.k	Assumptions, defaults, and choices for D1 (if reported)	*Same as above*
B.04.l	Other assumptions and choices (e.g. biogenic carbon, discounting of future emissions, etc.)	*-1/+1 for biogenic carbon,* *No physical discounting*
B.05	Assumptions and choices only relevant for top-down budget-based target values	*Global budget chosen* *Effort-sharing principle chosen to derive the country budget* *Effort-sharing principle chosen to derive the sector budget*
B.06	Allowable types of balancing and/or offsetting as per Table 5.2 for the different life cycle stages and modules incl. the hierarchy	*Type Aa for B6.1-3* *Type C for A1-5, B4 and C*
B.07	Timing of balancing and/or offsetting for the different life cycle stages and modules	*A1-5, C1-4: Offsetting at practical completion based on actual bill of materials and product-specific emission factors for A1-5 (for C1-4 modelled data are used)* *B1-5: Annually in use offsetting* *Upstream impacts (Scope 3) of B6.1-3, B7: Annually in use offsetting*
B.08	Side requirements for allowable renewable energy procurement options incl. the hierarchy	*Only physical or corporate PPAs in the case of off-site RE generation – if this requirement is fulfilled provider-specific emission factors can be used*[62]
PART C	**Source and type of information**	**Example**
C.01	Source of data if bottom-up (incl. sample size and age)	*Calculated data based on design stage analyses (modelled building variants)* *100 buildings* *Data from 2016-2018*
C.02	Statistical values chosen for the representation of the benchmark (if bottom-up)	*95th Percentile as a target value*
C.03	Source of target if top-down (standard/ political goal/ global goal or budget)	*Not applicable*

[62] If green electricity is connected to the grid, one should think of using the residual mix.

6.2 Communication of Benchmark Achievement

Among the existing life cycle-based benchmarking systems, two options for communication of benchmark achievement for individual indicators can be distinguished:

1. direct communication of benchmark values (e.g. kg CO_2 eq) – this is seen in SIA 2040 (SIA, 2017) and most research-based benchmark systems
2. use of performance classes (e.g. label A to G) – this is seen in a French design tool (Wurtz et al., 2021), and it is also now proposed for the UK[63].

There are also benchmarking systems, such as the legal requirements on the environmental performance of buildings in the Netherlands (MPG) which combine both options, and therefore also their advantages, while counteracting their disadvantages (Table 6.2). In general, the preferred communication depends on the target group. Due to its transparency, the preferred communication from a scientific perspective and experts in the field is the provision of benchmark values. On the other hand, real estate agents prefer the performance classes as more informative for people comparing different buildings when buying or renting new or existing buildings.

Table 6.2: Advantages and disadvantages of the two prevalent communication approaches.

Communication approach	Advantage (+)/ Disadvantage (-)
Benchmark value	(+) transparent, position of the LCA result can be precisely specified as a "distance to target / next performance level / minimum requirement" (+) timelessly interpretable (-) not for quick comparison (-) very specific in nature, therefore unfriendly for non-experts (e.g. real estate buyers and renters) (-) values from different countries not directly comparable as they may have these different scopes
Performance class	(+) very informative for non-experts (+) potential for harmonization of communication in a broader sense[64] to assist international portfolios, if it is globally agreed which class represents the average, which the best practice and which the lowest performance (e.g. % of average of the local market). (-) may represent a wide range of values (-) currently different from country to country in relation to what they represent (e.g. in one country class D may be the average, while in another country class C) (-) if the definition of the classes is based on statistical analyses, it requires large amount of information on the relevant buildings to be "represented" in different classes, to be able to set thresholds (-) the thresholds of classes may change over time (-) classes from different countries not directly comparable as they may have different scopes.

A compromise is needed where both the classes are specified to allow quick comparisons of ambition across various portfolios and the particular benchmark values are given. This system can be used to report against different scopes, such as (see also rules in Section 4.4): upfront impacts (modules A1-5, excluding sequestration in case of GHG emissions) and total embodied impacts (A1-5, B1-5, C1-4), regulated operational impacts (B6.1) and total operational impacts (B6.1-3, including B7 if relevant), and whole life impacts. How

[63] See: https://www.leti.london/_files/ugd/252d09_3c7a09c2c0344ca58db190c5e13584bb.pdf
[64] Meaning that the classes will not be comparable but they will represent the same broad performance based on the local market (e.g. average, above average, below average, etc.)

this could look like is illustrated in Figure 6.1. Such a system of classes can be a representation format of any type of benchmark, e.g. also the benchmarks for biogenic carbon content.

Figure 6.1: Illustration of how the fulfillment of benchmarks for the environmental indicator GHG emissions can look like (inspired from LETI Embodied Carbon Target Alignment[65]). Note: (a) Specific values are not provided to avoid indicating a recommendation in this direction; (b) according to the new EPBD proposal the classes will be A-G. However, depending on the country sometimes there is A, AA, AAA, or A, A+, A++. The indication of A, A+ does not represent a recommendation, it is only used for visualization purposes (c) module D is divided into module D1 and module D2 according to the latest version of EN 15643.

[65] See: https://www.leti.uk/carbonalignment

When it comes to the presentation of achievement for multiple indicators, this can be done by showing different bands or points in a spider or ring format. However, in many cases a total score based on the benchmark values is calculated as seen in most sustainability certification systems, such as BNB/DGNB, BREEAM, LEED, etc. The urgency of the individual environmental impacts can and should be made visible by showing the weighting of indicators and the fulfillment for the most important indicators as visualized in Figure 6.1 (as an example) along the total score.

6.3 Conclusions and Guidance

Methods shall ensure transparency and interpretability of the benchmarks they provide. To do so supporting information that describe benchmarks needs to become available. Rules (Table 6.3) and recommendations are provided below.

Table 6.3: Rules for improving communication of benchmark descriptions and achievement.

ISSUE(S)	RULE(S)
How to declare and communicate supporting information of benchmarks?	1. For benchmarks of all kinds, all supporting information shall be documented in an open, comprehensive and understandable way.
	2. When information about any benchmark is made available, the information described in Table 6.3 shall be given. This constitutes the minimum declaration requirement to ensure the transparency, applicability and comprehensive understanding about the benchmarks of a benchmark system.
How to communicate benchmark achievement per individual indicator?	3. A communication approach providing both benchmark values and classes shall be applied to cover communication to different groups of actors to the extent possible. The highest achievement shall be (net) zero emissions at the minimum ((net) positive solutions may also be strived for).
	4. Different scopes shall be provided following a common communication approach even if the benchmarks for some scopes have the role of guidance and are not binding. This helps the separation of embodied impacts from operational impacts (identification of trade-offs), of current construction impacts from future ongoing impacts (less manageable), of building-related operational impacts from user-related impacts (less manageable).
	5. For clarity, the separate reporting of biogenic carbon and module D shall be part of the benchmark achievement visualisation, as they constitute beneficial aspects of a design solution.
	6. In the case of net zero solutions, the two parts of the balance shall be requested to be indicated as part of the communication of the benchmark achievement. Therefore, the two sides of the balance shall be always provided separately.
	7. A special reporting template shall be provided by the method to the users so that they can document detailed values per life cycle stage and building component, as well as indicator. This is useful for better understanding the LCA scores of a building. The fully completed templates are to be publicly disclosed by the user in order to claim a rating against the classes.

7. Outlook

The importance of benchmarks and target values in the field of environmental performance assessment of buildings is currently growing rapidly. This will continue and further accelerate. So far, the sustainability assessment systems with their demand for assessment standards have been the drivers for this but these are gradually being replaced by approaches promoted by state and supranational institutions (e.g. European Commission). The latter do not aim any more to introducing voluntary requirements but binding ones. Currently, the following trends can be observed:

a. In a **first phase**, on top of limiting operational GHG emissions, more and more countries are introducing binding requirements to limit embodied GHG emissions (see A72 background report by Rasmussen et al. (2023) and A72 report by Lützkendorf et al. (2022)), and in some cases with additional requirements in the area of upfront emissions. Following the new EPBD proposal (currently in a draft status) it is also expected that, at least in Europe, a requirement for (net) zero GHG emissions in operation will soon be the norm. These requirements will collectively supplement previous requirements for limiting operational energy consumption. Primary energy consumption represents the use of finite energy resources, while the greenhouse gas emissions represent global effects on the environment. It is assumed that both indicators will continue to play a dominant role in a system of environmental performance requirements.
b. In a **second phase** that is already beginning, there will be binding life cycle-based requirements for additional environmental indicators to avoid burden-shifting such as resource consumption (which also serves as a bridge to circular economy). These requirements will increasingly be based on the available global budgets.
c. In a **third phase**, there is a transition to the requirement of reaching zero or fully offset GHG emissions in the life cycle of buildings. This must go hand in hand with an adjustment of the principles of a cost-benefit analysis. A search for a 'cost-optimal' requirement level can no longer exist in the interest of preserving the natural basis of life. The requirement level results from the need to observe and comply with planetary boundaries. In the future, the question of how to realise climate-neutral buildings with minimal life cycle costs and without unacceptable impacts on other environmental categories, health and other basic requirements for buildings will be prevalent.
   - The increasing use of renewable energy to the point of the obligation to install systems on the building or on its site makes it necessary to deal methodically with questions relating to BIPV, among other things. It also forces to expand the traditionally considered system boundaries within Module B6. It would be useful to include Modules B6.2 and B6.3 to be able to represent the self-consumed share of the energy generated on-site in a more complete fashion.
   - A reconciliation between the consideration of individual buildings as consumers and producers of renewable energy and of national energy supply systems must be the subject of further scientific investigations.
   - Due to the high dynamics in the decarbonisation of the energy supply and the production processes of building materials, a transition from static to dynamic considerations and its pros and cons must be discussed in view of credible scenarios, reliable data, calculation rules and benchmarks.
   - The conservation of natural resources and here in particular the primary raw materials is another important goal of sustainable development. There are close connections between energy saving, climate protection and resource conservation. It is assumed that in a next wave of developments the reduction of the use of primary mineral resources will be central. The prerequisite is the determination, description and assessment of the material composition of buildings based on the information on the materials, components and systems used in a material inventory. For this, the creation of a material inventory parallel to the life cycle assessment result becomes essential.

8. References

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ANNEX 72

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