ANNEX **72**

EBC

Energy in Building and Communities Programme

International Energy Agency

Context-specific assessment methods for life cycle-related environmental impacts caused by buildings

Energy in Buildings and Communities Technology Collaboration Programme

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ANNEX 72

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Energy in Buildings and Communities Technology Collaboration Programme

February 2023

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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

Buildings cause considerable energy and material flows and undesirable effects on the global and local environment in their life cycle. Reducing the use of natural resources, e.g. in the form of primary raw materials, as well as greenhouse gas (GHG) emissions are sub-goals in the area of improving the environmental performance of buildings. Appropriate calculation and assessment methods are needed to assess and influence buildings' environmental performance.

The method of life cycle assessment (LCA), which can also be supplemented by an assessment of non-LCA impacts and aspects, provides the basis for the environmental performance assessment. In addition to the principles according to ISO 14040 and ISO 14044, the methods of applied life cycle assessment according to ISO 21931 and EN 15978 (both under re-development) are used in the construction and building sector.

However, assessing environmental performance is no longer a task for science. It is increasingly used in design, to demonstrate compliance with requirements of funding programs, in sustainability assessment systems as well as in the context of legal requirements. The results are already affecting building rentability and marketability, valuation, the determination of financing conditions and the sustainability reporting of companies. Accordingly, the assessment methods must be used by a broader audience. It becomes clear that the methodological principles must be prepared in such a way that they can be used by organizations of all kinds and legislative institutions in connection with the formulation of requirements and can also be specified as a binding basis for the verification process.

Methods for assessing environmental performance must respond to current and already identifiable future challenges. Standards with long deadlines for revision and updating prove to be disadvantageous in this sense. Hence, this report attempts to provide both the basic foundations and current topics of an applied life cycle assessment in the context of an environmental performance assessment and to translate them into rules and recommendations. These are aimed at organizations and stakeholders who want to further develop the methodological bases of an applied life cycle assessment, prepare them in a practical way and apply them correctly themselves.

Objectives and contents of the report

This report focuses on methodological issues related to the determination, assessment and presentation of the environmental performance of buildings. The purpose of this report is to provide the foundations to responsible parties for further developing their specific methods to assess the primary energy demand, GHG emissions and further environmental impacts of buildings and to increase the mainstreaming of practice globally. As far as possible, this should lead to a standardization of methods used worldwide. Where this goal cannot be achieved, methodological differences can be at least identified. The specific objectives of this report are to:

- clarify methodological questions that have been shown as significant but are under-addressed in the analysis of methods currently in use in the Annex 72 participating countries
- provide a consistent and transparent basis for a methodology and reporting structure for environmental performance assessment in line with international standards to enable comparability and usability of results

- 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
- promote the application of principles for circular economy by encouraging the early consideration of the deconstructability of buildings and building components and quantification of their reuse, recycling and/or recovery potential
- enable benchmarking and target-setting.

Key messages

In the field of further development of environmental performance assessment methods for buildings using applied life cycle assessment (LCA), the following recommendations can be given:

a. **The physical building scope and the life cycle scope shall be defined and considered as completely as possible based on a harmonized building model and life cycle model.** These models will create the basis for design decisions and assessment results. For this, existing standards shall be the first choice, or any deviations from these standards should be justified. The life cycle model is based on convention of a reference study period, where the building's end-of-life (fictively) takes place at the end of this period.

b. **Within the life cycle of a complete building, the life cycle of building components shall be modelled and assessed.** Contribution analysis is useful, particularly when the benchmark for the building cannot be fulfilled so as to check which components, processes or life cycle stages create the problem.

c. **The provision of average and default values for life cycle stages, as well as building components and services, to support early design is becoming essential.** Already some national methods provide such default values. The lack of details on the building and its life cycle in early design stages can be compensated for with default values provided by the methods. This task is critical to ensure completeness and that exclusions of building components/elements and/or life cycle stages are avoided as much as possible. As design progresses default values shall be replaced by specific values.

d. **The minimum requirements for describing the functional equivalent (or functional unit) of buildings shall be as comprehensive as possible to ensure comparability of results to the highest extend reasonable.** This shall include, in addition to typical technical and functional requirements influencing environmental performance, client requirements for adaptability during use and/or planned refurbishment of the building (if appropriate). It is also useful to request a detailed description of surrounding conditions (climate type, soil type, etc.) as background information to further facilitate interpretation of results.

e. **The calculation method used to derive the environmental performance result and the method used to derive a target shall be consistent.** If there is an agreement between the client and the designer early in the design for a particular environmental performance target, it shall be ensured that the target (the way it was derived) fits with the chosen calculation and assessment method. Clients may desire to fulfil different types of targets which may not follow the same method.

f. **Against the background of a reference study period of 50 years and above, a transition from static to dynamic considerations should take place in scientific studies**. Research can be a pathfinder applying such approaches both in operational and embodied part and showing the emission reductions achievable and the measures to be taken to reach these reductions. Although there is currently consensus that building regulation, and certification systems should prefer a static approach in the operational and in particular the embodied part, countries with confidence in their future energy policy may apply a dynamic approach. A dynamic approach additionally increases the pressure on the construction product industries if there are legally binding emission reduction paths and on lowering emissions caused today (upfront emissions).

g. **The impacts and benefits of renewable energy systems – building integrated and/or located on a building's site – shall be appropriately addressed in the life cycle assessment**. This applies to the allocation of both the embodied impacts of the renewable energy technology used and the net potential benefits associated with the self-used and exported energy shares of the renewable energy generated. Different approaches exist. Double-counting needs to be avoided.

h. **Solely focusing on the calculation and assessment of regulated operational energy use, as is usually the case, does not represent an accurate reflection of reality.** For the real estate and housing industry, it is essential to gain a better understanding of the total operational energy use and related emissions by including the building-related and user-related unregulated parts in the minimum documentation scope. Although it can be argued that building design cannot influence unregulated energy use, extending the scope of methods can: (a) provide a better picture of the internal heat gains and cooling loads within the building, (b) improve the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity, (c) fulfil the clients' expectation of becoming aware of the real-life energy use and related running costs of their buildings early on so that they can target control alterations and user behaviour-change programs more efficiently.

i. **Effects of green electricity use and other forms of procurement of renewable energy can only be considered after fulfilment of upstream secondary requirements and under strict conditions**. Particularly, the purchaser shall be allowed to consider the effects from the purchase of green electricity only if it is verified that the purchase of the electricity (physical consideration) is coupled with the purchase of the Guarantee of Origin (GO), i.e. they both come from the same power plant(s). It is currently problematic to meet these conditions at the time of the building permit application, which is why the consideration of green electricity is currently still excluded in several countries.

j. **Modules D1 (reuse, recycling, recovery potential) and D2 (exported utilities potential) as well as the biogenic carbon content form important additional information.** Another piece of additional information is the fossil carbon content as a result of the use of plastics. For further details, see Section 4.4.2.

k. **Construction products that are manufactured using biogenic materials should be accounted for in a life cycle assessment in accordance with the current standard following the -1/+1 approach, except for the share of biogenic carbon which is permanently stored.** For biogenic carbon permanently stored, the +1 approach does not apply. For the consideration of upfront impacts, an adjusted approach is needed, e.g. a "0" approach for the biogenic part.

l. **For the LCA of a refurbishment project, how the already occurred embodied impacts of building components retained from the original building are allocated shall be clearly specified.** It is recommended to consider them as zero due to the complexities inherent in retracing past environmental impacts, as well as the inability to influence them. In any case, the minimum inclusions shall always be the life cycle impacts associated with any new installed parts, components and ancillary products needed for the refurbishment (and end-of-life impacts of decommissioned elements, unless other choice is used and justified), and the impacts of replacements of initial building components occurring during the second life cycle as well as their end-of-life impacts.

m. **Life cycle assessment results shall conform to standards and be reported disaggregated into individual life cycle stages in addition to the whole life result.** It would also be useful to report values for individual building elements, materials/products to enable a thorough analysis. Total GHG emissions should be broken down in addition into fossil-based GHG emissions, biogenic GHG emissions and GWP luluc.

n. **F-gas emissions need to be reduced via secondary requirements and/or be accounted for under the module B1**. Currently, the life cycle emissions of a building affected by fluorocarbon gas, either used as a refrigerant in various building-integrated systems or as blowing agents in insulation materials, is considerable, although their phase down and replacement with low-GWP alternatives is already regulated to change in the short-term. A secondary requirement can be the demand to use refrigerants with low GWP (i.e. <150) and ensure acceptable refrigerant leakage rates.

o. **The system of indicators chosen to quantify the environmental performance shall ensure that a burden-shifting to other environmental areas is avoided**. At the minimum, the assessment method should concentrate on only a few core indicators that are relevant in terms of legislation and environmental policy of the respective country, while also ensuring that environmental loads cannot be shifted. This may result in addressing additional indicators to the typical ones proposed as core in the standards (predominantly PE,nr and GHG-emissions), such as radioactive waste, particulate matter and biodiversity loss, among others.

p. **Assuming a remaining budget for GHG emissions to remain within 1.5°C of global warming, current and future emissions are considered as of equal importance.** This means that physical discounting of future emissions should not take place. In case the time factor should be considered in corresponding considerations, a conversion into external costs is recommended. However, a discount rate of 0-1% is recommended.

q. **The impact of the climate change on the energy performance of buildings, according to projections of future weather data, is relevant and shall be considered in building LCA**. To identify climate resilient buildings, the use of future climate data for determining the operational energy demand shall be encouraged. However, future climate data should not affect the level of benchmarks to fulfil. A building design is resilient when it is robust enough to fulfil all mandatory requirements by the method (withstand) also during extreme climate conditions.

r. **In addition to dynamic considerations, aspects of uncertainty should be taken into account in research studies.** This should be done – among other options – using the Monte Carlo simulation. A prerequisite is the determination/indication of ranges or distributions for input variables.

Table of content

Abbreviations

Abbreviations	Meaning
AP	Acidification Potential
ADP	Abiotic Depletion Potential
A72	IEA EBC Annex 72
BES	Building Energy Simulation
BIPV	Building-integrated Photovoltaic
BoQ	Bill of Quantities
BoM	Bill of Materials
CF	Characterisation Factor
CFC	Chlorofluorocarbons
CIBSE	Chartered Institution of Building Services Engineers
dCF	Dynamic Characterisation Factor
EoL	End-of-Life
EP	Eutrophication Potential
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
DLCA	Dynamic Life Cycle Assessment
GFA	Gross Floor Area
GHG	Greenhouse Gas Emissions
GCM	Global Circulation Model
GO	Guarantee of Origin
GWP	Global Warming Potential
HFA	Heated Floor Area
HFC	Hydrofluorocarbons
HCFC	Hydrochlorofluorocarbon
HFO	Hydrofluoro-olefins
HVAC	Heating, Ventilation, Air-conditioning
IAM	Integrated Assessment Model
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KBOB	Koordinationsgremium der Bauorgane des Bundes
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MEP	Mechanical, Electrical and Plumbing
NFA	Net Floor Area

ODP	Ozone Depletion Potential
PE	Primary Energy
PE,nr	Primary Energy, non-renewable
POCP	Photochemical Ozone Creation Potential
RCM	Regional Circulation Model
ReqSL	Required Service Life
RSP	Reference Study Period
SDG	Sustainable Development Goal
SIA	Schweizerischer ingenieur- und architektenverein
TH	Time horizon
VOC	Volatile Organic Compound

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.

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).

Global Warming Potential (GWP): Impact category (or characterization factor for climate change) describing the radiative forcing impact of one mass-based unit of a given greenhouse gas relative to that of carbon dioxide over a given period of time. A time frame of 100 years is currently most commonly used and accepted. [kg-CO2eq] (adapted from ISO 14067:2018)

Indicator: quantitative, qualitative or descriptive measure (ISO 15392:2019).

Life cycle stage: 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 21930:2017).

Information module: distinct parts for a building's life cycle for which impacts are to be declared. Each building's life cycle stage is comprised of more than one information modules.

Design phase or design step or design stage: The design process is typically paced by different design steps, in which lifecycle-based environmental performance assessment can be integrated to various extents. For example, in the early design phase, the first steps are the strategic definition of the project and the preliminary studies, that have to be made in order to get to the concept design. In the detailed design phase, the next step is the developed design, which is followed by a precise technical design step where all the detail technical solutions are developed and the documentation for the procurement is prepared. A detailed description of the various design steps can be found in A72 report by Passer et al. (2022).

Operational impacts: Impacts associated with energy and water consumed during a building's operation.

Embodied impacts: When an environmental impact of a product is characterized as "embodied" it does not mean that it is really embodied in the product itself. It is used in a metaphorical sense to describe the impacts caused by life cycle stages of a product other than the operation (embodied in a virtual sense).

System boundary: boundary representing what building parts and life cycle stages are included and what not in the building assessment (adapted from EN 15978:2011)

Component: item manufactured as a distinct unit to serve a specific function or functions. A building component is a part of a building, fulfilling specific requirements/functions (e.g. a window or a heating system). The service life of a building component can be shorter than the full service life of the building. Building components are sometimes referred to as "building elements" (ISO 21931-1:2022).

Benchmark: reference point against which comparisons can be made (ISO 21678:2020).

Environmental Product Declaration (EPD): claim which indicates the environmental impacts and aspects of a product, providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information (prEN 15978-1:2021)

Carbon content: refers to the amount of carbon stored in (physically contained in) a product or building. This physical carbon is contained in biogenic products such as timber (called biogenic carbon) as well as fossil-based products such as plastics.

Physical discounting: When the physical quantities of impacts are discounted based on a time horizon, leading to assign a different importance on current and future emissions.

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 6707-2:2017).

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

Functional equivalent: It represents the quantified functional requirements and/or technical requirements for a building for use as a reference basis for comparison (ISO 21931-1:2022).

Upfront emissions: All embodied emissions associated with the pre-handover stages of a building's lifecycle, i.e. all emissions associated with the production of construction products and in most cases also transport to site and installation processes of the construction products (depending from system boundaries this is represented using modules A1-A3 or A1-A5 in an LCA of buildings).

Refurbishment: planned large scale (substantial) modification and improvements to an existing construction works to bring it up to an acceptable condition. Refurbishment can be undertaken to facilitate continuation of the current function, including technical modernization and a change of space plan, or a change of function to new use. Synonymous: deep renovation, deep retrofit (prEN 15978-1: 2021).

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 residential areas. The latter is closely interrelated with goals such as SDG 3, 6, 7, 9, 12, 13. Sustainable urban development is closely linked to the advancement and adaptation of the existing building stock through the addition of new advanced buildings, or the repurposing and refurbishment of existing buildings. One aspect is the requirement to take the environmental, economic and social implications into account in all design and investment decisions related to new construction and renovation building projects, as well as the operation of buildings. To support the actors involved in their decisions, the provision of specific methods, data and aiding tools is necessary. The level of detail required for this goes far beyond that of the very general SDGs.

ISO 15392:2019 is an international standard that provides the general principles to establish a common understanding of sustainability in the construction and real estate industries. The starting point of all design is the specification and fulfilment of technical and functional requirements, possibly supplemented by considerations of the architectural design quality and the integration into the urban environment. An assessment of the contribution of an individual building to sustainable development goes beyond that: it requires simultaneous and equal reporting of all impacts on the environment, society and economy, as well as the assessment and communication of the environmental, social and economic performance. The use of indicators is recommended for the assessment of the respective performance. These can be derived from areas of protection and protection goals, ISO 21929-1:2011 provides information on the minimum scope of indicators to be considered.

For a concrete implementation of the principles of sustainable development in the construction and real estate industry, in addition to a uniform understanding of sustainability and an agreement on minimum indicators to be used, methodological bases for calculation, assessment and verification rules as well as communication formats are required. Design and investment decisions can only be supported and influenced by the provision of methods that lead to transparent and understandable results.

Countries and institutions, such as the developers and providers of sustainability assessment systems, are currently faced with the task of developing and introducing calculation, assessment and verification rules and procedures based on international standards to suit their specific circumstances, and to introduce communication formats. This also applies to the environmental performance assessment for buildings, which is the focus area of this report. For methods to be applicable the development and provision of the following is essential:

- suitable 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 (2023) and Palaniappan et al. (2023) respectively
- benchmarks – see A72 report "Benchmarking and target-setting for the life cycle-based environmental performance of buildings" by Lützkendorf et al. (2023)
- suitable 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. (2023) and Longo et al. (2023) respectively.

The job-sharing of the different reports is shown in Figure 1.1.

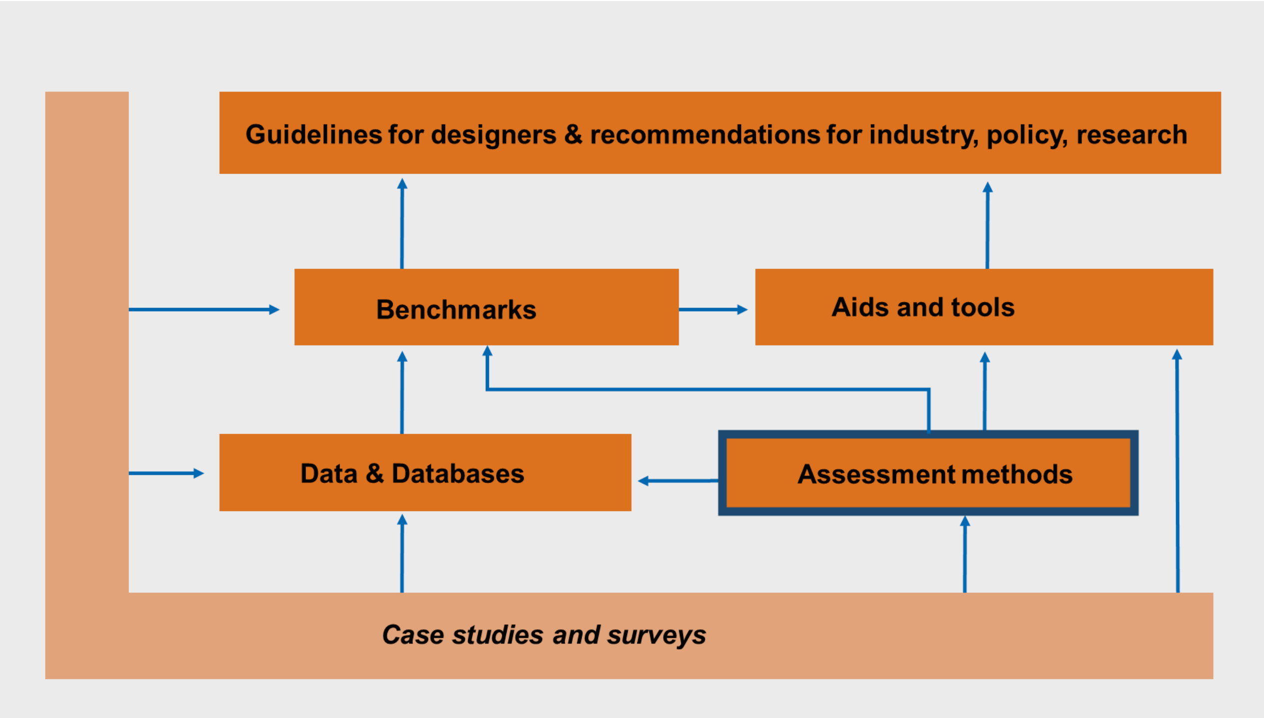

Figure 1.1: Overview of A72 main reports and their interconnections.

Essential aspects of an environmental performance assessment are the determination and evaluation of undesirable effects on the global and local environment (including the assessment of life cycle related global warming potential (GWP)) as well as the use of natural resources such as mineral raw materials, ores, biomass and fossil fuels. These two aspects are extensively discussed in this report together with further environmental impacts.

1.2 Target Audience

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 (1) the increasing availability of generally recognized bases for the life cycle assessment, (2) the willingness of the industry to provide environmental product information as well as (3) the development of new aids in the form of databases and design tools. Nevertheless, the use of the recommended indicators and methods remained limited to individual cases.

This situation is currently changing. Initiatives to limit global warming by reducing GHG emissions are a trigger. The fact that planetary boundaries exist and must be respected in order to preserve the natural foundations of life is also increasingly recognized. Both governments and representatives of civil society recognize their responsibility. This leads to a need for methods, data, tools and benchmarks to support an environmental performance assessment for buildings during the various design and decision-making steps. However, all these must be adapted to the object of assessment, the workflow and area of responsibility of the decision-makers and must be practical. In particular, they must lead to verifiable assessment results.

The results of an environmental performance assessment already have an impact on the rentability and marketability of buildings, the value of real estate and its further development, the terms of financing and insurance, and the reputation of owners. In contrast to a scientific discourse, the aim is to arrive at legally binding/court-proof assessment statements based on generally recognized methods with no room for interpretation. 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 aspects of resource use or environmental impacts.

In Table 1.1 below, all actors are identified to whom the content of this report is primarily directed. A distinction is made between groups of actors who:

a. are directly involved in the development/refinement of rules for calculation, assessment and verification procedures including communication formats
b. apply the relevant rules, or integrate them into design tools, or collect and communicate environmental data, and therefore have an in-depth and ready-to-use methodological knowledge.

Table 1.1: Actors to whom the content of this report is directly and indirectly addressed. Note: For the actors having the role of both developer and user of assessment methods, the main role is in bold.

Nr.	Group of actors / stakeholders	Method developer or user?	d – direct i - indirect
1	Researchers, - basic research on LCA		-
2	Researchers – applied research	**Developer** & user	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	Developer & **user**	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	Developer & **user**	i
11	Construction product manufacturers	Developer & **user**	i
12	Construction companies	User	-
13	Facility managers	Developer & **user**	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**	i
18	Building users	User	-
19	Society	User	i
20	Media representatives (Specialised press/ general press)	User	i

1.3 General Application Cases for a Methodological Basis

This specific report provides rules, recommendations and background information to support

- the further development and harmonization of the methodological basis for LCA and the way it is used in the construction sector
- the (further) development of national methods for the assessment of life cycle related environmental impacts caused by buildings as part of the creation of legal requirements
- the (further) development of assessment methods as part of environmental performance assessment systems or sustainability assessment systems
- the further development of national and international standards
- knowledge creation for all types of users of such methods

in the context of the following application cases (Table 1.2).

An application case is understood here as the application of this report by different actors for the purposes mentioned. In contrast to the application cases which refer to the specific document, the use cases denote in which general cases an environmental performance assessment method is used.

Table 1.2: Application cases of this report for the creation and use of assessment methods

Code	Application cases	Application scope of this report	Use of methods
A	(Further) development of scientific methods	X	
B	Use of scientific methods for studies of all kinds		X
C	Establishment of calculation, assessment and verification procedures based on defined methods (e.g. for laws, funding programs, sustainability assessment systems)*	X	
D	Use of calculation, assessment and verification procedures using defined methods (e.g. to demonstrate compliance with the requirements of laws, funding programs or sustainability assessment systems, for comparing variants in planning)		X
E	Use and interpretation of the results of calculation, assessment and verification procedures taking into consideration and with knowledge of the methodological basis (e.g. for purchase and rental decisions, to determine financing and insurance conditions, for value determination)		X
F	Provision of data using specified methods for application in the context of defined methods (e.g. environmental product information for life cycle assessment of buildings)		X
G	Provision of design tools and aids that integrate or build on LCA methods		X
H	Information for policymakers and society based on calculation and assessment results using defined methods		X

* Design aid is also an important application case. In the list of application cases, add “the (further) development of design tools” – see A72 report by Passer et al. (2023).

1.4 Purpose and Objectives of this Report

This report focuses on methodological issues related to the determination, assessment and presentation of the environmental performance of buildings. It enriches and brings specification to the content of **ISO 21931-1:2022** *Sustainability in building construction — Framework for methods of assessment of the environmental performance of construction works — Part 1: Buildings* and makes it more manageable. When assessing environmental performance, the indicators are derived from the areas of protection “resources” and “ecosystem” in accordance with **ISO 15392:2019** *Sustainability in buildings and civil engineering works — General principles* and **ISO 21929-1:2011** *Sustainability in building construction — Sustainability indicators — Part 1: Framework for the development of indicators and a core set of indicators for buildings*. The aim is to conserve natural resources and avoid their complete depletion, as well as protect the ecosystem (and in particular the climate), also in the interest of preserving the natural foundations of life. Impacts on the ecosystem are described via environmental impacts (midpoints) and possibly damage indicators (endpoints).

The purpose of this report is to provide the foundations to responsible parties for further developing their specific methods to assess the primary energy demand, GHG emissions and further environmental impacts of buildings and to increase the mainstreaming of practice globally. As far as possible, this should lead to consistent and transparent methods used worldwide. Where this goal cannot be achieved, methodological differences can be at least identified, justified and communicated.

This guideline covers modelling aspects such as allocation and recycling, onsite electricity production, uncertainty or electricity mix as well as recommendations on environmental indicators. The specific objectives of this report are to:

- clarify methodological questions that have been shown as significant but under-addressed in the analysis of methods currently in use in the Annex 72 participating countries
- provide a consistent and transparent basis for a methodology and reporting structure for environmental performance assessment in line with international standards to enable comparability and usability of results
- 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
- promote the application of principles for circular economy by encouraging the early consideration of the deconstructability of buildings and building components and quantification of their recovery, reuse and/or recycling potential
- enable benchmarking and target setting.

1.5 How to Use this Report

The development or update of methodological foundations is always successful if these are well adapted to the goal, the object of assessment and the needs of the actors. This report takes into account that the rules and requirements of such context-specific methodological foundations should be tailored to specific application cases. Considering the interests and demands of actor groups primarily addressed in this report (Table 1.1), the focus is on adapting rules and recommendations for creating or further developing an assessment method to typical application cases (Table 1.2).

The results of IEA Annex 31 (www.iisbe.org/annex31/index.html) and IEA EBC Annex 57 (http://www.annex57.org/) form a starting point, as does a list of current detailed questions on calculation and assessment methods that have been identified by the editors and contributors. The latest state of the scientific discussion, as well as of international standardization, are considered. In particular, the report includes current developments up to April 2022.

This report makes recommendations for action with respect to individual methodological questions and specifies rules by which method developers can orient themselves. The aim is to offer a solution that is as consensual as possible for each sub-problem. A level of detail is achieved that can solve specific problems in interpretation of assessment rules, system boundaries and other topics. If there are several options for action, these are presented. A typology of possibilities is offered that can be assigned to individual application cases. By referring to the respective option used, the transparency and traceability of the methods used can be improved. The methodological foundations applied can also be communicated in detail to third parties. Latest research provides the questions that still need to be clarified and are dealt with in the context of this report. This report is therefore also suitable to support an introduction to the topic.

Each sub-section of Section 4 addresses an individual methodological question and contains
- an introduction to the sub-topic and problem
- rules, if necessary, references to specific options to act in the context of concrete application cases
- recommendations for action for specific actor groups
- reference to one or more background reports dealing with the particular topic in more detail, if available

The background reports connected to this report cover the following topics:
- survey on the use of national LCA-based assessment methods for buildings in selected countries (Balouktsi & Lützkendorf 2023b)
- modelling of processes for transport, construction and deconstruction in building LCA (Soust-Verdaguer et al. 2023)
- influence of service life of building components on replacement rates and LCA-based assessment results (Lasvaux et al. 2023)
- electricity mix models and their application in buildings LCA (Peuportier et al. 2023)
- influence of future electricity supplies on LCA- based building assessments (Zhang 2023)
- assessment of biomass-based products in building LCAs: the case of biogenic carbon (Saade et al. 2023)
- influence of future climate change on prediction of operational energy consumption (Guarino et al. 2023)
- discounting in LCA and consideration of external cost of GHG emissions (Szalay et al. 2023)
- aggregation and communication of LCA-based building assessment results (Gomes et al. 2023)

2. Existing Approaches

To develop a well-informed report for national authorities and private organisations on how to create, improve use and/or interpret context-specific methods for the assessment of life cycle related environmental impacts caused by buildings (the focus of this report), it is important to examine existing standards and methods at first. A brief overview of the current situation is provided in this Section.

2.1 Key Standards Referred to in this Report

Table 2.1 lists the standards that deal with the assessment of sustainability or environmental performance of buildings and construction works. International standards are taken into account as well as standards that are used and form a common basis of principles in selected regions (e.g. Europe).

Table 2.1: Overview of international and regional standards related to the assessment of the life cycle-related environmental performance of buildings.

Standard	Ful title	Geographical scope
ISO/TS 12720:2014	Sustainability in buildings and civil engineering works — Guidelines on the application of the general principles in ISO 15392	World
ISO 15392:2019	Sustainability in buildings and civil engineering works — General principles	World
ISO 16745-1:2017	Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage — Part 1: Calculation, reporting and communication	World
ISO 16745-2:2017	Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage — Part 2: Verification	World
ISO 20887:2020	Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance	World
ISO 21678:2020	Sustainability in buildings and civil engineering works — Indicators and benchmarks — Principles, requirements and guidelines	World
ISO 21929-1:2011	Sustainability in building construction — Sustainability indicators — Part 1: Framework for the development of indicators and a core set of indicators for buildings	World
ISO/TS 21929-2:2015	Sustainability in building construction — Sustainability indicators — Part 2: Framework for the development of indicators for civil engineering works	World
ISO 21931-1:2010 (under revision)	Sustainability in building construction — Framework for methods of assessment of the environmental performance of construction works — Part 1: Buildings	World
ISO/TR 21932:2013	Sustainability in buildings and civil engineering works — A review of terminology	World
EN 15643:2021	Sustainability of construction works - Framework for assessment of buildings and civil engineering works	Europe
EN 15978: 2011 (under revision)	Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method	Europe

The assessment of the environmental performance of buildings and construction works is based, among other things, on environmental data on construction products. Table 2.2 lists the standards on the basis of which environmental data on construction products are determined and communicated.

Table 2.2: Overview of international and regional standards related to the provision of life cycle-related environmental data for construction products.

Standard	Ful title	Geographical scope
ISO 21930:2017	Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services	World
ISO 22057:2022	Sustainability in buildings and civil engineering works – Data templates for the use of environmental product declarations (EPDs) for construction products in building information modelling (BIM)	World
EN 15804:2012+ A2:2019	Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products	Europe
EN 15942:2021	Sustainability of construction works - Environmental product declarations - Communication format business-to-business	Europe

2.2 Existing Approaches in Selected Countries

To understand the major variations in building LCA among existing methods, and therefore the challenges of harmonising it, a collection of the details of methods in different countries has been provided by country representatives as part of the IEA EBC Annex 72 project and presented in the A72 background report by Balouktsi and Lützkendorf (2023b). The intention was to reveal the various levels of development of different methods and differences in approaching life cycle environmental assessments of buildings. Topics covered were system description, modelling aspects, environmental indicators, assessment standards, data, tools and benchmarks as well as market conditions and driving forces. To show the practical implications of the variations in the methods, three reference buildings were also assessed by some of the national representatives (see: Frischknecht et al., 2019 and 2020; Ouellet-Plamondon et al., 2022).

Major sources of deviations identified in the assessments of the three reference buildings were the background data used, the scope of the assessment (exclusion of certain building components), the reference study period applied, the emission intensity of the operational electricity demand as well as whether or not landfills and recycling are considered a (partly) permanent sequestration of biogenic carbon. During the process of modelling and assessing the buildings, flaws in the underlying data were discovered, in particular regarding the biogenic CO_2 removals and emissions of wood-based materials. The diversity of results of the assessments of identical buildings with national methods proved the need for a harmonised set of LCA method, data, tools and benchmarks to be applied in a country.

The following key points arise from the survey among A72 experts and analyses (see also A72 background report by Balouktsi and Lützkendorf (2023b)):

– **Despite most countries having some kind of method in place, some of them official, voluntary (e.g. part of a certification system) or more academic, and some are almost a decade old, the level of acceptance and application of these methods still lags behind**. The highest acceptance is mostly seen for methods that are already part of the public procurement and have or will have a legal character soon (e.g. Sweden and Denmark). Therefore, having specific requirements either in legislation or funding programmes always drives application and request for such results.

- **While most countries have legal requirements in place for operational primary energy, only a few have such requirements for operational GHG emissions and even fewer for embodied impacts** (Table 2.3). Particularly, legal limits for the embodied GHG emissions are currently only in place in the Netherlands and France, while they are soon expected to be in force in Denmark, Sweden, Finland and the UK (in some cases proposed values already exist. It also becomes clear that most countries are introducing the regulatory requirements incrementally. First the reporting and data collection are mandated, and the life cycle-cycle-based or embodied GHG emission limits are added at a later stage. In Germany, methods for environmental performance assessment and benchmarks to limit primary energy demand and GHG emissions in the full life cycle are used in funding programmes for residential and non-residential buildings[1]. Another recent development in the European Union is the new Energy Performance of Buildings Directive (EPBD) draft proposal released on December 2021 which requires the life-cycle GHG emissions of new buildings to be calculated as of 2030 in accordance with the Level(s) framework. This will lead to European countries to introduce accounting regulations. However, both the new EPBD and the current EU Taxonomy[2] will require the calculation, but specific limit values have not yet been placed.
- **The most common reference study period (RSP) indicated by the various national methods is 50 years irrespective of the type of building.** What changes is the range of the RSPs considered, with the largest ranges seen for residential buildings.
- **Most methods focus on residential and office buildings.** This can be the case because most assessments have been so far done for these types of buildings. Only a few methods go beyond these two types and consider e.g. industrial and/or educational buildings.
- **Transport and construction processes have started being more and more integrated into the scope of national methods.** Modules A4-5 (construction process stage acc. to the European and international standards in Table 2.1 – see Figure 4.4 for an overview of modules) are now considered by a significant number of methods. This trend can be observed especially in countries where transport distances seem to be non-negligible, such as Spain and New Zealand (Frischknecht et al. 2019; 2020) or in countries where the methods are or will be part of building regulations. Such a trend is not the case for C1-2 modules (deconstruction and transport to landfill or waste processing) with the justification that these activities happen far into the future.
- **Although replacements typically constitute the most important embodied share after product stage impacts, especially in the case of buildings with a significant share of technical equipment, some methods prefer to focus on emissions that happen today in the short-term.** This means that replacement (module B4) is not considered by all methods at least not in the minimum scope.
- **Modules such as B1, B2 and B3 are the least considered**. This may be the case because they are still unclear to method developers, and/or are considered unimportant.
- **The overwhelming majority of methods focus for the operational part on regulated building-related energy use.** This is called B6.1 in the context of Annex 72 and recent standard updates like EN 15643. An extended scope of operational energy use including user-related energy consumption is considered in only two countries with official methods at the moment (i.e. New Zealand and Germany) and two academic methods (i.e. France and Spain). The reason is to deal with questions of the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity.[3]
- **The physical system boundaries of the different methods show great variance, especially when it comes to the inclusion of building services like HVAC-systems.** Most methods show completeness in the consideration of substructure, superstructure and finishes. The inclusion/exclusion of elements that cause variance are (1) stairs and ramps, as well as internal doors, perhaps due to the use of simple building geometric models by some methods; (2) building systems, due to the lack of data; (3) furniture, especially user furniture as it is hard to predict not only during a building's design, but also at the handover,

[1] https://www.nachhaltigesbauen.de/fileadmin/pdf/QNG-BEG/QNG_GMS_311_Anlage_3_LCA_Bilanzregeln_Wohngeb%C3%A4ude_210625.pdf
[2] See: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[3] If the embodied carbon of PV systems is evaluated in terms of a self-use ratio including non-regulated (user-related) electricity consumption, the operational carbon should also account for this non-regulated consumption otherwise only the charges and not the benefit of the corresponding part of the PV system would be accounted for.

since it is dependent on the tenant's choices. In any case, the results occurring in the analysis of one of the reference buildings – a high-rise residential building located in Tianjin (Frischknecht et al. 2020) – imply that it is necessary to include building systems as their contribution to the overall environmental impacts is not negligible.

– **There are methodological questions about the type and scope of assigning the embodied impacts of building-integrated or on-site renewable energy systems such as PVs**. The importance of the question is increasing, since solar roof obligations are being introduced in countries such as Germany. The topic has been dealt with in the ISO standard 50000-1, and further considerations are being made in the context of the revision of EN 15978.
– **Due to climate emergency, some methods now focus exclusively on GHG emissions.** This will cause problems with burden-shifting. In any case, most methods choose a limited list of indicators, e.g. also including indicators such as Photochemical Ozone Creation Potential (POCP), Acidification potential (AC), Ozone Depletion Potential (ODP) and non-renewable primary energy demand/use. A lower acceptance/consideration of the dis-aggregated indicators ADPfossil and ADPelements can be especially observed. On the one hand, this subdivision is still very new - see EN 15804 - on the other hand, hardly any data is available so far. Nevertheless, there are first examples of corresponding assessments (Hafner and Rueter 2018).
– **The methods with the broadest list of indicators are choosing to present their final results in a partially or even fully aggregated form.** Different approaches of aggregation can be observed.
– **There are different perspectives on biogenic carbon consideration in life cycle assessment.** Different options are currently followed in assessments and it can influence the outcome of a study and the decisions and actions of some stakeholders.

Table 2.3: High-level non-exhaustive overview of country-level, municipality-level or region-level requirements in relation to the reporting and/or limiting of the life cycle-based environmental impacts of buildings.

Jurisdiction	Type of requirement	Introduction
Vancouver, CA	life cycle GHG emission reporting requirement, limit values by 2030	In force (since 2021)
Netherlands	national life-cycle impact limit values on new buildings	In force (since 2018)
London, UK	life cycle GHG emission reporting requirement for new projects	In force (since 2021)
Germany	national LCA requirement for federal buildings	In force (since 2008)
California, U.S.	limit values on certain construction materials for public projects	In force (since 2021)
Canada	national LCA requirement for federal buildings, limit values by 2025	In force (since 2022)
France	life cycle GHG emission limit values on new buildings	In force (since 2021)
Sweden	life cycle GHG emission reporting for new buildings, limit values by 2027 (or earlier, currently under investigation)	In force (since 2022)
Denmark	national life-cycle GHG emission limit values on new buildings	2023
Finland	National life-cycle GHG emission limit values on new buildings	2025
UK	national life-cycle GHG emission limit values on new buildings	Open
New Zealand	national life-cycle emission limit values on new buildings	Open
United States	national materials LCA requirement for federal buildings	Open
European Union	EU-wide life cycle GHG emission reporting requirement for new buildings	2030
Switzerland	national limit values for embodied primary energy of buildings	In consultation (2022)

What can be expected in the background report on national methods by Balouktsi and Lützkendorf (2023b)?

1. A concise overview of the situation in most participating countries in Annex 72 in relation to: (a) historical background of the application of LCA in the construction sector; (b) current situation in the field of LCA application; (c) methodological bases; (d) databases; (e) number of applications and users; (f) integration into the design process; (g) acceptance and dissemination.
2. The results of a survey among selected Annex 72 participating countries with a particular method in place, to provide a more detailed understanding of topics such as: (a) completeness of system boundary description; (b) modelling aspects; (c) environmental indicators; (d) assessment standards, data, tools and benchmarks; (e) market conditions and driving forces.

2.3 Examples of Existing Guidelines

Various publications in the form of guidelines or standards dealing with LCA as a whole, or specifically with the aspects of embodied carbon, exist in different countries (Table 2.4). These constitute an indication that countries and organizations do not (yet) consider the international standards to be sufficient to clarify all questions in detail. It becomes obvious that professional associations assume that the contents of standards should be adapted to their specific target groups.

Table 2.4: Non-exhaustive overview of international and regional standards and guidelines related to the assessment of the life cycle-related environmental performance of buildings.

Publisher	Year	Full title (version)	Country/ Region	Link
TOTEM	2021	Environmental profile of buildings (update 2021)	Belgium	https://www.totem-building.be/services/rest/downloads/download?id=1&lang=EN&transId=1
Boverket	2020	Guideline for climate declarations	Sweden	https://www.boverket.se/sv/klimatdeklaration/
IVL (Swedish Environmental Institute)	2020	Digital guideline for LCA calculations in construction projects	Sweden	https://www.ivl.se/projektwebbar/klimatkrav-till-rimlig-kostnad/digital-vagledning.html
The Carbon Leadership Forum	2019	Life Cycle Assessment of Buildings: A Practice Guide (Version 1.1)	USA	http://carbonleadershipforum.org/what-we-do/resources/clf-publications/
DGNB	2018	Life Cycle Assessments: A guide on using the LCA	Germany	www.dgnb.de/en/council/publications/index.php
RICS	2017	Whole life carbon assessment for the built environment	UK	www.rics.org/globalassets/rics-website/media/news/whole-life-carbon-assessment-for-the--built-environment-november-2017.pdf
London Energy Transformation Initiative (LETI)	2020	LETI Embodied Carbon Primer	UK	www.leti.london/ecp
CIBSE	2021	TM65 Embodied carbon in building services	UK	www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000IPZOhQAP

World Green Building Council	2020	Bringing Embodied Carbon Upfront.	Global	www.worldgbc.org/bringing-embodied-carbon-upfront-report-webform
MilieuPrestatie Gebouwen (MPG)	2012	Mandatory materials performance calculation based on LCA	Netherlands	www.rvo.nl/onderwerpen/duurzaam-ondernemen/gebouwen/wetten-en-regels/nieuwbouw/milieuprestatie-gebouwen
National Environmental Database Foundation	2020	Guide to environmental performance calculations		https://milieudatabase.nl/en/environmental-performance/environmental-performance-calculation/
Schweizerischer Ingenieur- und Architektenverein (SIA)	2020	SIA 2032: Graue Energie – Ökobilanzierung für die Erstellung von Gebäuden	Switzerland	shop.sia.ch/normenwerk/architekt/sia%202032/d/2020/D/Product
KBOB, eco-bau and IPB	2015	Regeln für die Ökobilanzierung von Gebäuden in der Schweiz, (Version 1.0)	Switzerland	www.eco-bau.ch/resources/uploads/Gebaeudespezifische_Regeln.pdf
GB/T 51366-2019	2019	Standard for building carbon emission calculation	China	gbstandards.org/GB_standard_english.asp?code=GB/T%2051366-2019
European Commission	2020-2021	Level(s) common framework	Europe	https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/412/documents

3. Basics

3.1 General Requirements for an Assessment Method

When developing or advancing methods for the environmental performance assessment of buildings, common quality requirements must be fulfilled. Specifically, a method shall be:

- **Scientifically based**: Developed using scientific principles
- **Transparent**: Guarantees that all system boundaries, assumptions, rules and assessment steps are documented and communicated in a comprehensive manner.
- **Comprehensible/user-friendly**: Designed for the intended purpose and the intended users
- **Clear**: Leaves no room for interpretation
- **Tested, proven**: Has been checked and tested by third parties
- **Efficient**: Achieves a meaningful/usable result within a reasonable time frame and at a reasonable cost for the particular use context.
- **Quality-proven** (In the case it becomes part of the legislation): Since the development of methods in the context of the development of legal requirements to limit the amount of primary energy, non-renewable, GHG emissions and other environmental impacts is an application case of this report, special care should be taken to ensure that the method is clearly described to such an extent that can be quality-proof.

3.2 Use of a Method Across Different Design Steps, Project Phases and Life Cycle Stages

This report can be used in the context of the application cases described in Section 1.3. This report is particularly suitable for supporting an establishment of calculation procedures based on defined methods (e.g. for laws, funding programs, sustainability assessment systems). After calculation, assessment and verification follows with the help of benchmarks, therefore this report is closely connected to the A72 report by Lützkendorf et al. (2023).

The resulting method must meet requirements that result from the use context (use cases). What is decisive is in which phase of the project for new construction or refurbishment the method should provide a basis for

a. Comparison and optimization of design variants
b. Evidence of compliance with legal requirements
c. Evidence that the eligibility requirements have been met
d. Provision of calculation results for a sustainability assessment

In all the cases mentioned, an assessment can take place at several points in time during design or project development. Case a) practically concerns every design step, case b) usually concerns late design steps where an official approval is requested as well as the creation of final evidence (as-built condition); case c) usually concerns the completion and case d) the pre-certificate and the actual assessment result.

For new construction and larger refurbishment projects different information is available at specific times in the design process. The method must be able to react to the differences in data granularity and availability at different design steps with respect to the level of detail of the description of the object of assessment, as well as the type and source and uncertainty of input variables.

To be able to explain and assign special methodological features, the typical design process in the form of design steps is proposed below in Figure 3.1. A design step corresponds to a design phase (or stage). The design process in the narrower sense corresponds to steps 1-6. In principle, a rough distinction can be made between early design steps (Steps 0-2), detailed design steps (Steps 3-4) and completion/handover (Steps 5-6). Such design and realisation processes take place in new building projects, building refurbishment projects, as well as building repurposing and deconstruction projects. An analysis of how selected national workflows fit into this generic system can be found in A72 report by Passer et al. (2023).

This system is used in this report to assign methodological details to selected steps, when necessary. The same breakdown of steps is used in the report by Passer et al. (2023) to show the information requirements from the side of designers in the different workflows and the integration of the necessary environmental information in the design tools.

Figure 3.1: Common definition of design steps and project phases (source: A72 report by Passer et al. 2023).

This report also makes a basic distinction between the life cycle stages of a building and the steps/stages in the design and decision-making process. The design processes can be integrated in the life cycle of the building as module A0. This makes it possible to show at which point in the life cycle such design processes take place, which information is available and which parts of the life cycle are considered and how. This report distinguishes between:

Design of new buildings (Figure 3.2): Design process is assigned to module A0 of the life cycle model of the building. In relation to the full life cycle of the building, the design process is usually short. Typically, it takes place before construction. However, construction stage may be accompanied by further design work. The entire life cycle of the building is considered in every design step, albeit with different levels of accuracy and depth. Regarding data availability on the one hand, and the range of results on the other hand, there are differences between early design steps and detailed design. A0 is taken into account when determining life cycle costs. When determining the energy and material flows and the effects on the environment, A0 is usually neglected. It can be assumed that A0 and A1-A3 take place more or less in parallel.

The life cycle of a building can be viewed from different perspectives during design. The consideration of energy and material flows as well as the resulting impacts focuses on the physical life cycle and thus on modules A1-C4. During design, however, the alternative strategies design by reuse and design for reuse (i.e. design for deconstruction) should also be considered (De Wolf et al. 2020). The recycling or reuse potential (D1) is an important parameter for the designer. It usually flows into the design as additional information, as it shall always be presented separately according to the related international and European standards (ISO 21931-1 and EN 15978, both currently under revision). The importance of these aspects is also reflected in the recent ISO 20887:2020 which provides principles, requirements and guidance for “Design for disassembly and adaptability”.

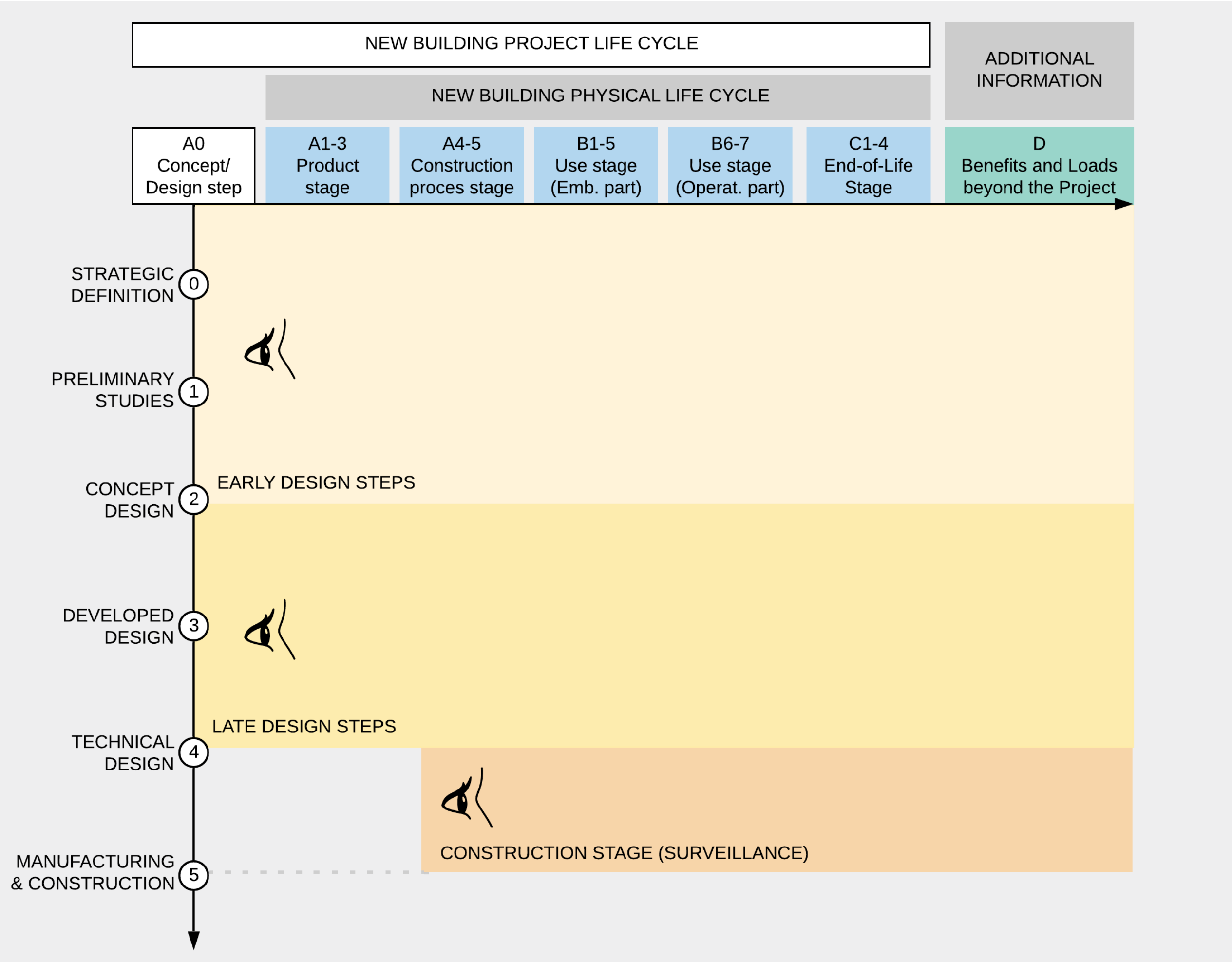

Figure 3.2: Relationship between the typical project and design steps for a new building and the building's physical life cycle (authors' own illustration). Note: The Illustration highlights that the designer should consider the entire building life cycle and in addition the recycling potential as a result of design for deconstruction in all steps of the design process in the A0 stage. The different shadings of orange indicate the shift from more generic to more specific information along the design process.

Design for refurbishment and/or repurposing of existing buildings (Figure 3.3): In the early design steps, it is decided whether and which components will continue to be used (RETAINED B1-5, Figure 3.3) and therefore remain in the building or which will be dismantled and recycled/ disposed of (OLD C1-4 and D, Figure 3.3). This means that there is a specific lifecycle of building components that are still used and one of newly installed building components, which must lead to the adaptation of the lifecycle model of the building. There may be the case that reused parts are installed into the building that come from building stock that has been demolished. How to account of the continued use of existing building components from the first life cycle in the environmental performance assessment of a refurbishment project is the subject of methodological considerations - see Section 4.6.

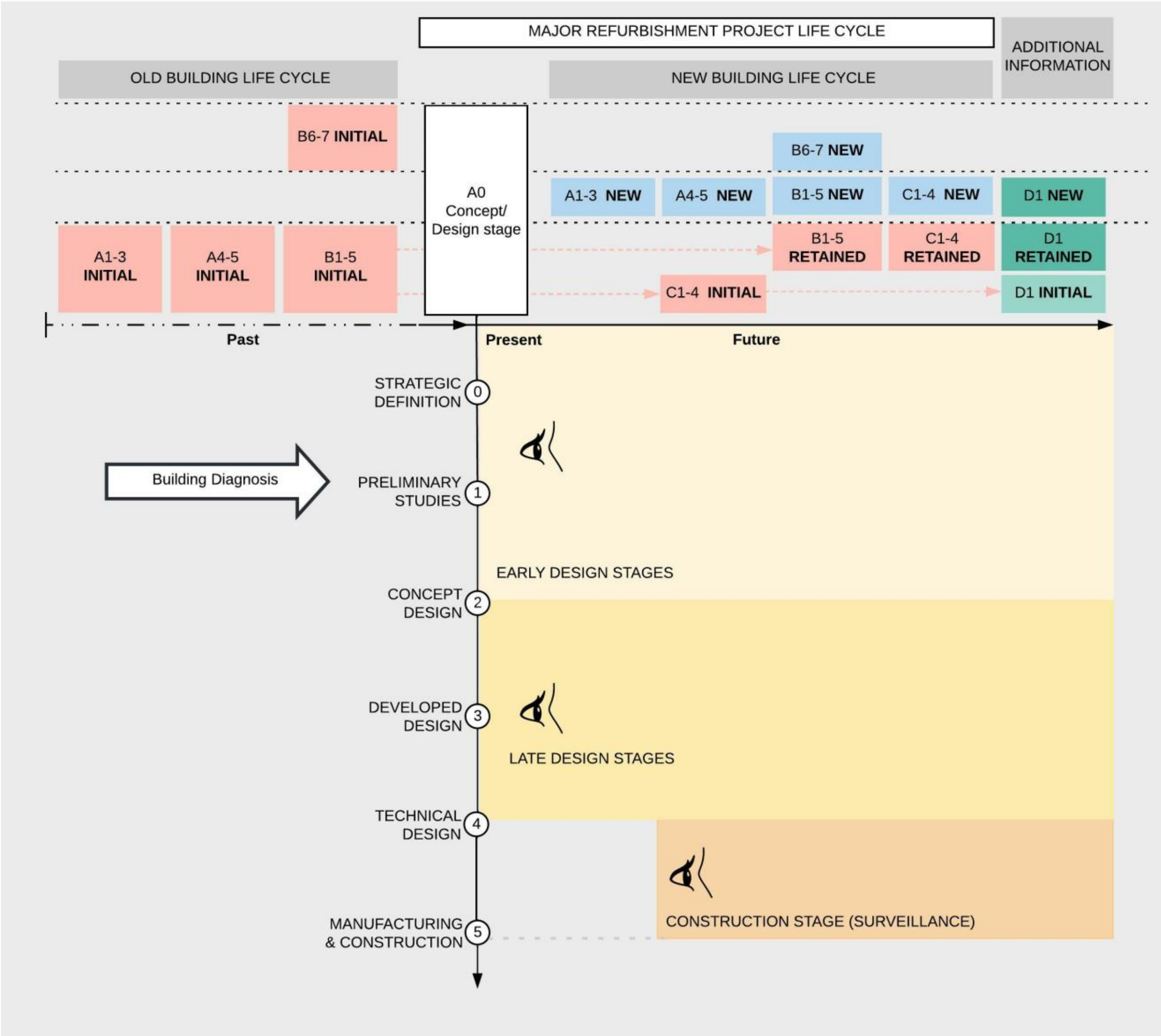

Figure 3.3: Relationship between the typical project and design steps for a building to be refurbished or repurposed and the building's physical life cycle (authors' own illustration). Note: The designer should consider the entire building life cycle in all steps of the design process in the A0 stage to the extent possible based on availability of appropriate data.

It should be noted that a special case is the assessment of buildings "in use". This is not covered here. However, it is pointed out that by investigating the actual energy consumption (i.e. based on measurements) in the use phase of different building types and in different locations, existing models and tools for determining the energy demand can be checked and further developed.

4. Guidance to Develop and Advance Methods: Rules and Recommendations

In the following, selected questions in the development, advancement, or interpretation of a life cycle-based environmental performance assessment method are explained, as well as rules and recommendations are provided. Results from previous Annexes (A31 and A57) have also been considered. It is here assumed that there is a need for clarification and further development for practically all existing methods. The sequence of topics treated in this Section predominantly follows the typical process of an environmental performance assessment as defined by the most frequently used standard EN 15978 (Figure 4.1). Although most methods nowadays follow a static deterministic approach, particular emphasis is given to topics such as how to deal with time-dependent effects, both cross-cutting (relevant for more than one life cycle stage such as grid decarbonisation) and particular to certain life cycle stages or processes (such as the climate change effect which mainly influences the operational energy use), as well as how to handle uncertainties to improve the reliability of results. Additional topics of high interest treated here are how to account for biogenic carbon and how to deal with the case of refurbishment, among others. All these topics have not so far been discussed in detail in standards.

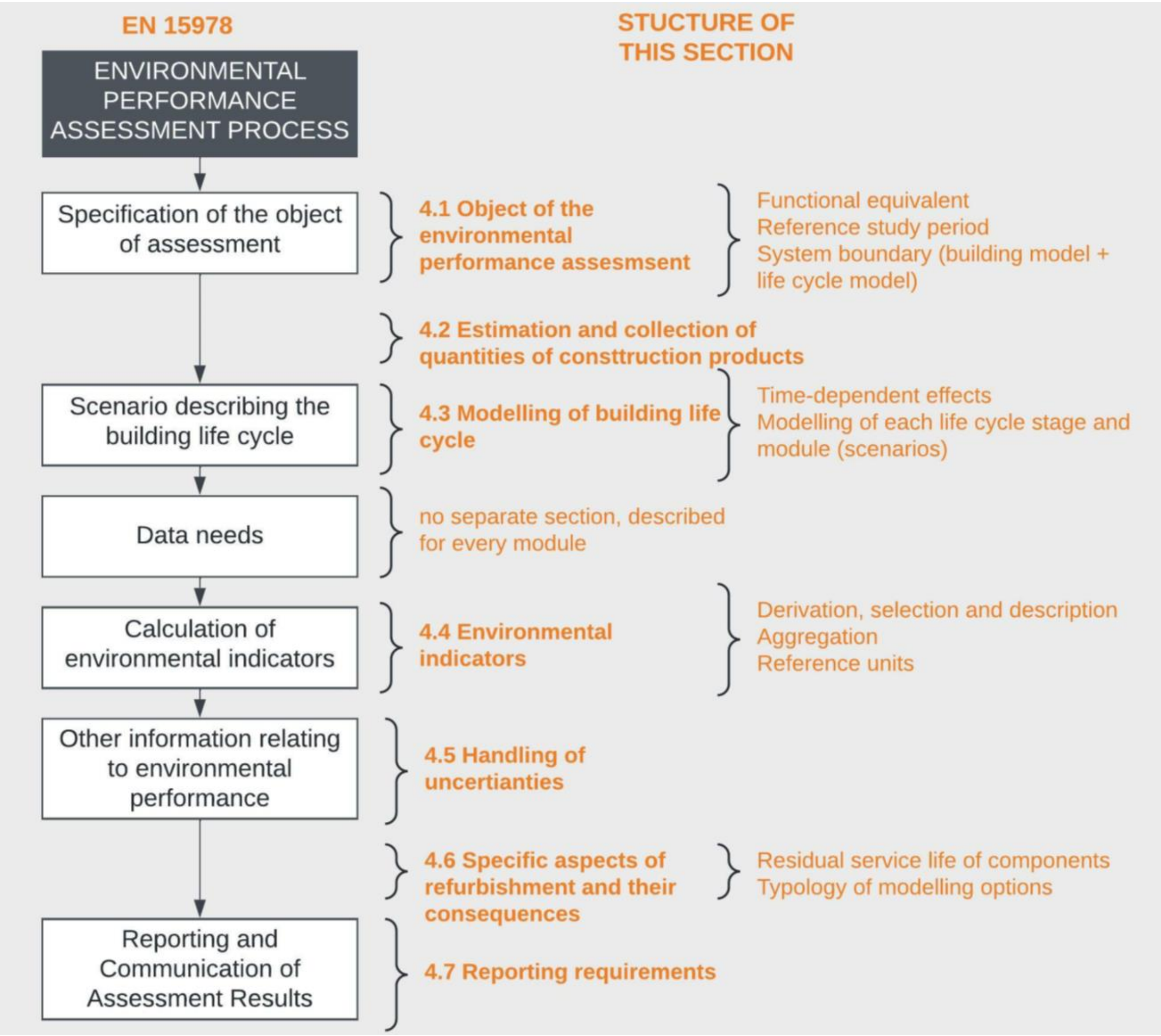

Figure 4.1: High-level overview of the structure and content of Section 4 (guidance providing Section).

4.1 Object of the Environmental Performance Assessment

4.1.1 General

Comparability of the assessment results of the environmental performance of a building is particularly critical when different buildings are being assessed using a single method. To ensure that such comparisons are made on a common basis, according to ISO 21931-1:2022 and EN 15978:2011 (currently under redevelopment, next version expected in 2023), the description of the object of assessment must include, but not be limited to, the following information:

1. Functional equivalent[4]
   - Building type (e.g. residential, office, industrial, mixed-use incl. details of share of each use, etc.);
   - Pattern of use (e.g. occupancy);
   - Relevant technical and functional requirements (e.g. the regulatory and – if available – client's specific requirements) (mentioned only in EN 15978 as part of functional equivalent);
   - Required service life or design life;
2. Reference study period
3. System boundaries

EN 15978:2011 notes that specific requirements and exposure to climate and to other conditions from the immediate surroundings may also be relevant for inclusion in the functional equivalent-related information. Regarding the system boundary, it describes: (a) the physical scope of the building; (b) the scope of the life cycle assessment stages. The background for each individual aspect necessary for the specification of the object of assessment as well as respective guidance are given in the next sections (4.1.2-9), including a discussion on the need to extend this minimum list.

4.1.2 Compliance with functional requirements/ functional equivalent: General

The terms functional equivalent (construction specific term) or functional unit (more generic term used in LCA) are used in LCA standards to describe the key function(s) of the object of assessment (which in this case is a building) using a set of requirements or characteristics (attributes). In a method, the purpose is to establish minimum reporting/description requirements for buildings so that the LCA results are both meaningful to stakeholders in the building industry and rigorous enough to make LCA-based comparisons. The functional equivalent is the basis/reference for any kind of comparison or benchmarking of design options when being assessed using a single method but is differentiated from the reference unit (i.e. the expression of the results in terms of m² or number of people) in the sense that it includes various aspects related to the characteristics of the building. The aspects that shall be included in the functional equivalent according to the standards are here discussed.

Building type: It can be e.g. residential building, office building, school, hospital etc. A building can also be multi-functional. The functions are defined at the time when the LCA is performed. A change of function during the life cycle may be planed and accounted for in the LCA according to a scenario (see also Section 4.3.19). Such plans may also be reflected in the design load (statics). One typical example are buildings for Olympic games which are typically designed for a second life. The type of use can be used to derive the type of requirements, the need for energy and the degree of stress caused by the use (before changing the function of a building, it must be checked whether it meets the technical requirements for the new function or whether, for example, the load bearing structure needs to be adjusted). This has an impact on service life, cleaning and energy consumption among others. In some cases, buildings have an additional use in addition to the intended use. If the additional use, e.g. a gymnasium can also be used as a room for music events, is known or even planned from the start, it can be integrated into the description of the functional equivalent[5].

[4] ISO 14040 uses the term functional unit which is seen by some experts as an extended functional equivalent including relevant technical and functional features as described on page 37.

[5] In countries, where benchmarks (e.g. limit values) depend on the building type, a question raised is how to set limit values for buildings with multiple functions. For example, benchmarks that apply to individual zones can be combined. This is further discussed in A72 report by Lützkendorf et al. (2023).

Pattern of use: The function may be more precisely defined, e.g. indicating a presence scenario (e.g. from 8h to 19h in offices), a number of persons (e.g. 100 tenants, 10 m² office area per person). The number of persons generally influences energy consumption directly (e.g. for electric appliances, computers etc.) and indirectly (e.g. need of fresh air, and consequences on ventilation, heating and cooling energy consumption), as well as water consumption.

Relevant technical and functional requirements: The technical and functional requirements can be related to a vast number of aspects including comfort, indoor air quality and health, aesthetics etc. Specific aspects are not referred to in EN 15978.[6] Including such requirements can be seen as a sort of extended functional equivalent. To fill this gap, the most influential ones for the environmental performance and the reasons are briefly provided and explained below:

– Thermal comfort
– Visual comfort
– Acoustic comfort
– Indoor air quality and health
– All other requirements expressed by the client like level of adaptability or planned refurbishment.

Justification and explanation

– **Thermal comfort**: Material choices may influence the thermal mass (i.e. inertia) of a building to a large extent, and in consequence heating and cooling needs. For instance, timber may be chosen to reduce impacts on climate change, but a low thermal mass reduces heat storage which leads to larger temperature variation. This can be critical in summer, leading to a higher risk of overheating.
– **Visual comfort**: Variants with differing window sizes may correspond to different daylighting performances, inducing a variation of energy consumption for artificial lighting if a requirement in lux is fixed.
– **Acoustic comfort**: Varying the type of insulation or the masonry may lead to different acoustic performances. This is particularly important in a noisy environment. For instance, rigid insulation panels like polyurethane can transmit vibrations which is less the case for e.g. wool materials. Respecting strict requirements may induce implementing supplementary elements.
– **Indoor air quality and health**: Some materials emit VOCs in the air or produce dust which can be harmful to human health. There are studies that integrate indoor emissions in LCA but at the moment it is still difficult to account for this issue in current LCA tools. In such situation, integrating indoor air quality in the functional requirements seems relevant. influencing the energy consumption and impacts of ventilation),
– **All other requirements expressed by the client**: Elaborating a comprehensive program or clients' brief should be recommended in building projects in general, because construction works generally correspond to a high investment. This is particularly true if high environmental performance is targeted. If there is no requirement regarding limited environmental impacts, then the design team has no incentive to use tools like LCA. In the absence of functional requirements, it will be difficult to define a precise functional unit which is one important step in LCA. Requirements may induce a supplementary function of the building, e.g. producing food on an agricultural roof, producing electricity with photovoltaic modules.

Figure 4.2 shows the role and importance of the functional equivalent using the example of the state of standardization in Europe. First, the technical and functional requirements that result from legal requirements and the client's specifications are combined. The technical solutions that meet them are derived from the

[6] It should be noted that such requirements are more relevant if the purpose is design aid because in the case of checking the compliance with regulation, benchmarks do not usually fix such parameters, e.g. it would be difficult to obtain the same comfort level in the project and in the archetype building(s) used to elaborate the benchmarks).

requirements and specifications. These technical solutions are in turn the subject of the actual assessment of the environmental performance or the complete contribution to sustainable development. When communicating the results of the assessment, the specification of the functional equivalent forms the basis for determining the (non-)comparability of the building with design alternatives or external benchmarks.

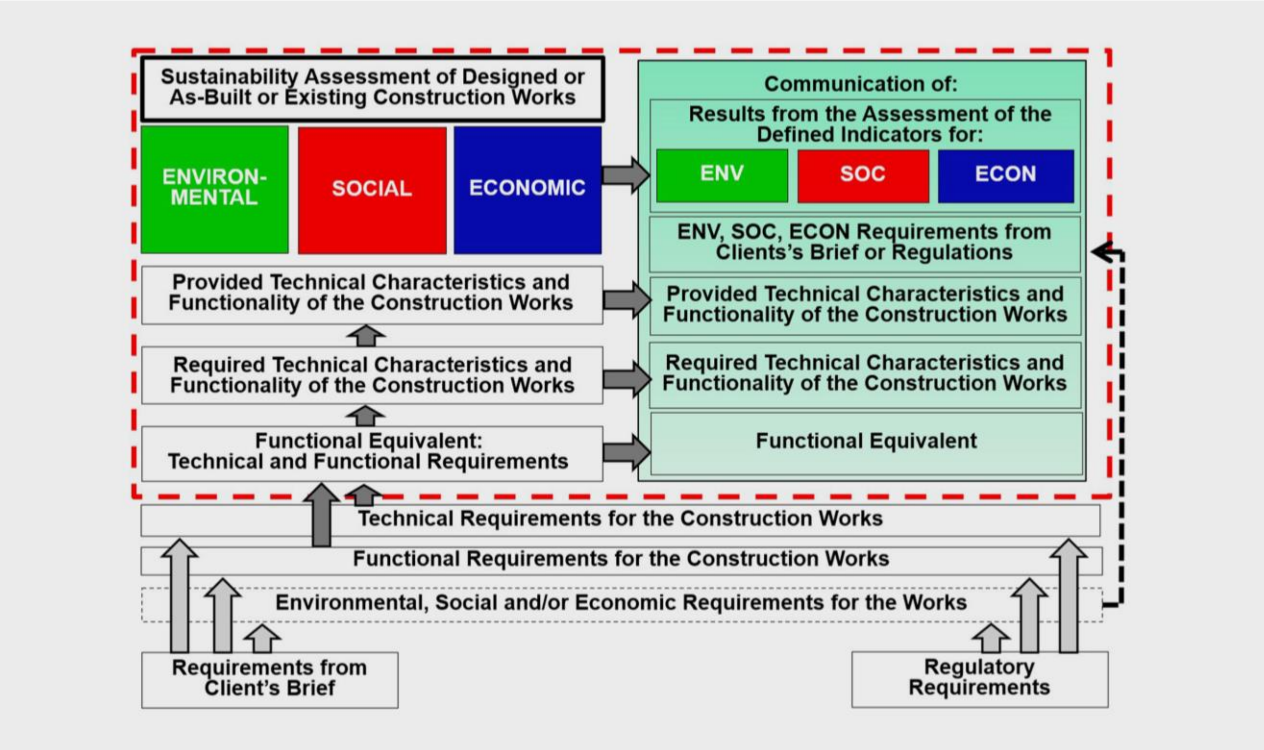

Figure 4.2: Classification of the functional equivalent (see: EN 15643:2021)

Research has shown that also other important building and location characteristics have to be declared, such as climate zone, the seismic zone, the soil properties, the number of stories (elevator), etc. The use of an extended list of additional parameters (i.e. building-related and location-related factors) has both advantages and disadvantages depending on the use case of a method (e.g. see Table 4.1). A short list of features provides a robust solution in the light of compliance with legal or certification requirements, while an extended list can better support scientific analyses.

Table 4.1: Applicable list of features per use case

Use case	Short list of features	Extended list of features
Compliance with legal requirements (see D, Table 1.2)	✓	-
Assessment/ certification (see D, Table 1.2)	✓	-
Scientific study with scenarios, design aid (see B, Table 1.2)	-	✓

Required service life (ReqSL): This is the service life of the building as required by the client or the regulations, while the design life is the building's service life as intended by the designer. When the former is not available, the latter can be given instead. If there is no information available it should be possible to use a defined reference study period, an expected technical service life or any kind of other realistic assumption (see Section 4.1.4).

4.1.3 Functional equivalent: Conclusions and guidance

Defining, describing and communicating the functional equivalent (or unit) is an important task. It takes place in the clients' brief and describes the technical and functional requirements for the building in the narrower and broader sense. This provides the basis for determining the (non-)comparability of design variants, therefore its clear description is essential. In this context, the following rules (Table 4.2) and recommendations (grey box) are provided and apply to both new building projects and refurbishment projects. They also apply to assessments at any design step.

Table 4.2: Rules for establishing minimum requirements for a definition of the functional equivalent

ISSUE(S)		RULE(S)
How shall the functional equivalent be defined?	1.	To consider assessment results comparable, methods shall request users to report: (1) the functional equivalent; (2) the reference study period (RSP); (3) the system boundaries. For the functional equivalent, methods shall follow principles outlined in the standards (ISO 21931-1:2022; EN 15978:2011). This means that a user shall be requested to report at the minimum: – Building type – Pattern of use – Relevant technical and functional requirements (only in EN 15978) – Required service life or design life; NOTE: If appropriate, the assessment results of buildings that have different functional equivalents (e.g. the same types of buildings exposed to different conditions) can also be compared based on a common unit of reference (which will depend on a specific requirement of a technical, functional, environmental, social or economic aspect, or combination thereof, which is common to all these buildings) (see preliminary draft of new EN 15978 in its version from 2022).
	2.	For transparency reasons, methods shall request designers to document additional location, site and building related characteristics as part of a functional equivalent if considered relevant for inclusion, i.e.: – Climate zone – Seismic zone (or details on external loads) – Height of the building – Soil properties
	3.	A planned change of function (repurposing) at some point in the future shall be expressed as a required characteristic in the functional equivalent.
	4.	For the assessment of buildings in use to declare the real performance the description of pattern of use defined during design shall be adapted to the real situation.

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Define one generic description of the functional equivalent per use type at the minimum to reduce granularity. Ask the reporting of further information only if relevant.

Researchers (application / use case: B, see Table 1.2)

b. Develop and provide an extended list of characteristics that are critical for embodied and operational impacts and should form part of an extended functional equivalent (functional unit).

4.1.4 Reference study period: General

The reference study period (RSP) denotes the total number of years considered for the environmental performance assessment study. The selected period has a significant influence on how many replacements of construction products and building systems are included in the study, and what the total use of operational energy is. It therefore affects the overall in-use stage LCA results. The RSP is often used to make buildings' LCA results comparable, even when the required service life for the compared buildings is not identical. If a short RSP is used, for example 30 years, long-lasting materials will appear worse than if a period of 80 years is selected. On the other hand, if a long RSP is used, for example 150 years, the uncertainty associated with future building processes is increased. 50 years is the most common RSP used in standards and guidelines (Table 4.3).

It is important to note that, while the required service life is defined by the client right at the beginning and expresses a building's intended durability, RSP is, in the case of regulation or other type of defined environmental performance assessment method, a convention defined by the assessment method and does not change according to the constructional durability – in some cases ReqSL and RSP can be identical. If the method user is free to choose, then ReqSL can be chosen as a basis. In principle, the assessment method specifies an RSP and clarifies what rules apply in the event that the ReqSL is shorter or longer than the RSP.

Table 4.3: Typical ranges of reference study periods (RSPs) used per building type in assessment methods in different parts of the world (based on an A72 survey – see A72 background report by Balouktsi and Lützkendorf (2023b))

Building type	Example	Typical RSP range (most common RSP)
Residential	Single family houses, multi-family residential buildings, etc.	50-120 (50)
Non-residential	Office, etc.	50-80 (50)
Smaller buildings for storage	Industrial, etc.	20-60 (50)

4.1.5 Reference study period: Conclusions and guidance

Determining the RSP is important and has a significant impact on the assessment result. For studies of all kinds, it can be useful to consider several scenarios. For methods that are used in connection with sustainability or environmental performance assessment systems, funding programs or legal requirements, a defined RSP in the sense of a convention is essential. If the RSP is shorter than the design service life, the method must define ways to deal with the resulting consequences. It is possible and sensible to define specific RSPs for different building types. Based on these considerations, Table 4.4 provides rules that apply to both new building projects and refurbishment projects. Recommendations (grey box) are also given.

Table 4.4: Rules for establishing minimum requirements for a definition of the functional equivalent

ISSUE(S)	RULE(S)
How shall the RSP be defined?	1. One fixed RSP for all building types or one fixed RSP per major building type (see Table 4.3) shall be proposed to enable comparability between the LCA results for different projects.
	2. The proposed RSPs shall be intended to be: – broadly representative of typical ReqSLs of the different building types – long enough to allow for a sufficient period of time for the building to undergo wear and tear and specifically the replacement cycles of major building components and systems; and – short enough to allow for a time period in the future that is reasonably predictable.

3. When the RSP is longer than the ReqSL (design life) of a project specified in the brief, project-specific scenarios shall always cover the period until the end of the RSP specified (e.g. assumption that the building will be reconstructed).
4. When the RSP is shorter than the ReqSL it shall be ensured that the building is assessed for the duration of the RSP, even though the project is expected to have further service life beyond the RSP (see EN 15978:2011).

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Define one RSP according to rule 2-6, if necessary, per building use type
b. The RSP for new buildings and refurbishment projects should be chosen to be identical in order to enable a comparison between demolition and replacement construction on the one hand and modernization/change of use on the other.

Designers and engineers (application / use case: D, see Table 1.2)

c. Discuss the planned building service life with the client and perform a sensitivity study to check if comparative results of design alternatives are robust when changing the expected service life (equal to the study period).

Researchers (application / use case: B, see Table 1.2)

d. Provide empirical data on the actual service lives of different types of buildings.
e. In addition to the mandatory RSPs specified, for comparative assessments, request users to also report whole life impact results against different values (e.g., from 30 to 120 years) to handle uncertainty and check if the conclusions of the assessment remain robust enough. The typical ranges in Table 4.3 can be used for this.

4.1.6 System boundary: Coverage of physical building scope

The exact completeness of a building model cannot be checked without a systematic approach to the building decomposition in place. A standardised building decomposition model provides transparency and guarantees a traceable and comprehensive organization of the building elements, sub-elements and materials. No international or regional standard exists that provides a consensus-based building description model.

Current status of methods: So far, each national standard and method has its own systematic way to report the physical scope of the building, and with different levels of dis-aggregation or aggregation (from the material level to the building element level) (Soust-Verdaguer et al., 2020; A72 report by Passer et al., 2023). An example is depicted in Figure 4.3. Due to the heterogeneity in the organization and grouping principles of the building information structures in the different national standards used for building decomposition and the strong connection of these structures with national datasets, A72 report by Passer et al. (2023) concluded that (at least at the moment) it cannot be possible, in the short term, to define one harmonized information structure to the systematic building decomposition for implementing the LCA. However, in the long term, the possibility of defining a common reference or harmonized standard can be addressed.

In addition to the variations in the building decomposition itself, different building parts and elements are chosen to be included in different methods depending on the purpose of the assessment and the available data at the point of the time of the assessment. According to an A72 survey (see A72 background report by Balouktsi and Lützkendorf (2023b)) the physical scope of a building LCA typically includes at least the building shell (i.e. structure, facade, and foundations) because structural building frame elements are generally identified as being the highest contributing ones to total embodied impacts. Often, the building internal elements and finishes are also included. More advanced methods also include the impacts of the main building operations (building services[7]), as well as internal fixed furnishings. The reason these components are often excluded is the difficulty in collecting the necessary data. The physical scope usually excludes construction of infrastructure outside of the site (e.g. roadways), but several of the newest methods include construction works and infrastructures on the site. Finally, user furniture is hardly included in any method as it is hard to predict the type and quantity not only during a building's design, but also at the handover, since it also depends on the tenant's choices.

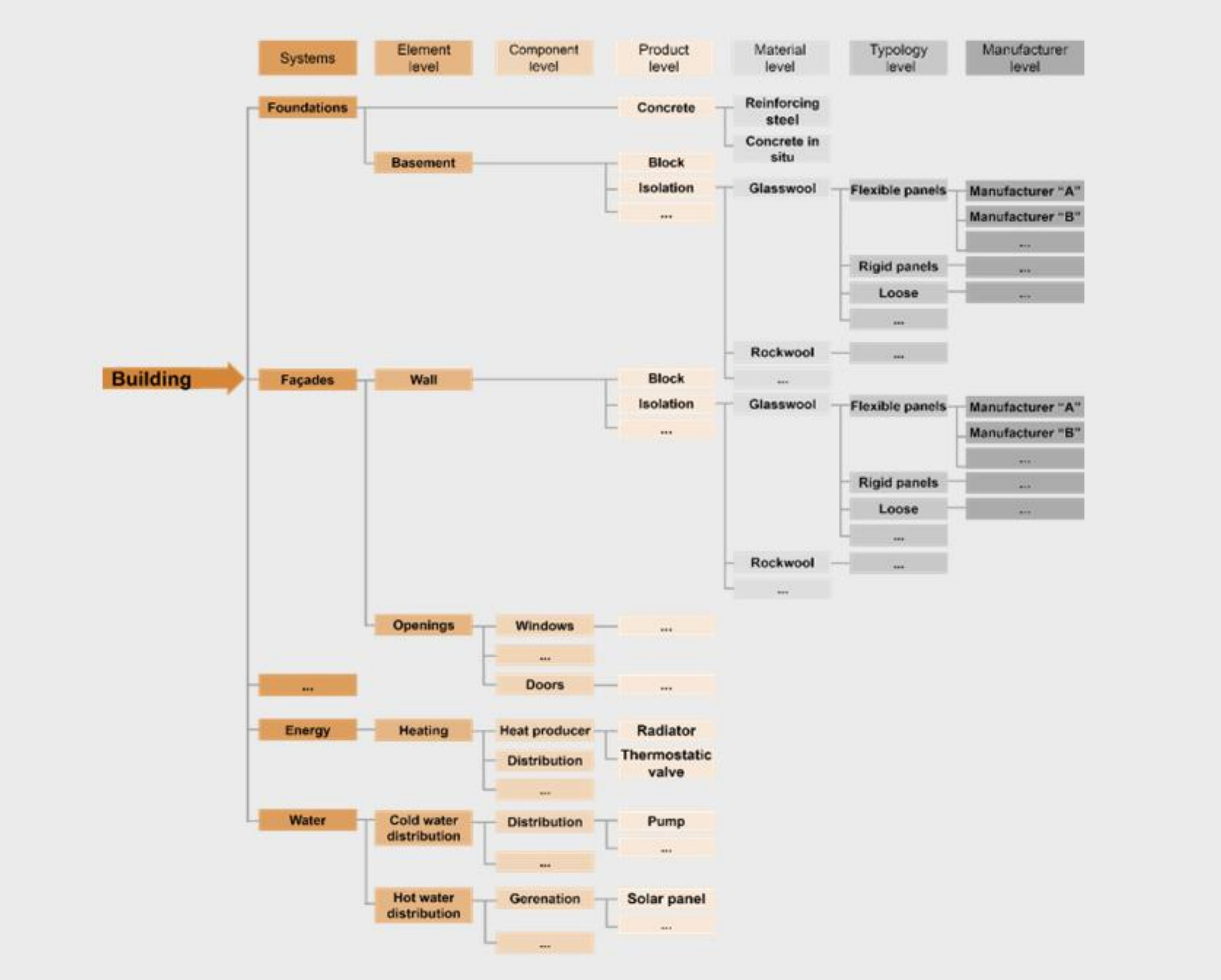

Figure 4.3: An example for a building decomposition model (source: A72 report by Passer et al. (2022))

It is important to extend the scope of typical LCAs as full life-cycle emission analyses have revealed that building elements like internal elements or HVAC-systems can be more significant than previously thought. For example, based on limited studies that have been carried out so far, mechanical, electrical and plumbing systems (MEP) could account for about 20-50% of the embodied GHG emissions of new-build projects depending on the building type, the extent of the use of PVs and the level of detail of MEP description (Hoxha et al., 2020a; George et al., 2019; Birgisdottir et al., 2017). In refurbishment projects, the proportion of embodied GHG emissions related to building services can be considerably higher, accounting for more than 70% of the embodied GHG emissions in some cases (Hamot, 2019[8]). Building systems can stand out even more when it comes to other impacts such as eutrophication, ecotoxicity and human toxicity potential (Gomes & Pulgrossi, 2020).

7 Alias terms: building technology, building equipment, building systems, etc.
8 See the following CIBSE article: https://www.cibsejournal.com/general/getting-to-grips-with-whole-life-carbon/

Table 4.5 shows an overview of selected studies providing values for different building systems, internal elements, as well as fixed and user furniture in $kgCO_2eq$. per m^2 of building. The large variation in values is often attributed to the simplified vs detailed calculation of the environmental impacts of building equipment. For example, the highest values are seen in Kiamili et al. (2020) and Hoxha et al. (2021) who have performed detailed calculations to highlight the gap between detailed and simplified assessments.

To assist users, and avoid exclusions of important equipment from early design stages, some national methods provide default values for such systems (e.g. see examples in Table 4.6). Such values will be also provided by the British organisation CIBSE (Chartered Institution of Building Services Engineers) in future calculated based on collected data on material composition breakdown of MEP products from manufacturers (Butcher 2021). For late design stages, there are EPDs in several countries (e.g. values of PV systems are available in several EPD systems such as INIES, Ökobau.dat, etc.) but even in these countries data gaps can still be observed (see A72 report by Chang and Kim (2022)). In relation to fixed furniture, in most countries official default values do not yet exist.

Table 4.5: Examples of studies showing the importance of elements and products other than the building shell with regard to their absolute contribution to GHG emissions (expressed in $kgCO_2eq/m^2$)

STUDIES	ELEMENTS OTHER THAN BUILDING SHELL						
	HVAC	Electrical systems	Plumbing systems	PV systems	Internal elements	Fixed furniture	User furniture
Hoxha et al. (2021)	385			-	85	-	-
Kiamili et al. (2020)[9]	183	-	-	-	-	-	-
Säynäjoki et al. (2017)	160-117*		-	-	-	16	-
CLF (2019)	30-60	5-16	3	-	-	45-135	
Liljenström and Malmqvist (2016)							22
Case study 02 in Birgisdóttir and Stranddorf (2022)	-	-	-	145-310	-	-	-
Malmqvist et al. (2021, pg. 49-50)	11-43				14-40[10]		

Table 4.6: Examples of default values for building services provided by official national methods (expressed in $kgCO_2eq/m^2$). Note: surface area indicated for each solar panel collector.

Examples of default values by methods		Finish method (Kuittinen et al. 2020)	Swiss method (KBOB 2009/1:2022)
Conventional systems	Lift	7585 $kgCO_{2eq.}$/item	-
	Electrical installations and wiring	5.28 $kgCO_{2eq.}/m^2$	13.0 / 24.2 $kgCO_{2eq.}/m^2$*
	Sprinkler system	5.85 $kgCO_{2eq.}/m^2$	-
Sanitary systems	Waste supply	2.70 $kgCO_{2eq.}/m^2$	4.48-11.8 $kgCO_2eq./m^2$
	Piping	0.52 $kgCO_{2eq.}/m^2$	12.6 / 4.7-12.3 kgCO2eq./m^2*
Heating systems	Radiators	6.67 $kgCO_{2eq.}/m^2$	6.50 $kgCO_2eq./m^2$
	Floor heating	-	5.10 $kgCO_2eq./m^2$
	District heating substation	0.53 $kgCO_{2eq.}/m^2$	-

[9] See also case study 16 in Birgisdottir et al. (2022).
[10] Internal layers + furnishing (variation of default values acc. to the type of building)

	Ventilation system	6.97 kg$CO_{2eq.}$/m^2	7.7; 14 / 15-51 kgCO_2eq./m^2**
	Brine/Water heat pump	-	2400 kgCO_2eq./item
	Air/Water heat pump	-	4000 kgCO_2eq./item
Solar panels and collectors (surface area indicated for each solar panel collector)	Crystalline silicon solar panel	242 kg$CO_{2eq.}$/m^2	1000-1220 kgCO_2eq./kWp***
	Thin-film solar panel	67 kg$CO_{2eq.}$/m^2	
	Network inverter	22 kg$CO_{2eq.}$/item	-
	Solar hot water collector	-	169-290 kgCO_2eq/m^2***

* residential building/ office building
** residential buildings, plastic; metal office buildings, range for ventilation systems with 1 to 8 m^3 per hm2
***Depending on the mounting system (façade, flat roof, etc.)
***Depending on type of collector, SFH or MFH, hot water or hot water and space heating, flat or vacuum tube

4.1.7 Coverage of physical building scope: Conclusions and guidance

Part of the definition of the object of assessment is to define a building model. Methods need to introduce clear rules for this. The final target is to include any relevant building component with an impact on its environmental performance into the study and to provide the user of the assessment result with a clear statement of the completeness of the building model or excluded parts (it can be the case that there are no environmental data for small parts). The second option needs justification. In some cases, it can be useful to use the structure of a construction cost estimation also for the description of a building from point of view of environmental performance assessment. If there is a cost calculation in parallel to the environmental performance assessment (cradle to handover) the result of the cost calculation can be an indicator for the completeness of the building model. A similar possibility exists for plausibility checks using the building quantities. The creation of material inventories to record the material composition of buildings in the context of the circular economy is increasingly required and carried out. In this case, average values must be determined and published for construction types.

In specific cases it can be useful to introduce cut off rules. These are only justifiable when based on scientific analyses, considering at first all the details to assess the contribution of small elements to the overall result. There is an interest in reducing the effort involved in detailed calculations and readopting the 20:80 rule. This effort is not only associated with quantifying all building products in a building, but also with trying to find climate data that all products can be connected to. If such cut-off rules are introduced, it is important to request users to describe the coverage factor in detail. Alternatively, default values or safety factors can be used to avoid determining small quantities. It is important that the method provides consistent system boundaries for verification.

Based on these considerations, the following rules (Table 4.7) and recommendations (gray box) are provided. These apply to both new building projects and refurbishment projects. Note that rule 3 is only applicable to early design stages.

Table 4.7: Rules for establishing minimum requirements for the coverage of the physical building scope

ISSUE(S)	RULE(S)
How to check building model completeness?	1. A classification system based on hierarchical grouping principles shall be established to allow to identify the main systems and elements that compose the building and improve transparency on LCA application and support during the design stages.
Which building components / elements shall always be part of a method?	2. The following minimum list of elements shall be included in an assessment regardless of whether it takes place on early or late design stages. Note that user furniture is excluded from this list since even at the handover, this information cannot be verified. If such information exists, it can be reported separately. a. Minimum: – Foundation – Load bearing structure – Envelope – Internal elements – Finishes (external and internal) – HVAC-systems (including production, storage, transport, hand over) – PV systems – Plumbing/sanitary equipment (services) – Electricity (cables), fixed lighting – Internal transport (elevator) – Building related structures onsite (on the site) b. Additional information: – Fixed furniture
How to fill the gap of incomplete data on building systems at early design steps?	3. A table of default environmental impact values of typical building service systems shall be provided to guarantee that users include this component type even when an assessment takes place at an early stage of a project and data are incomplete or imperfect.

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Provide a standardised building model description, composed of at least four horizontal levels of building decomposition in the early design steps, and at least six in the late design steps (see Figure 4.2, 'orange' boxes indicate the minimum four levels); Usually, such descriptions are provided by national standardisation bodies and then law makers and sustainability assessment system providers make a reference to them. If such standards do not exist, building models from the national cost calculation method can be adopted.
b. Before accepting an LCA study as evidence of the superior environmental performance of a building, carefully review the building model for gaps, limitations and simplifications that may have significant impacts on conclusions.

Researchers (application / use case: B, see Table 1.2)

c. Test and systematic review cut-off rules, as well as determine default values or safety factors to assist method developers

4.1.8 System boundary: Coverage of building life cycle stages

One part of the description of the object of assessment is the definition of the life cycle of the building. Therefore, rules to define the life cycle model and indicating the included life cycle scope are needed. To model the life cycle, its subdivision in stages and modules is common. The life cycle scope/life cycle stages are defined by ISO 21931-1 and EN 15978. Figure 4.4 shows the activities within each life cycle stage, based on information modules (A-C) and supplementary module D as laid out in these two standards. Some changes in relation to the model presented in the current version standards (these changes can also be seen in EN 15643:2021) are:

- **Further detailing**: A further disaggregation of the operational energy module (B6) into three sub-modules is here proposed to distinguish regulated building-related energy use (B6.1) from its non-regulated building-related part (B6.2), as well as building-related energy consumption from user-related energy consumption (B6.3). The services that can be assigned to each category are shown in Table 4.8. Furthermore, Module D is divided into two sub-modules: one for reporting the benefits and loads from the reuse, recycling and/or energy recovery of materials and substances exiting the system boundary (D1), and one for reporting exported utilities, such as exported renewable energy produced on building site (D2).[11]
- **An additional information module**: Considering the increasing attention on the environmental impacts associated with the location of the building as a complementary consideration alongside building design in environmental performance assessments and the fact that concentrating on one or the other can shift impacts, module B8 is added to the use stage as optional to report impacts associated with building-induced mobility, i.e. users' travelling to and from the building.

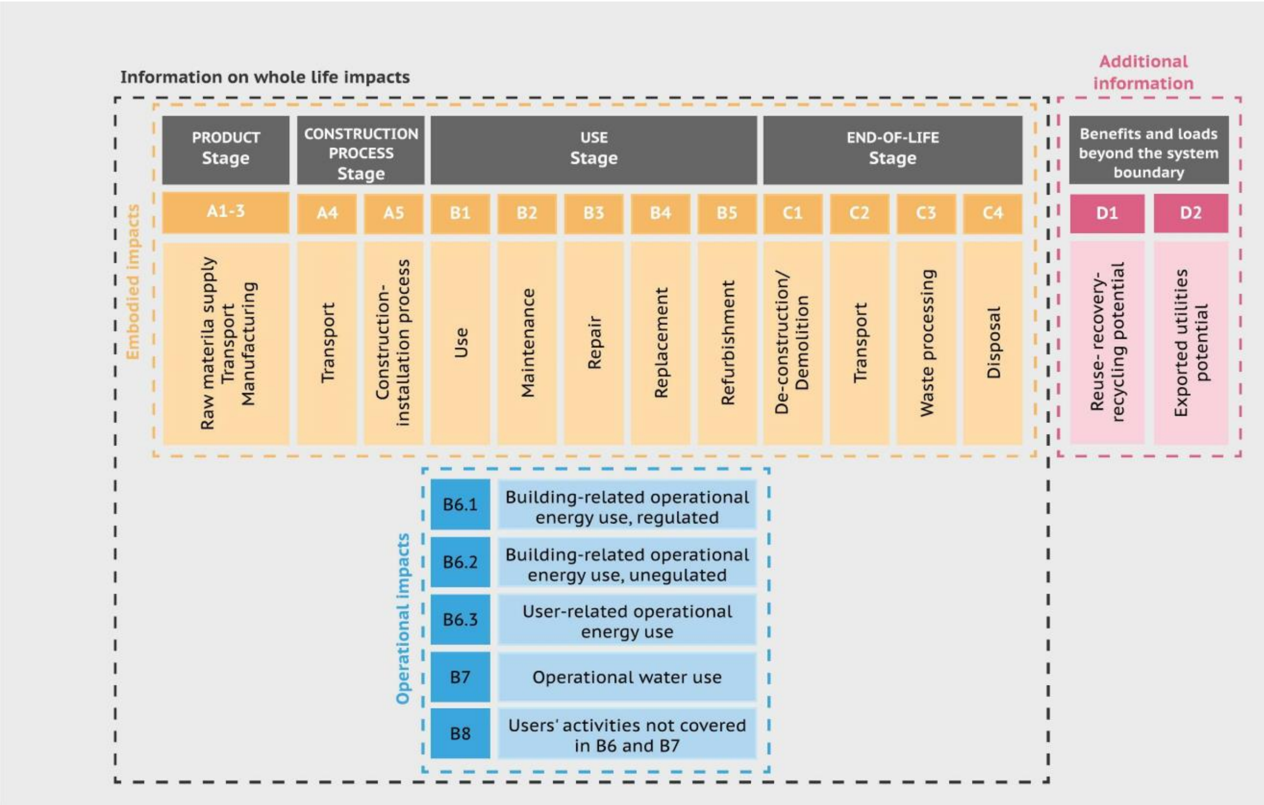

Figure 4.4: Modular approach of building life cycle impacts, distinguishing between the impacts arising from embodied (green dotted line) and operational aspects (blue dotted line). Adapted from EN 15643:2021.

[11] In national methods further detailing can also be seen for other modules, e.g. the Swedish regulation also distinguishes between A5 waste and A5 energy

Table 4.8: Modules for reporting of energy use following the structure of ISO carbon metric use stage ISO 16745-1 (ISO 2017). The assignment is based on the current revisions of EN 15978-1. Note: for some specific services variations can be seen across countries regarding whether they belong to the regulated part, this is here indicated as "Yes/No".

Building service	Residential buildings		Non-residential buildings	
	Regulated[1]	Module	Regulated[1]	Module
Heating	Yes	B6.1	Yes	B6.1
Cooling	Yes	B6.1	Yes	B6.1
Ventilation	Yes	B6.1	Yes	B6.1
Humidification	Yes	B6.1	Yes	B6.1
Dehumidification	Yes	B6.1	Yes	B6.1
Domestic hot water	Yes	B6.1	Yes	B6.1
Fixed (installed) Lighting	Yes/No	B6.1	Yes	B6.1
External lighting	No	B6.2	No	B6.2
Auxiliary energy (e.g. heating distribution pumps)	Yes/No	B6.2	No	B6.2
Indoor transport (e.g., elevators, escalators)	Yes/No	B6.2	No	B6.2
Other building-related-technical systems[2] (e.g. security and communication systems, vehicle charging?)	No	B6.2	No	B6.2
Other services[2] consuming energy (e.g., plug-in lighting, electrical equipment and appliances)	No	B6.3	No	B6.3

[1]'Regulated' means energy demand from building integrated systems (services) covered under Energy Performance Regulations. The services that are included can be a national or regional choice.
[2]the included other services shall be documented in detail

Figure 4.5 shows an alternative view of the building life-cycle information modules from the perspective of the building as a whole. The horizontal axis represents the building through its lifecycle stages A-C (from conception to disposal), and Module D. The vertical axis represents the same life-cycle model from the perspective of the building's components. The latter is of specific importance in cases where the life cycle of components is shorter than the life cycle of the entire building (the impacts and aspects of which need to be taken into account each time a building element/component or product is replaced) and how this contributes to the total results calculated. The Figure shows that the manufacturing, transport and installation of building products and components (A1-5), as well as their deconstruction, removal and disposal (C1-4), is not only related to the beginning of the building's life cycle and its end-of-life, but also to the replacement of building components (B4) during the use stage.

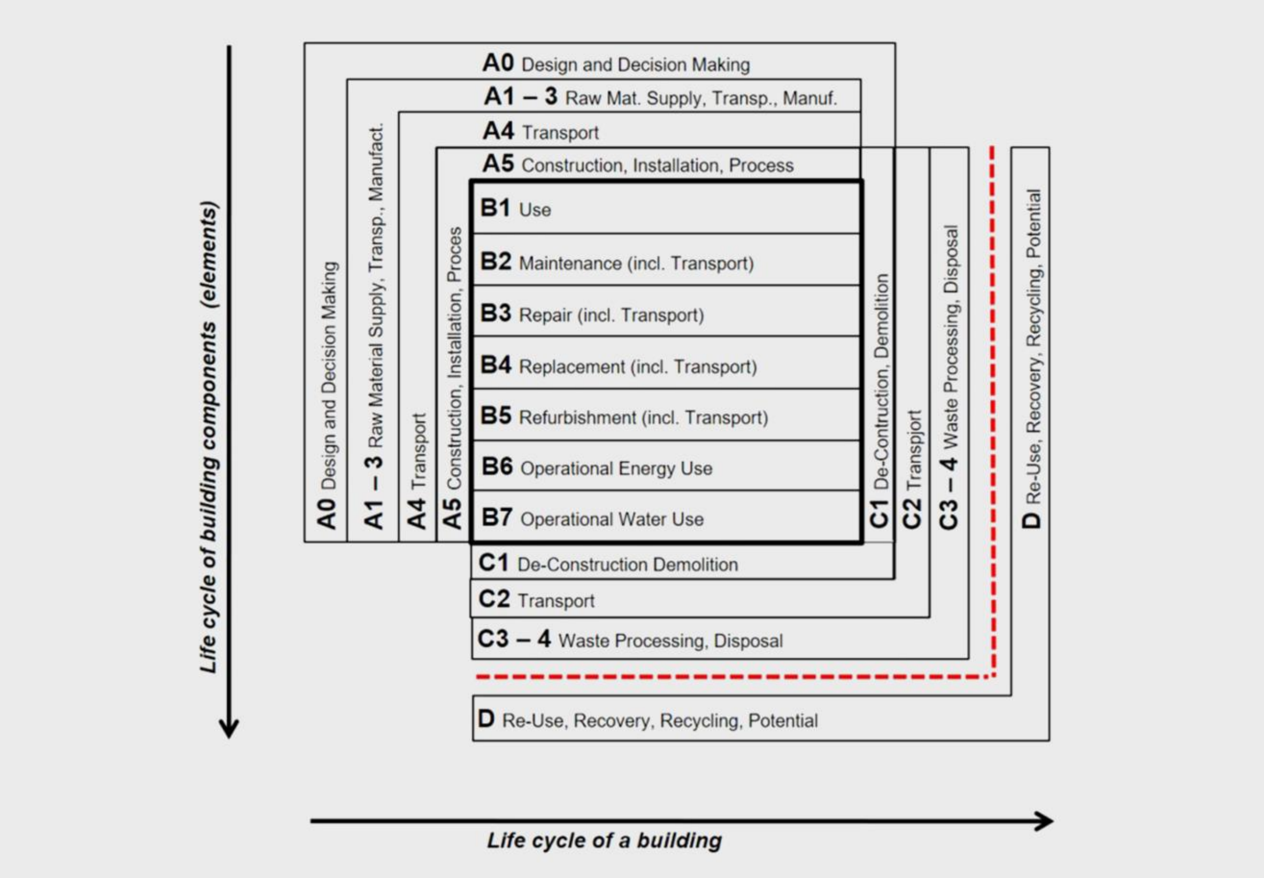

Figure 4.5: Alternative model of the life cycle of buildings and building components (Lützkendorf 2019)

Current status of methods: Methods differ in their scope in relation to life cycle stages covered. In relation to the operational part: acc. to an A72 survey all participating countries deal with the calculation of operational energy use (module B6) either as a separate topic or as part of a life cycle-related approach. When it comes to the services included under B6, most methods focus on regulated building-related energy use (B6.1). Only a few methods additionally include indoor transportation (B6.2) and user-related energy use (B6.3), although they can account for around 5-10% (Karlis 2014; De Almeida 2012) and 10-50% (Hoxha et al. 2016; Roux et al. 2016) of the total operational energy consumption in function of building energy efficiency (e.g. best practice or not), respectively. These ranges will be different in the case of GHG emissions and other indicators as different types of energy will affect the environment differently, but still significant. However, it is expected that more methods will shift to a full B6 scope to deal with questions of the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity. With respect to modules B7 and B8, the former is rarely included in LCA tools, while the latter, not being part of the standards up to now, has only formed part of two national standards, the Swiss standard SIA 2032 (SIA 2020), and the Norwegian standard NS 3720 (Norsk standard 2018). The reason is that both these standards attempt to synchronize LCA studies on building at neighbourhood scale.

In relation to embodied part: Most methods cover product related modules (A1-3, C3-4), due to the availability of such information in national databases and EPDs (see A72 report by Chang and Kim (2022)). Most methods also cover replacements of building components (B4) as their estimation is based on information reported in A and C modules. Some advanced methodologies additionally include transport (A4 and C2) and (de-)construction process (A5 and C1) modules, as well as B2 module, while stages B1[12], B3 and B5 are rarely included in LCA tools. There are different reasons for this. B5 is only required if planned refurbishments have been taken into account in the functional equivalent. B3 is rarely recorded accurately.

[12] effects on the local environment through outgassing and leaching could be recorded via B1, often regarded as non-LCA aspects.as well as the F-gases that occur during the building use, see Section 4.3.13.

4.1.9 Coverage of building life cycle stages: Conclusions and guidance

The modeling of the life cycle provides the basis for the environmental performance assessment. Theoretically, the complete life cycle must be covered. An attempt is often made to exclude some modules in the interests of simplification. This places particularly high demands on the transparency of the presentation of the result. If a module turns out to be less relevant for one indicator, this does not automatically apply to the other indicators. The relevance of individual stages or modules needs to be examined for each indicator in a specific dominance analysis. If there is interest in a simplification, options for default or proxy values should first be checked and used if necessary. This is preferable to omitting. In the following (Table 4.9), rules 1-3 apply to both new building projects and refurbishment projects. Rule 4 applies only to new building projects. Minimum requirements for the refurbishment projects are provided in separate section (4.7).

Table 4.9: Rules for establishing minimum requirements for the coverage of the life cycle scope

ISSUE(S)	RULE(S)
How shall the system boundary on life cycle stages be defined?	1. To specify the life cycle scope considered in an assessment method, the standardized module designations according to the latest versions of the standards EN 15978 and ISO 21931-1 (modules A1-C4, and optionally D) as shown in Figure 4.3 shall be used.
	2. The commonly regulated building-related energy use (e.g. heating, domestic hot water supply, air conditioning, ventilation, lighting and auxiliary energy used for pumps, control and automation) shall be reported separately from the commonly non-regulated building-related energy use (e.g. lifts, escalators, etc.) and the non-building-related energy use (e.g. user appliances). This is expressed via three different modules in the context of this guideline (Figure 4.3).
	3. Mobility induced by the building, including the electricity consumption of an e-car, shall be reported separately from other operational impacts (indicated as module B8 in this guideline).
	4. Embodied part: A1-5, B4, C3-4 shall be a minimum reporting requirement, unless there are valid reasons for exclusion (e.g. proven low significance in a national context). A1-3 presents the biggest share of life cycle impacts, and with the inclusion of A4-5 it is ensured that all emissions occurring today and are verifiable at the hand-over can be targeted. B4 is significant for building equipment which shall be part of the minimum list of components reported acc. to rule 2 in Section 4.1.7. Although C3-4 modules are highly impacted by assumptions, their reporting is unavoidable for certain materials, e.g. wooden products.
	5. Operational part: In the case of (nearly/net) zero or positive energy or emission buildings, the full scope of B6 shall be included in assessments, as it is important to have the full overview of operational energy demand for a proper dimensioning of renewable energy systems.

To foster transparency and facilitate communication among different methods, it is recommended to standardisation bodies to introduce typologies for system boundary description to declare the broader scope of a method. Such an example is shown below in Table 4.10 (only five SB types are shown for simplification).

Table 4.10: Example of a simple typology of life cycle system boundaries.

Included modules	Predefined set of system boundaries in life cycle environmental performance assessment of buildings (Examples only)				
	SB1 (min)	SB2	SB3	SB4	SB5 (max)
A1	■	■	■	■	■
A2	■	■	■	■	■
A3	■	■	■	■	■
A4				■	■
A5			■	■	■
B1				■	■
B2			■	■	■
B3		■	■	■	■
B4	■	■	■	■	■
B5					(■)*
B6.1	■	■	■	■	■
B6.2			■	■	■
B6.3		■	■	■	■
B7				■	■
B8					(■)**
C1			■	■	■
C2				■	■
C3	■	■	■	■	■
C4	■	■	■	■	■
	Provided as additional information				
D1				■	■
D2				■	■
Biogenic carbon content			■	■	■

'* in the case of planned refurbishment as part of functional equivalent
'** in the case of inclusion of additional user related activities

4.2 Estimation and Collection of Quantities of Construction Products

4.2.1 General

In a life cycle-based environmental performance assessment of a building, all data dealing with type and quantities of construction products in sense of materials, components and technical systems are collected into a body of information known as the material inventory, bill of quantities (BoQ), or bill of materials (BoM). These quantities are multiplied with the appropriate impact coefficients for each unit of construction product to calculate the production stage (modules A1-A3), the repair, replacement, and refurbishment stages (modules B3 - B5) as some materials, components and systems also appear in the use stage, as well as the end-of-life stage (modules C3-4 and D). If a material appears in the use stage, it will require scenario definitions, which are discussed later in this guideline (section 4.3.5-6). In the end-of-life stage of building components, all materials, components and systems will require the definition of scenarios in relation to rates of recycling/reuse/recovery (see Section 4.3.32).

Compiling this inventory can be relatively straightforward or complex depending on requirements for the completeness of the building model (as defined in the LCA scope), the complexity of the building, and the level of information already known about the building at the specific project stage. The **net quantity** of products, materials, components and elements that together form the building can be determined by using one out of the following sources of information (RICS 2017):

a. estimations from design drawings,

b. BoQ, BoM or cost plan,
c. BIM models,
d. material delivery records.

Option d) represents the actual BoQ of all materials, components and systems used and is only available post construction. For early design stages the first three options can only be used. There are LCA tools designed to help estimate quantities from templates of preconfigured materials take-off for standard construction elements (e.g. foundations, floors, walls, windows, roofs etc.) or BIM models (see A72 report by Passer et al. 2023). The question of how detailed a BIM model needs to be to produce accurate results is still open. In general, it is expected that in early design stages the quantity take-offs for certain construction materials and products, as well as building equipment (e.g. HVAC systems including pipes) is coarse, and therefore there is a considerable level of uncertainty around this parameter. In a study variations of mass parameters were defined between −5% and +10% of material quantity for all building materials and systems (Hoxha et al. 2017).

However, a significant amount of waste is generated during transportation of materials to the construction site (transport losses and damages) and their transformation during the construction process itself (construction waste). The fraction of materials lost due to mistreatment, design flaws, construction errors and unavoidable process waste is also referred to as waste factor. The waste factor depends on the type of material used and studies have derived different waste factors for different building materials. As shown in Table 4.11 such factors range from 0-10% (Dixit et al. 2013), with the 0% factor typically assigned to building products/materials that arrive on site preassembled (e.g. precast panels and equipment). Some studies also provide the waste factor per element which is useful for early design stages (Jalaei et al.2021)). The construction waste factor for each material added to the bill of net quantities provides the **gross quantity** of materials.

Table 4.11: Waste factors suggested by various studies. Note: Partly taken by Dixit et al. (2013).

Building materials	Study					
	Chen et al. (2001)	Treloar et al. (2003)	Worth et al. (2007)	Chau et al. (2007)	Blengini et al. (2009)	Jalaei et al. (2021)
Steel	5%	5%	6%*	5%	7%	1%
Aluminium	2.5%	10%	6%	5%	5%	1%
Copper	2.5%	10%*	6%*	5%	5%	1%
Concrete	2.5%	5%	-	3%	7%	5%
Glass	0	3%	-	5%	7%	-
Brick	-	5%**	-	3%	10%	5-7%
Insulation	5%	-	6%	8%	7%	5%
Finishes, e.g. paints	-	5%	0%	5%	7%	2%
Plaster	-	10%	-	5%	10%	-
Timber	2.5%	10%	11%	-	7%	-
Plastic	5%	10%	-	3-5%	7%	-
Equipment	-	0%	-	-	-	-

*%indicated for metals in actual study
**%indicated for masonry/clay in actual study

This is also in line with EN 15978:2011 (currently under revision), which states that in environmental performance assessments, the gross amounts of materials and products used to construct the object of assessment must be taken into account. The “losses” resulting from several factors must be considered, including:
– loss/ damage in transport;
– loss/ damage on site;
– losses in the normal processing of products, materials, components, etc. on site;
– design losses due to dimensional relationships in the design and product dimensions;
– requirements for ordering minimum quantities

Current status of methods: Usually, assessment methods adopt one or more of the following approaches (from more generic to more detailed):
– applies a global add-on of 5% on all material quantities. Examples: the Belgian method (Lam and Trigaux 2021) and by default in the method used by the French tool EQUER[13]. In some cases, a global add-on can also be chosen by the user (French method).
– applies a differentiated default values for losses per material type. Example: the Dutch approach GWW (SBK 2014)[14]
– directs users to specific national waste databases (e.g. WRAP’s default rates[15] and the Swedish Climate database from Boverket[16])
– allows users to use contractor’s site waste data recorded for similar buildings.
– refrains from adding “production wastes” to the net amount of construction materials needed for reasons such as: (a) the net amounts are uncertain and, in many instances, overestimated (neglecting the openings for doors in inner walls etc.), therefore, adding 2-5 % does not reduce the uncertainty (at least in the early design stages); (b) there is no statistical data available from a reasonably large sample (e.g. SIA 2032 and DGNB method).

It is important that default waste factors either provided by the method or included in national databases are frequently updated from field surveys. Sometimes, site waste data can be found in component/product EPDs, but these are typically overridden by the default rates provided by official documents for consistency purposes, as EPD-specific site waste rates may vary largely depending on different installation/construction assumptions for different product applications and locations (RICS 2017).

4.2.2 Conclusions and guidance

To determine the type and quantity of installed products provides a basis for the life cycle-based environmental performance assessment. This task is designers’ responsibility, and the use of suitable tools can support them. As far as possible, the gross quantity must be determined; this requires the inclusion of transport and processing losses. The sum of the losses on the construction site represents a separate indicator (i.e. construction waste) and should be minimized.

The materialization of the building design depends on the design progress. In early phases, the choice of construction method influences the type and quantities of main building materials. With the exception of prefabricated houses or prefabricated parts, the specific manufacturer is not yet known at this point in time. As the design progresses, further types and quantities of installed products can be determined as a result of the detailed design. A final documentation of installed products is only possible upon handover and then corresponds to the "as built" status. The special features of the design process, which takes place in several steps, must be taken into account both when using design tools and when considering uncertainties in the quantity determination – the A72 report by Passer et al. (2023) describes this in more detail.

[13] See: Online user’s manual of Pleiades LCA (EQUER), see https://docs.izuba.fr/v4/fr/index.php/Bibliothèques_/_Données_du_projet?toc-id=1079

[14] Particularly, it distinguishes between 3 different groups: prefab products (3% losses), in-situ products (5% losses), ancillary and finishing materials (15% losses).

[15] See the report: https://nwtool.wrap.org.uk/Documents/WRAP%20NW%20Tool%20Data%20Report.pdf

[16] See: https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/

The following rules (Table 4.12) and recommendations (grey box) apply to both new building projects and refurbishment projects.

Table 4.12: Rules for increasing the transparency behind material quantities

ISSUE(S)		RULE(S)
Which sources of material quantities shall be used in an assessment?	1.	The user of the method shall always specify the source of material quantities (drawings, BIM, BoM, BoQ, material delivery records, other) at every stage of the design and construction process.
How to account for the gross material quantities?	2.	Whether or not different types of losses are considered as part of a method, the added % and the reasons for inclusion/exclusion shall be described transparently. This add-on shall be applied to the net quantities during the entire design process. Whether this % is underestimated/overestimated or close to reality can only be confirmed during the construction process.
	3.	As design progresses product types and product/material quantities shall be updated.

Recommendations for action

Policy, regulation and law makers, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Provide clear and well-justified specifications on how users shall include material and product losses in the quantity determination.
b. If statistical data on transport and construction losses per building material/product type do not exist, instead of requesting designers to add a non-differentiated percentage per material type, consider the losses when setting benchmarks (e.g. slightly lower benchmarks because losses are excluded). In general: if different losses are considered as part of a method, make sure that benchmarks also include material losses (package of rules, LCI/LCA data, tools and benchmarks). If benchmarks exclude such losses, the assessment may omit them as well.
c. To treat the uncertainties of the mass parameters, require a +10% of material quantity for all building materials at early design stages as a safety margin. This will help the method users to increase the probability that benchmarks are also met at late design stages where the effect of design decisions decreases (i.e. in late design stages quantities are recalculated and uncertainty decreases, therefore such add-on becomes irrelevant).

National standardization bodies (application / use case: C, see Table 1.2)

d. Provide national waste factors per type of construction product, and update them at the latest every 5 years

4.3 Modelling of Building Life Cycle Stages (Scenarios)

Each life cycle stage (and module) is subject to different modelling choices and scenario assumptions. It is important for method providers to specify all these modelling choices and scenarios to the highest degree of detail and in the most comprehensive way possible without, at the same time, complicating the application of the method by its users (e.g. designers). This question is explored per building life cycle module in the following sections. According to the draft European standard prEN 15978-1:2021, "Scenarios shall be: (a) realistic, (b) representative (i.e. be one of the most common of possibilities used in the local context); (c) in accordance with the current industry practice and/or technology available (e.g. existing infrastructural conditions for energy production); (d) aligned to the technical and functional requirements as given in the functional equivalent." Therefore, this standard generally uses a static approach. This means that scenarios are seen as a "snapshot" of the processes occurring during the life cycle of a building as if they have been brought from the future into present day without any effect of timing.

However, buildings, as long-lived objects, evolve in time and are characterized by a great number of time-dependent effects. Some time-dependent effects are more particular to a certain stage or module, such as the climate change effect which only affects in a significant way the operation of buildings (module B6), others are more "cross-cutting", i.e., they influence more than one life cycle stage or module. The most influential time-dependent effects are discussed in this Section.

Against this background, this Section is structured as follows:
- Section 4.3.1 provides the background of time-dependent effects, explains the difference between static and dynamic approaches and provides an overview of which effects affect each life cycle module.
- Sections 4.3.2-7 deal with selected cross-cutting time-dependent effects
- Section 4.3.8 provides guidance for the selected cross-cutting effects.
- Sections 4.3.8-35 provide a detailed stage-by-stage analysis on scenarios, including conclusions and guidance.

4.3.1 General: Time-dependent effects

The results of an environmental performance assessment usually relate either to a defined point in time (e.g. as built at the time of completion / handover / commissioning) or to a defined period (e.g. during reference study period). Compared to other goods, buildings have a particularly long lifespan or useful life. This is considered in the life cycle models by choosing RSPs of 50 or more years. Significant changes can occur during these RSPs. These range from a change in the economic and social framework (including legislation) through technical progress to changes in user behaviour and / or changes in climatic conditions. This has consequences for the modelling of the energy and material flows as well as the determination and evaluation of the effects on the environment. Individual questions are discussed below. The respective consequences have an effect in different phases and modules of the life cycle model. They are therefore dealt with here in advance in order to provide basic information. First, it is important to make a fundamental decision between a static or a dynamic view.

Time-dependent effects are only relevant to environmental impacts that will arise in the future, i.e. during the use and EoL stages of a project (i.e. stages B and C, and in addition module D), and can affect the environmental impact assessment results considerably. Since LCA is used here as an aid for an environmental performance assessment, relevant questions should be discussed using the example of life cycle assessment. A distinction can be made between two different LCA application approaches in relation to the consideration of time:

Static approach: Within this approach a static consideration of influence factors is considered. This means that no prospective forecasts regarding changing influence factors (input values) are made and the conditions from the start of the period under study are assumed for the whole lifecycle / study period. Up to now, this is the traditional way of looking at environmental impacts within the context of a sustainability assessment and is in line with EN 15978:2011 (currently under review) and EN 15804+A2 which suggest that current practices shall apply to any future conditions. Future projections in the calculations are not allowed to limit the uncertainty factors influencing the results of the assessments. This simplified but limited approach, however, is not expedient as buildings are complex engineering systems affected by a multitude of continuous changing direct and indirect factors during the lifecycle / study period.

Dynamic approach: the application of LCA takes prospective developments such as technical as well as social challenges and changing conditions like climate change into account. As shown in Table 4.13, there are several time dependent factors and sub-factors that occur after the building is built and ready-to-use. The ones with a "cross-cutting" effect are highlighted in yellow. By considering these aspects as changing influence factors the received outcomes of a conventional / static LCA alters immensely. Within science and research there are increasingly approaches to perform a dynamic LCA (DLCA) (Su et al., 2017; Roux et al., 2017; Negishi et al., 2018). By considering changing influence factors (input values) it is aimed to provide realistic estimates to further facilitate the decision-making process for stakeholders. Hence, the research issue arises to identify time-dependent influence factors and to identify whether it is possible to develop forecasts and explore future scenarios for different input parameters.

In this report, dynamic is also called the production of several static inventories for several scenarios, each one representative of a specific time period. This is not a continuous function, but it represents the easiest way to consider future changes and is adopted by some methods. It should be noted that time-related aspects can be considered at different steps of an LCA, such as (Cardellini et al., 2018):

- LCI definition, by explicitly considering the temporal relationship between flows;
- LCIA, by using dynamic characterization factors (dCF) in place of characterization factors (CF)
- the weighting of impacts, for example by discounting them

The following sections deal in detail with only selected cross-cutting time-dependent issues – particularly the technological development in relation to different processes affecting both the embodied impacts of building components installed in the building and building-level processes such as transport and operation (Sections 4.3.2-4) and the carbon storage effect relevant for certain building materials (Sections 4.3.5-6). Although physical discounting is not shown in Table 4.13, is treated under Section 4.3.7. The effects of changing climate and user behaviour are in general also handled in detail in this report under specific dedicated sections to the modelling of module B6 (Sections 4.3.23-24).

Time-dependent issues not handled in this report for which studies exist are:

- **Technical progress in relation to products and product characteristics:** It is highly likely that in future when the periodical replacements and refurbishment take place new innovative technologies will be available in the market to satisfy thermal comfort levels and building functions. For example, insulation materials with higher performances may be available or are already available but not yet widely used (Grazieschi et al. 2021).
- **Deterioration of technical performance**: Operational energy consumption levels are influenced with regard to deterioration/degradation of technical performance of building components and technical equipment. Typical examples are the deterioration of thermal resistance of insulation materials over time, as well as the deterioration of energy efficiency of heat pumps as well as production capacity of renewable energy technologies. For example, Negishi et al. (2018) assumes a 20% degradation of thermal resistance of insulation materials over a period of 25 years, as well as a 1% annual degradation of energy efficiency for heat pumps.
- **Availability of raw materials and secondary resources**: The availability of building products and the raw materials required for their manufacture are subject to dynamic change. The supply of natural raw materials can be exhausted in selected regions, new products (e.g. low carbon products, reused products) will be available in the future and the amount of secondary raw materials can increase.

– **Availability/ allowance to use energy carriers:** The type of energy supply chosen for a building today may not be available in future; it must be checked whether and to what extent certain energy sources which are currently available their use may be restricted in the future. In several countries there are discussions about phasing out the use of oil or gas for heating buildings.

Table 4.13: An overview of time-dependent factors and sub-factors in LCA of buildings. Note 1: where CP: Construction products; TS: Transport services; ES: Energy supply; CF: Characterisation factor. Note 2: A1-5 always represent the current situation and therefore are not relevant for time-related considerations.

Time-dependent influence factors		Data influenced	Module influenced												
Factor	**Sub factor**		B1	B2	B3	B4	B5	B6	B7	B8	C1	C2	C3	C4	D1
Technological development in relation to processes (Sections 4.3.2-4)	(material) production processes	LCI of CP			■	■	■								
	construction/deconstruction processes	Building data				■	■				■				
	(material) reuse/recycling processes	LCI of CP											■	■	■
	transport services	LCI of TS and CP		■	■	■	■			■	■	■			
	energy supply (energy mix)	All LCIs (ES; TS; CP)		■	■	■	■	■	■	■	■	■	■	■	■
Technical progress in relation to products and product characteristics	Availability of products and systems with better characteristics/higher performance or new innovative products	LCI of CP				■	■	■	■						
Carbon storage (Sections 4.3.5-6)	Carbon absorbed by and emitted from wood	CF	■										■	■	■
	Carbon absorbed by and emitted from other products than wood e.g. lime-containing products		■										■	■	■
Climate change (Sections 4.3.23)	Heating/Cooling demands	Weather data						■							
	Lighting demand							■							
Changes in user behaviour (Section 4.3.24)	Thermal comfort level	Building use profile						■							
	Presence time of users							■							
	Space per person and household size							■							
Deterioration of technical performance	…of building components	Technical data of components						■							
	…of energy production equipment							■							
Availability of raw materials and secondary resources		LCI of CP			■	■	■								
Availability / allowance to use energy carriers		Building use profile						■							

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4.3.2 Cross-cutting time-dependent effect: Technical progress with respect to energy supply

Current national and international environmental policies call for the mitigation of GHG emissions to limit the effects of climate change. The energy sector is a major GHG emission emitter and will subsequently need to significantly decarbonise over time. That is why most national governments and/or large energy service providers have already in place or are in process to develop decarbonisation strategies and roadmaps. These roadmaps are usually framed around three cornerstone energy supply systems: the electricity supply system (electricity mix[17]), the district heating supply system (district heating mix[18]) and the gas supply system (gas mix[19]).

When it comes of the question of considering present vs future energy mixes, particularly the evolution of electricity generation and consumption is one of the key issues to progress towards net zero GHG emissions, as shown in the IEA roadmap for the global energy sector (IEA 2021). The type of electricity generation affects the primary energy consumption (e.g. non-renewable primary energy consumption expressing depletion of fossil energy carriers), GHG emissions and other environmental impacts of buildings both directly during their operation (e.g. electricity consumption for cooling/heating, lighting, or other user-related activities) and indirectly through the electricity consumption in connection with the manufacturing of construction products installed in the building. The provenience and the technologies used to generate the electricity are key determining factors for the GHG intensity of electricity. That is why it is considered very important to choose the most appropriate model for the current and future generation of electricity in the LCA of buildings and in the LCA of construction products as a sub-aspect (see A72 background report by Peuportier et al. (2023)). This also raises the question of whether the effects of decarbonization are reflected in the mix or whether a distinction should be made in future between a "green" supply and a "residual mix"[20].

In general, the modelling of electricity mix is challenging as there are many options regarding the temporal and spatial scope (Esser & Sensfuss 2016). Focusing on the temporal scope in this Section, the most common approach applied in LCA is a static approach where a specific average national mix is used for the entire reference study period. This average mix may be an electricity mix from a specific recent year or an average of a longer period. This is in line with the current standards which suggest that current practices shall apply to any future projections and do not allow for decarbonisation in the calculations of life cycle environmental impacts in an effort to limit the uncertainty factors influencing the results of the assessments.

There are, however, some methods and tools considering future annual electricity mix (and sometimes also district heating mix), but only in the calculation of operational impacts (see Table 4.14 for some examples). Only the Norwegian FutureBuilt Zero method (Resch et al., 2022) extends future technological development to also apply to production, transport, and waste management of materials (this topic is the focus of Sections 4.3.3-4). Using Denmark as an example, the development of emission factors for different years can be seen in Table 4.15. The consequences of considering these future factors at least for operation in the Danish context is shown in Figure 4.6, where it becomes clear that if a dynamic approach is followed for operation, embodied impacts increase in relative importance.

In relation to studies, several of them exist but without being officially adopted in the respective countries so far – see A72 background report by Peuportier et al. (2023) for some examples particularly with respect to the electricity mix. An example of research study considering the evolution also of other energy sources and how they would influence the impacts of the future building stock is Lupíšek et al. (2021).

[17] The combination of primary energy sources used to generate power and meet the electricity needs in a given geographic region
[18] The combination of primary energy sources used to generate thermal heat and meet the district heating needs in a given geographic region
[19] The combination of gases (i.e. natural gas, biogas, hydrogen) used to generate thermal heat and power in a given geographic region
[20] For example, see: https://www.aib-net.org/facts/european-residual-mix

Table 4.14: Official methods in regulation, voluntary certification systems and/or tools that use future emission factors for electricity, district heating and/or gas mixes.

Method/Tool	Country	Energy mix scenarios
LCAbyg tool	Denmark	allows the user to choose between the use of static energy data based on dataset from year 2015 and forecasting of electricity and district heating according to the political goals until year 2050.
LCAQuick v3.4	New Zealand	New Zealand **Grid electricity** based on the **Mixed Renewables scenario to 2050**, published by the Ministry of Business, Innovation & Employment (MBIE) in its 2016 Electricity demand and generation scenarios report. The scenario assumes a mix of geothermal and wind plant built, starting in 2020. Annual electricity demand growth is 1%, reflecting moderate GDP and population growth. Grid impacts in 2050 assumed to continue beyond 2050.
RICS (2017)	UK	The conservative 'slow progression' scenario from the latest **Future Energy Scenarios developed by National Grid**[21] is recommended to calculate the decarbonisation adjustment coefficients to be applied to the respective carbon conversion factors based on modest future projections.
RE2020 regulation (2021)	France	The considered electricity mix is not indicated, but very low GHG emissions are fixed for different uses (e.g. 79 g CO_2 eq./kWh electric heating).
Pleiades LCA (EQUER) v5.21.1.2		Both static and dynamic mixes can be chosen by users. The most recent dynamic model is presented in (Frapin et al., 2021)
NollCO$_2$	Sweden	This certification scheme updates this value every two years, and also includes a future scenario. Following long term strategies from Sweden and the EU, **electricity is assumed to be carbon neutral in 2050**. Emission factors between 2020 and 2050 are estimated through linear interpolation.
Climate Declaration of Buildings (Boverket 2020)		The emission factors used to calculate greenhouse gas emissions should be based on emission scenarios that describe a **future development of the energy system** in line with the national climate targets. Erlandsson (2019) has drafted a proposal for such a scenario based on long-term prognoses from the Swedish Energy Agency, the Danish Energy Agency, the Swedish Wind Energy Association and the Swedish Environmental Protection Agency.
NS3720:2018	Norway	This standard provides two different energy-intensity scenarios to be used for electricity exchanges with the external power grid, and for both the evolution from 2020 to 2080 is considered.
FutureBuilt Zero method (Resch et al., 2022)		This method is more \`fixed' compared to NS 3720. It includes **future technology development for all emission sources**, while NS 3720 only has technology development for electricity.

[21] At the time of writing the latest version is of 2021: https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021

Table 4.15: Example: Greenhouse gas emissions of electricity and district heat incl. supply chains in g CO2-eq/kWh and MJ, respectively for the forecasting scenarios for five data points (year) for Denmark (COWI 2016, COWI 2020)

Energy supply	2015	2020	2025	2030	2035	2040	2050
Electricity: 2015 g CO_2-equiv./kWh	352	201	169		31		24
Electricity: 2020 g CO_2-equiv./kWh		264	135	47	41	40	
District heating: 2015 g CO_2-equiv./MJ	52	31	28		20		16
District heating: 2020 g CO_2-equiv./MJ		37	24	20	19	19	

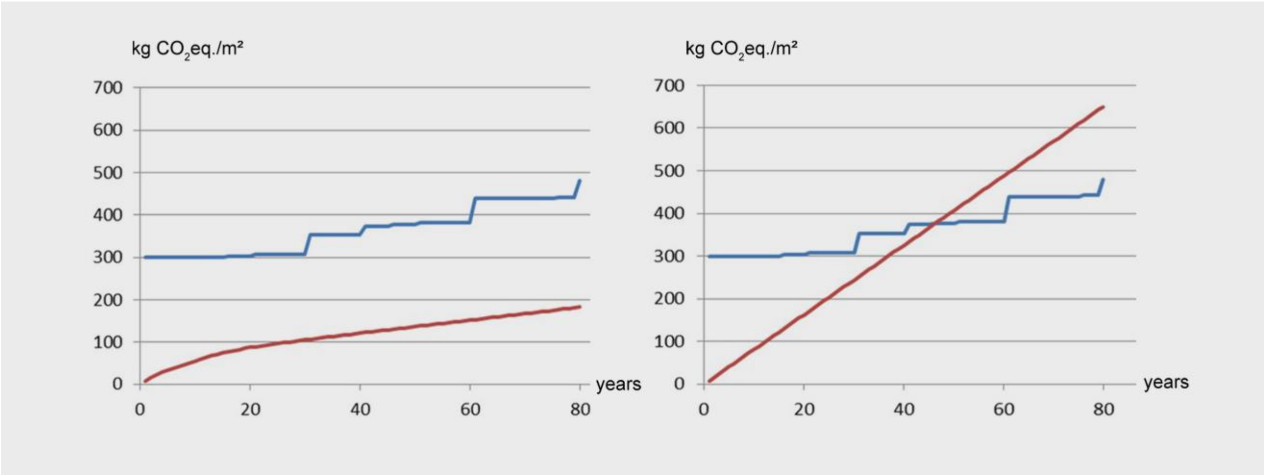


Figure 4.6: Embodied GHG emissions (blue line) and operational GHG emissions (red line) for an office building calculated over 80 years reference study period using forecasting scenario vs. static energy approach only for the operation part (Birgisdottir & Stenholt Madsen 2017).

What can be expected in the background report by Peuportier et al. (2023)?

1. Review of selected existing (official and individual) approaches to electricity mix modelling applied in different countries.
2. Provision of case-specific recommendations based on explanations of choices made in different contexts.

4.3.3 Cross-cutting time-dependent effect: Technical progress with respect to transport services

Another upcoming trend is the change of the transport industry, which will be relevant for any transport occurring during the use stage (i.e. as part of modules B3, B4 and B5) as well as transport occurring at the end-of-life, such as transport to disposal or waste processing facilities (reported under module C2). Vehicles will be operated increasingly by electricity or hydrogen in the future. Recent studies have proven that electric cars are emitting 50% less GHG emissions over the lifecycle in comparison to a usual car in the EU (Transport & Environment 2020). If the electricity supply is based more on renewable energies in the future as expected, this figure will escalate even further.

There is only a limited number of studies dealing with such considerations. By Resch et al. (2020a; 2020b) a continuous GHG emissions mitigation regarding transportation of 90% is assumed over the next 60 years. The authors follow a simplified modelling, where a linear decrease from the year of construction until the end of the study period is assumed and is the same for all materials. On the other hand, Alig et al. (2020) presents a more detailed modelling of future transport services (freight, cargo and ship) primarily for Switzerland and Europe as a whole (see Table 4.16 as an example). It is important to note that technological development in transport services also influences the impacts of future construction products (Section 4.3.4).

Table 4.16: Improvement in Environmental impacts of one tkm lorry transports in Switzerland and Europe in 2030-2050 compared to today. Values refer to the average lorry fleet operated (all payloads) (Source: Alig et al., 2020).

Indicators	Improvement achieved for freight transport, lorry, fleet average	
	Switzerland	Europe
CED – non-renewable	-66%	-64%
CED - renewable	11677%	11412%
Greenhouse gas emissions	-74%	-74%
Overall environmental impacts	-27%	-25%

4.3.4 Cross-cutting time-dependent effect: Technical progress with respect to construction products

The expected change of carbon intensity of electricity supplies (Section 4.3.2) will not only affect the impacts associated with a building's operational energy consumption but also the embodied impacts of future construction products. However, LCA methods and literature mostly focus on the influence of future electricity supply on the former one, if at all considering it, while its influence on building materials production has been rarely discussed. The same applies to the expected transport evolution (Section 4.3.3) which will particularly influence future raw materials transport to manufacturing site (A2) as well as any transport processes involved in landfilling/recycling/recovery/reuse (C3-4). In addition to the energy and transport sector, the construction product manufacturing industry is also anticipated to become cleaner, e.g. through change from fossil fuels to biogas or hydrogen, process optimisation and implementation of mitigation measures such as carbon capture and storage for process-related emissions. Furthermore, improvements in recycling rates of future construction products are also anticipated. These aspects are even more unaddressed by current LCAs. Considering that replacements (B4) of some building products or a planned building refurbishment (B5) take place in 20-40 years from the moment a new building is constructed, adapted inventories for different time periods become relevant for some construction products.

It is important to note that, up to now, the only method that considers this type of technical progress is FutureBuilt Zero in Norway (Resch et al. 2022). Particularly, this method follows a simplified approach, where: (a) a technology factor of 0.33 is assumed for the production of PV systems in year 30 (i.e. 2/3 reduction over 30 years); (b) for other material-related processes (production, transport and waste incineration) an 1% annual technology development is used, which is based historical development in Norwegian industry. Therefore, the same development is assumed for all building materials, except for energy-producing equipment (solar cell systems) where the reduction can be assumed to be greater.

However, the development in GHG emission intensity and other type of impact intensity from material production will depend on material types. Two examples of such detailed analysis per material type, and therefore how the consideration of such issues in the LCIs of future construction products can look like are provided below:

Example 1: This example is presented in detail in an A72 background report by Zhang (2023) and focuses on the influence of future electricity supplies only. In general, to get embodied impact data adapted to future development of electricity systems would require a consistent and transparent modification of electricity production datasets in the background databases to reflect future related scenarios and time horizon. This example takes into account the future electricity supplies from an integrated assessment model (IAM) at different time horizons (i.e. 2030, 2040, 2050), which ensures the consistency of energy supplies between the regions, to check how this influences building material, component and technical system manufacturing and end-of-life processes. To do so, a prospective background database based on ecoinvent v3.6 was built and linked with KBOB list LCA Data 2016. Particularly, 3 scenarios from REMIND IAM[22] were integrated: (1) Base scenario, which represents counter-factual scenario with no climate policy implemented; (2) Nationally Determined Contributions (NDC) scenario, in which emission reductions and other mitigation commitments of the nationally determined contributions under the Paris Agreement are implemented; (3) PkBudget 900 scenario, in which climate policies to limit cumulative CO2 emissions to 900 gigatons in the time horizon of 2011-2100. It corresponds to a global temperature of 1.5° increase target.

Depending on the material, its upstream processes and the selected future scenarios, the changes of life cycle GHG emission range from -80% to +20% in comparison with the materials as in current KBOB database can be achieved, which is significant. The life cycle GHG emissions of construction materials that are sensitive to future electricity supplies are concentrated in aluminium- (up to -60% emissions reduction), natural stones-related materials (up to -60%~-71% emissions reduction), as well as certain insulation (e.g. aerogel vilies, up to -83% emissions reduction) and coating materials (e.g. enamelling, up to -78% emissions reduction). Solar PV systems exhibit the highest GHG emissions reduction potential, of up to more than 60%, led by mono-silicon PV system among the selected PV technologies. This is due to the electricity-intensive manufacturing processes upstream, such as the purification of metallurgical grade silicon to solar-grade silicon. Even by choosing the most conservative scenario, for some products more than 20% future reductions in GHG emissions can be anticipated (see Table 4.17).

Table 4.17: Development of GHG emission factors of selected material types for the most conservative scenario. Note: only the materials most related to replacements and refurbishments (B4 and B5) are here shown. For more material types such as concrete, aluminium, natural stone, etc. (Source: Zhang 2022).

Material/ Components	Material/Components displayed name in figures	Unit	Life cycle GHG emissions per unit amount of material/ component				% change today-2050
			KBOB linked with ecoinvent v3.6	KBOB SSP2-Base_2030	KBOB SSP2-Base_2040	KBOB SSP2-Base_2050	
Windows	window frame, aluminium	m²	6.00E+02	4.87E+02	4.78E+02	4.69E+02	-22,0%
Windows	window frame, wood	m²	1.74E+02	1.49E+02	1.48E+02	1.48E+02	-15.0%
Windows	window frame, wood-aluminium	m²	3.27E+02	2.70E+02	2.67E+02	2.64E+02	-19.0%
Windows	window frame, PVC	m²	3.31E+02	2.92E+02	2.91E+02	2.90E+02	-12,5%
Insulation material	foam glass	kg	1.78E+00	1.43E+00	1.40E+00	1.37E+00	-23,0%
Insulation material	rock wool	kg	1.09E+00	1.11E+00	1.10E+00	1.10E+00	negligible
Cement motar	cement motar	kg	2.09E-01	2.13E-01	2.12E-01	2.11E-01	negligible
PV system	PV system, multi-Si, slanted-roof BAPV	unit	6.54E+03	4.99E+03	4.91E+03	4.83E+03	-26,0%
PV system	PV system, mono-Si, slanted-roof BAPV	unit	7.60E+03	5.66E+03	5.56E+03	5.46E+03	-28,0%
PV system	PV system, a-Si, BIPV	unit	4.83E+03	3.58E+03	3.51E+03	3.46E+03	-18,0%
PV system	PV system, CdTe, BIPV	unit	4.28E+03	3.38E+03	3.31E+03	3.23E+03	-24.5%

[22] See: https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/models/remind

Example 2: Alig et al. (2020) performed LCAs of future production of construction materials relevant in structural engineering, namely mineral and metal materials, wood and plastics produced and/or used in Switzerland and of future transport services and energy supply. The required information about the technological development of manufacturing processes, transport services and energy supply were collected in interviews with representatives from associations and pioneering companies and with desk top research. Data were consolidated and complemented with assumptions. The study refers to the time period between 2030 and 2050. The study showed that with future construction materials manufacture, GHG emissions are reduced on average by 65 %, non-renewable primary energy demand by 48 % and the total environmental impact (measured in Swiss UBP points) by 38 %. An overview of the improvements achieved with future building materials production per material type compared to current levels of GHG emissions in KBOB database are shown in Table 4.18.

To show how this translates into the building level a residential case study is used (Figure 4.7). At building level, GHG emissions of construction (including building technology) and dismantling can be reduced by 50-60%. If we consider that a building is built today, and only the impacts associated with future replacements and EoL (B4, C3-4) are to be considered in a dynamic way, a reduction of about 20% occurs. As this reduction is not insignificant, the question arises as to whether the consideration of technical progress should start being integrated into official methods together with the dynamic consideration of B6 module.

Table 4.18: Environmental impacts of future building materials production (see: A72 report by Birgisdóttir and Stranddorf, (2022), case study 05).

	lean concrete	building construction concrete	civil engineering concrete	drilled piles concrete	precast concrete, high perf.	precast concrete, standard	bricks	gypsum plaster-board	float glass	aluminium	copper	nickel	steel	rolled steel
GHG gas emissions of 1kg future building materials production [kgCO_2eq.]	0.012	0.021	0.023	0.025	0.042	0.037	0.036	0.17	0.22	4.0	0.35	0.15	0.63	0.27
GHG gas emissions improvement achieved with future building materials production	-76%	-77%	-76%	-77%	-84%	-77%	-85%	-27%	-80%	-56%	-89%	-98%	-62%	-63%

	Zinc	3-layered lam. board	Glued lam. timber outdoor	Glued lam. timber indoor	particleboard	fibreboard	glass wool	rockwool	linoleum	EPS	XPS	PE	PVC	PLA
GHG gas emissions of 1kg future building materials production [kgCO2eq.]	1.2	0.13	0.17	0.14	0.35	0.10	0.42	0.43	1.5	1.9	1.7	1.8	0.55	1.3
GHG gas emissions improvement achieved with future building materials production	-61%	-65%	-50%	-55%	-27%	-76%	-41%	-59%	-41%	-55%	-85%	-60%	-73%	-56%

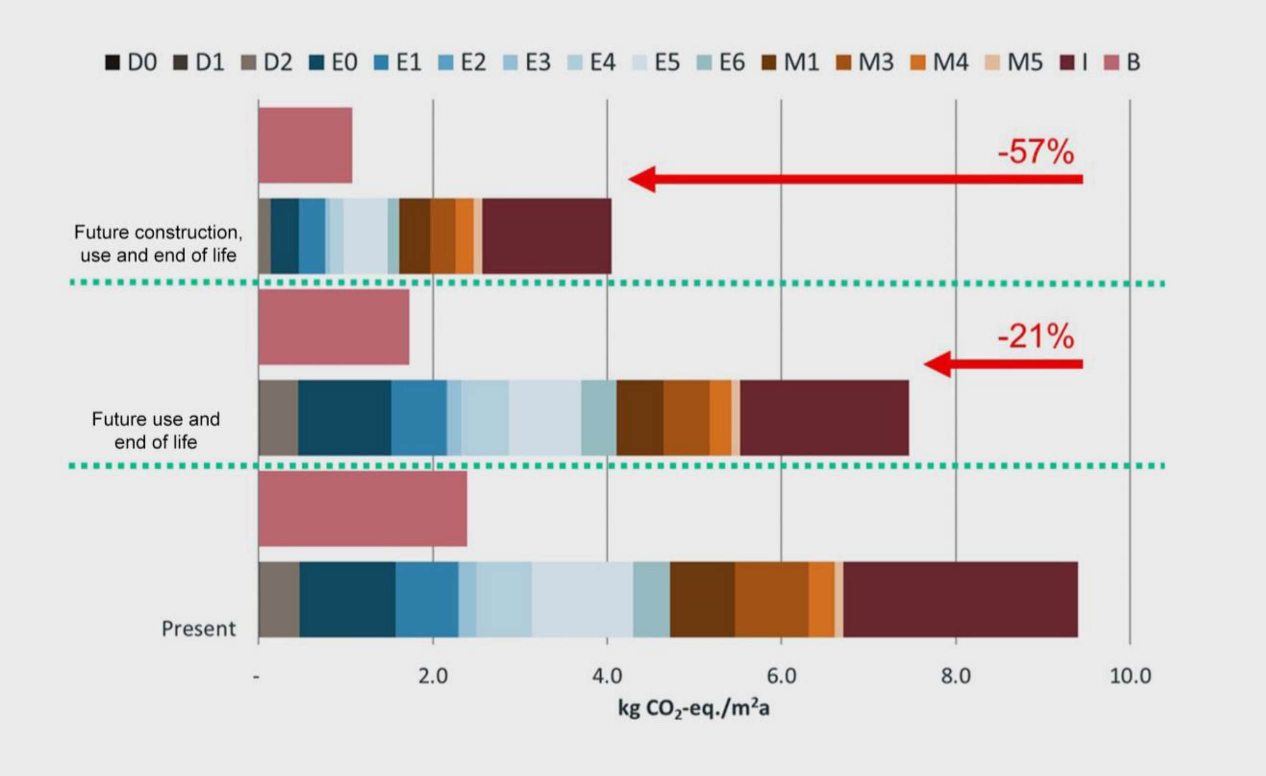


Figure 4.7: The greenhouse gas emissions per m2 and year of the residential building Rautistrasse of building construction and dismantling are reduced by 57%. Note. The residential building Rautistrasse has 104 apartments and has been built according to the Minergie Eco standard (for short description see: A72 report by Birgisdóttir and Stranddorf (2022), case study 05; for a detailed description see: Alig et al., 2020[23]).

What can be expected in the background report by Zhang (2023)?

1. Description of a method to incorporate future electricity supplies in background databases for construction materials, considering different future scenarios and time horizon.
2. Provision of future data on selected construction materials (2030, 2040, 2050) from KBOB relevant for future new construction and future replacements and refurbishments.

4.3.5 Cross-cutting time-dependent effect: Biogenic carbon storage along the life cycle

Carbon is absorbed in biomass during tree growth and is released into the air through the combustion or degradation of bio-based materials at the end-of-life stage. Therefore, the effect of biogenic carbon when using wood-based materials is twofold. First, the growth of new forest leads to carbon uptake, in that new trees grow up in the area where they were cut down. This carbon fixation takes place during the use stage of the building. Secondly, the wood products in the building will be disposed of at the end of their service life, and some of the carbon stored in the products will then return to the atmosphere. Three different approaches are distinguished in the LCA literature treating the calculation of the biogenic carbon (GHG); the 0/0, -1/+1 and the time-dependent approach. These approaches differ from how temporal biogenic carbon fixation and its release to the atmosphere are distinguished. They are presented in detail in a A72 background report by Saade et al. (2023) and briefly below:

0/0 approach: It considers neither fixation nor releases of biogenic carbon, which was questioned by (Rabl et al. 2007). Figure 4.8, extracted from Hoxha et al (2020b), illustrates the 0/0 approach for a wooden product used in a building. A distinction is made between the forest system, the building system and a potential

[23] The code names of elements represent the elementary cost classification (ECG) (SN 508502 1995) and include the following ECG items: D0: excavation building pit; D1: backfilling, construction; D2: bottom plate: construction; E0: ceiling: construction; E1: roof: construction; E2: pillar: construction; E3: exterior wall basement: reinforced: construction; E4: exterior wall upper floor: construction; E5: window: construction; E6: inner wall: brick built: construction; M1: stud wall: construction; M3: cement cast plaster floor: construction; M4: wall cover: construction; M5: roof cover: construction; I: building equipment: construction; B: operation of the building

subsequent product system, in case of wood recycling. A distinction is made between the forest system, the building system and a potential subsequent product system, in case of wood recycling. As can be seen in the figure, biogenic CO_2 is not considered in any of the modules. In the cases where wood is landfilled after reaching the end of its service life, the release of biogenic methane (CH_4) is modelled in module C, due to its higher impact on global warming compared to biogenic CO_2. Because biogenic CH_4 emissions shall be and are taken into account this approach is not to be considered nor called a "climate neutral" approach. Data collection for building LCAs following this approach therefore does not require any consideration of the amount of CO_2 absorbed during forest growth, nor released during end of life.

–1/+1 approach: it accounts for the fixation of biogenic carbon in the production stage and its release in the end-of-life (EN 15804+A2) (European Committee for Standardization (CEN) 2019). Figure 4.9 (Hoxha et al 2020b) illustrates the -1/+1 approach, in which both biogenic CO_2 uptake (-1) and release (+1) are considered, as well as the transfers of biogenic carbon between the different systems. The uptake of biogenic CO_2 during the forest growth is transferred to the building system and reported as a negative emission in module A, whereas at the end-of-life of the building, biogenic CO_2 (or CO or CH_4) is released or the carbon content is further transferred to a subsequent product system (in case of recycling). In both situations a positive emission is reported in module C. It must be noted that the biogenic carbon balance should be zero for all product systems. Also, because biogenic CH_4 emissions shall be and are taken into account this approach is not to be considered nor called a "climate neutral" approach. Building LCAs conducted with the -1/+1 approach therefore require the calculation of the amount of CO_2 absorbed by the wooden product(s) used in the building, which – at the end of life – will be considered as released in its entirety. It is noteworthy, however, that typical life cycle databases currently do not include detailed, mass-balanced information on the biogenic CO_2 content absorbed by biobased materials during their growth. In fact, when encountering biogenic CO_2 information in life cycle databases, practitioners must ensure that the carbon balance is maintained, which might entail in some efforts regarding data adaptation.

–1/+1* approach: In some countries, variations of the -1/+1 approach are observed, which are not allowed in others; some countries consider landfills and recycling as a partly permanent storage of biogenic carbon and thus less emissions are accounted for in the end-of-life stage. In this report, this variant is denoted as -1/+1*and is applied in Australia, New Zealand, Canada and France. Particularly, in these countries, wood sent to landfill gets a GWP factor substantially lower than +1 (often close to zero). Preconditions for using such a variant is that landfilling is a national option (for example, in most European countries this is not an option) and a robust scientific basis is in place for degradable organic carbon fraction (DOCf) value for wood in landfill in a country/jurisdiction. In Australia and New Zealand, two values of degradable organic carbon fraction (DOCf) for softwood timber are allowed: NZ applies the lower value of 0.1% while AU could use either 0.1% or applies the higher value of 10% (Australian Government, 2016; Wood Solutions, 2020), which results in 99.9% and 90 % assumed permanent sequestration in NZ and AU, respectively. Furthermore, in France a 0/+1 approach is used if no tree is regrowing (i.e. the forest is transformed to agricultural or built-up land) or if the wood stems from native forests (EN 15802+A2) and the wood is incinerated at the end of life (meaning that no fixation of biogenic carbon is considered, but emissions do happen at the end of life). At the end of life, the quantity of biogenic CO_2 is emitted if the wood is incinerated, but not if the wood is landfilled or recycled.

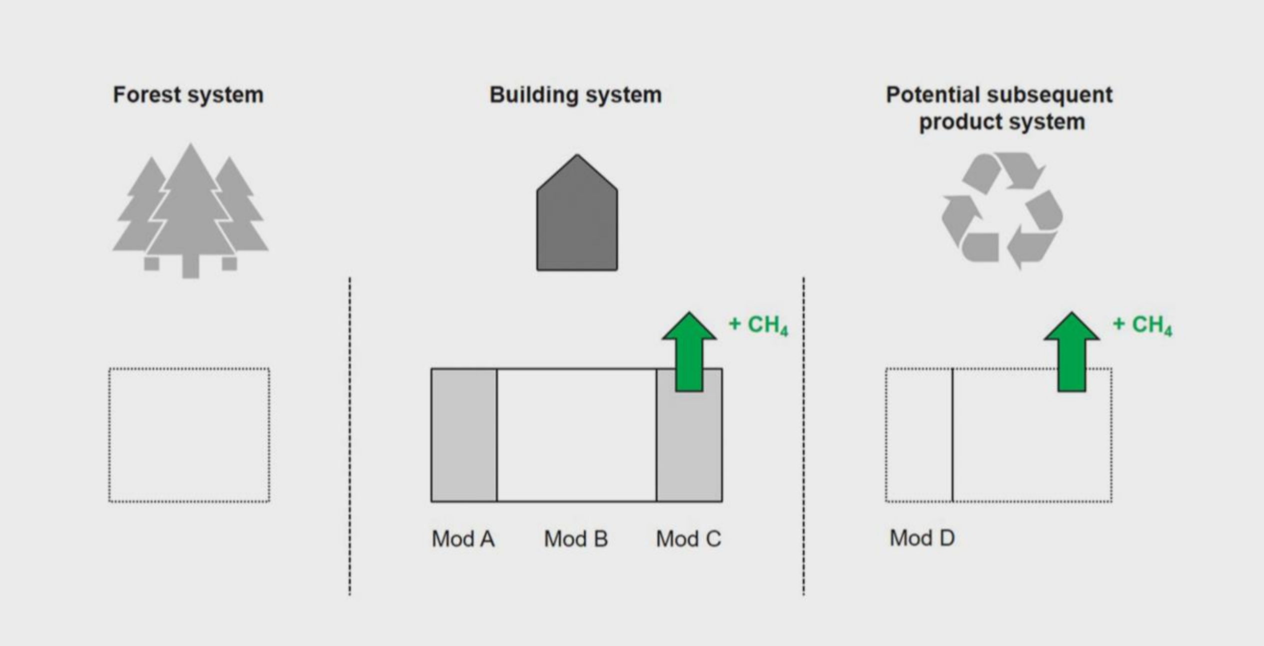


Figure 4.8: The 0/0 approach to model biogenic carbon uptake and release. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020b).

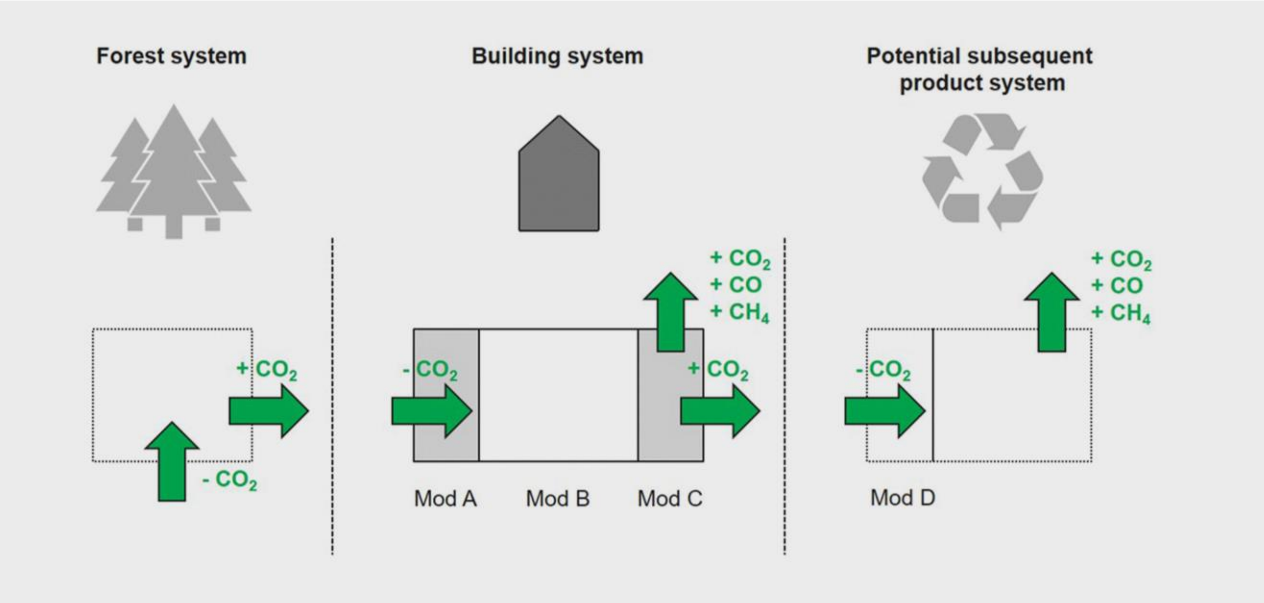


Figure 4.9: The -1/+1 approach to model biogenic carbon uptake and release. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020b).

The comparative case study in Ouellet Plamondon et al. (2022) shows the three different perspectives on biogenic carbon consideration in life cycle assessment as applied by A72 experts following their national approach. The assessment of the superstructure made of light frame wood construction highlights the influence of the end-of-life scenarios of the wood products and the choice of the methodology for the biogenic carbon accounting on the GHG emission results (Figure 4.10). The assessments of countries with a -1/+1* and a landfilling scenario approach report less GHG than those applying the 0/0 and -1/+1 method. While the time-dependent approach has not been used in any method until recently in only a few cases (i.e. it was lately introduced in the French regulation R2020 and the FutureBuilt Zero method (version 2)).

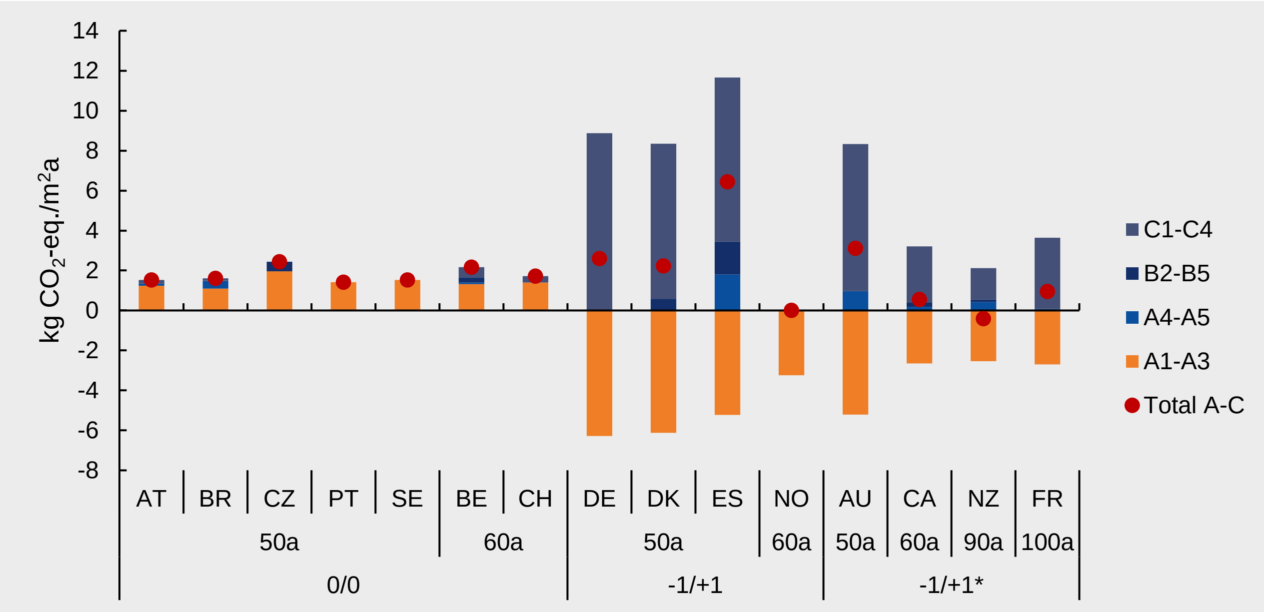


Figure 4.10: Greenhouse gas emissions of the superstructure of a Canadian wooden building assessed (see description of the case study and more results in Ouellet Plamodon et al. (2022)).

Time-dependent approach: The time-dependent approach is most frequently adopted by using the calculation procedure and the dynamic characterisation factors proposed by Levasseur et al. (2010; 2013). The following figures illustrate the two scenarios that can be considered related to the timing of biogenic carbon sequestration in the forest: (i) assuming that trees grow before the use of the harvested wood product, following the natural carbon cycle (Figure 4.11), or (ii) accounting for the so-called "regrowth" after harvesting, assuming an equal amount of the harvested trees would start growing right after the production process (Figure 4.12) (Peñaloza et al., 2016; Pittau et al., 2018). Results may vary considerably between the two approaches (Peñaloza et al., 2016).

Analogously to the -1/+1 approach, the time-dependent approach requires that all biogenic CO_2 considered to be absorbed during trees' growth is released at the end of life. The data requirements in this approach, however, are more complex than in the previous one, because the practitioner would need to determine (i) a yearly amount of CO_2 being absorbed during material growth, instead of the full content of CO_2 in the wooden product, and (ii) the rotation period of the forest, i.e. the time it takes for the trees to reach maturity and be felled. It is not uncommon to find building LCA studies relying on detailed forestry models to determine the latter parameters (Hoxha et al., 2020b; Pittau et al., 2020). In these cases, care must be taken to account only for the CO_2 that is actually transferred to the building system, i.e. "stored" within the mass of wooden product.

The results obtained with a time-dependent approach are highly sensitive to the choice of a time horizon. This is an arbitrary choice to be made by the LCA practitioner. If calculating the overall warming effect 100 years after the building was built, the effect of emissions associated to the end of life of the building (say 75 years after it was built) is significantly underestimated – because 25 years later there is a "cut-off" of that effect due to the time horizon adopted.

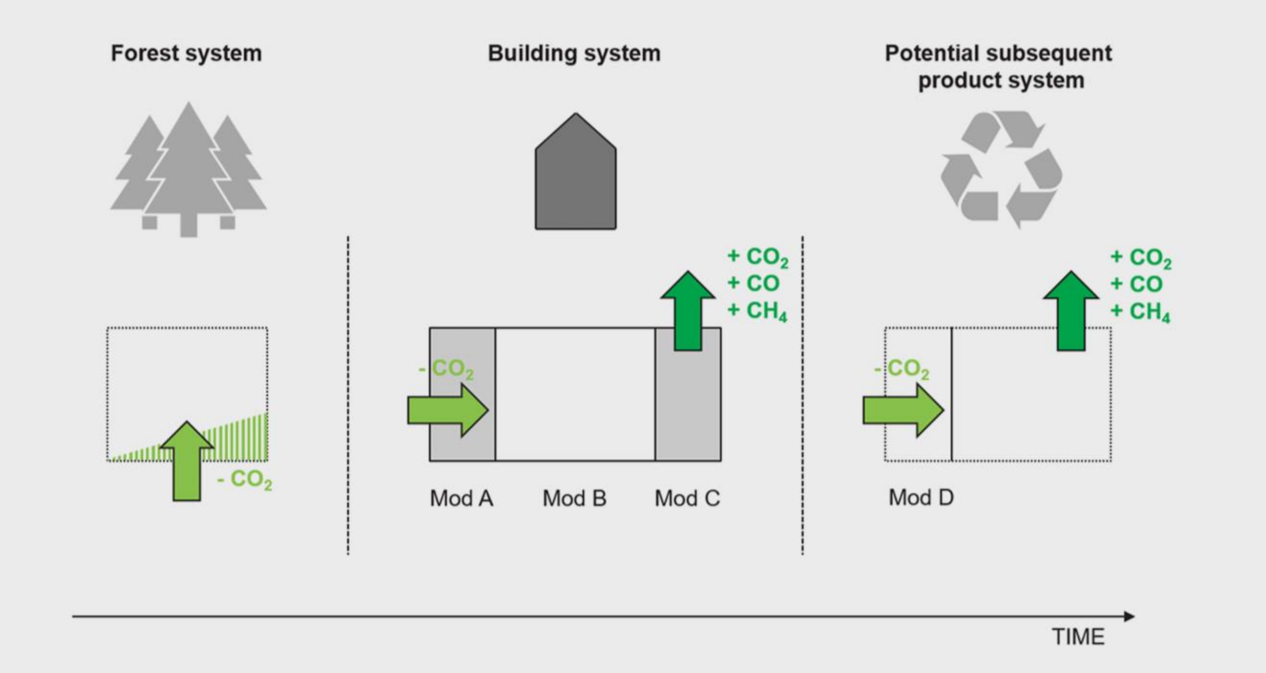


Figure 4.11: The time dependent approach, considering that trees grow before the use of the harvested wood product. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020b).

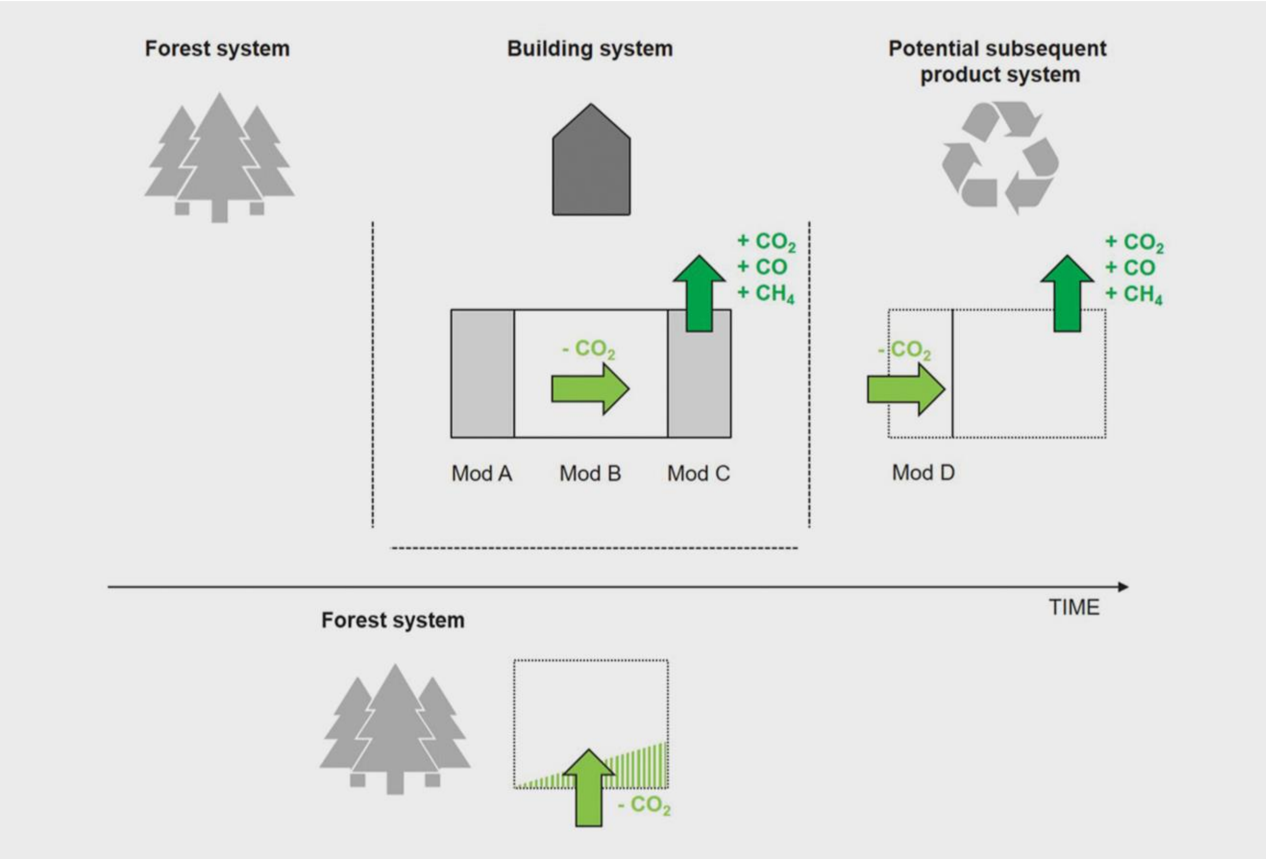


Figure 4.12: The time dependent approach, considering that trees regrow after harvesting. The dotted lines indicate the product systems which fall outside the building system boundaries. Source: Hoxha et al (2020b).

Furthermore, since the publication of Levasseur et al. (2013) scientific knowledge regarding climate change and CO_2 emissions progressed. While annual budgets were discussed in the past, global total budgets are considered relevant today (IPCC 2021). Hence, the time of release of a ton of CO_2 does not matter and has hardly an influence on its ultimate effect on the long-term rise of global mean surface temperature (which should not exceed 1.5 °C). In this context, valid questions can be raised as to the robustness and/or relevancy of a time-dependent approach:

a. there are no recommendations for time dependent characterisation factors in any official IPCC documents, despite the proposal having been published over ten years ago;
b. the concept of time zero for GHG emissions calculation is different than time zero for a specific LCA: the IPCC assumes that time zero for GHG emissions calculation is the time of emission, regardless of whether it is happening today or a few decades from now;
c. the setting of the time horizon (TH) for time-dependent LCAs seems to carry a political weight: a short TH decreases the relevance of emissions happening at a later stage, pointing to a stimulus on postponing emissions rather than avoiding them, whereas a very long TH allows for the perception that delaying emissions for a few decades has a negligible effect on the overall warming of the atmosphere.

What can be expected in the background report by Saade et al. (2023)?

1. Detailed description of modelling approaches of biogenic carbon in life cycle assessments of buildings
2. Synthesis of critical messages and recommendations for biogenic carbon accounting at (a) the inventory level, and (b) the impact assessment level.
3. A brief discussion on the development of non-binding orientation values or binding secondary requirements for greenhouse gases in building products, more specifically wood and biomass-based products.

4.3.6 Cross-cutting time-dependent effect: Natural carbonation of cementious and lime-based products along the life cycle

Construction products containing cementitious materials and/ or lime, such as concrete, mortar and bricks, have the potential to absorb CO_2 when their surfaces are exposed to the air as the contained calcium oxide (CaO) and calcium hydroxide ($Ca(OH)_2$) react with CO_2 in the atmosphere. This natural process is called carbonation and can compensate some of the GHG emissions emitted during the production of these products. However, carbonation beyond a certain level is not desirable in reinforced concrete as it may have adverse effects (corrosion) on the robustness of the embedded steel bars. It is therefore purposefully limited via appropriate mix design and reinforcement cover allowances.

The carbonation process occurs over the life of the components subject to this phenomenon and is therefore usually accounted for in the use module B1 and EoL stages C3-4, if reported at all. Carbonation rates depend on the duration of exposure, concrete designation and the exposure conditions including any concrete surface treatments. It should therefore be pointed out that carbonation will only affect exposed concrete elements whose surfaces are untreated/uncoated. It should also be noted that there is a maximum CO_2 absorbing capacity associated with any given quantity of cementitious material which varies depending on the influential factors specified. Once reached, no further carbonation can take place.

According to findings by Resch et al. (2020) and Alig et al. (2020), natural carbonation of cement products during the use stage seems to play a minor role (1% max of the GHG emissions of a massive building) and may be ignored. Similarly, to biogenic carbon, also carbonation can be taken into account in a dynamic way (e.g. see Pittau et al., 2018). FutureBuilt Zero method (Resch et al., 2022) in Norway follows a simplified approach (different than Pittau et al., 2018): an uptake of 94 kg CO_2 is assumed per tonne of cement after a service life of 100 years following the study by Engelsen and Justnes (2014). It is also assumed that most storage is considered to happen in the first years, and the absorptions are then decreased exponentially. According to these assumptions and the function (curve) provided by the method, after 25 years, approximately half of the uptake that takes place over a 100-year period will have taken place. From this only the uptake that takes place in the years that are part of the building's lifetime is attributed to the building. This approach is called simplified as it does not consider the different concrete strength classes and levels of exposure to air.

4.3.7 Cross-cutting time-dependent effect: Future discounting of GHG emissions

GHG emissions over the life cycle of a product or building occur at different points in time. This raises the question of how to deal with it.

a) time-related importance of GHG emissions

As far as a budget that is still available is assumed, it is irrelevant whether the emission occurs now or in the future. They are considered equal.

For the sake of completeness, alternative positions are also presented here. The consideration of the temporal differentiation in LCA calculations and assessments can alternatively be done with the application of a temporally differentiated weighting of impacts (i.e. discounting). An example is economics, where future cash flows are weighted differently than today's cash flows to account for the time value of money. In economic approaches the external cost levels of GHG emissions is of concern, as well as its practical application in the decision-making processes and policy-making. A key publication that critically discussed and assessed the concept of discounting in LCA was the publication of Hellweg et al. (2003)[24], which was followed by some other papers.

Discounting is still seldom applied in LCA studies and there is no consensus in the literature on its application. A summary of possible approaches is given below:

No temporal differentiation: The current common practice is to avoid temporal differentiation of emissions and the impact of emissions. Time horizons are considered and selected by the user.

Strict time horizons: An option could be to use strict time horizons. This would mean that if the impact of CO_2 emitted today is determined for a time horizon of 100 years, then the impact of CO_2 emitted in 20 years should be determined based in a time horizon of 80 years. Such an approach would be possible by using a dynamic LCI (Levasseur et al. 2010). This is the approach proposed by the French Regulation RE2020, but the disadvantages were already discussed in Section 4.3.5.

Physical discounting based on the modelling the actual behaviour of emissions in the environment: released emissions have an initial concentration in the environment, but through various routes and pathways their concentration is dynamically changing (e.g. transported by the fluid flow, chemical reaction, degradation by itself, interaction with other medium for interphase transport and change, absorption in the environmental sinks, precursors). The changes in the amount can be mathematically determined through appropriate fate and transport models, but this involves complex modelling. These effects do hardly apply to CO_2 because of its chemical stability and thus long-term presence in the atmosphere.

Physical discounting based on increasing scarcity considerations: There is a (residual) budget of emissions determined using scientific methods that may still be emitted if the goal of limiting global warming is met. This remaining budget is getting smaller and smaller as a result of continued release of emissions, and the amount of emissions that are still permitted is therefore smaller and scarcer. In some impact assessment methods such as the ecological scarcity method, increasing scarcity is expressed by increasing the weighting factor.

b) Transformation in external cost

One way is to transfer this discussion into the world of economic considerations. There, for example, the external climate cost (also called 'social cost of carbon' in literature) is increasing over time. At the same time, future environmental and climate costs can be discounted with a social discount rate of 0-2%, for example, to integrate them into economic considerations.

[24] Particularly, a discount rate of 0% was recommended in section 2.5 of this paper.

c) summary

It should be noted that the concept of physical discounting is rejected by several authors (O'Hare et al., 2009; Lueddeckens et al., 2021) who agree that discounting can apply to costs and benefits, but not to physical phenomena that generate them. That is why some methods apply discounting after monetizing environmental impacts. In other words, once the environmental impacts are monetized, it is possible to apply a standard economic discounting on the results, however, a social discounting approach is generally recommended. The topic of monetisation and aggregation of environmental impacts is further discussed under Section 5.4.4.

For a detailed analysis of this topic see the related A72 background report by Szalay et al. (2023) (short description below).

What can be expected in the background report by Szalay et al. (2023)?

1. Description of the different approaches of discounting of future impacts found in literature
2. Recommendations

4.3.8 Cross-cutting time-dependent effect: Conclusions and guidance

Considering the current state of knowledge on dynamic modelling in LCA as a whole: there are currently methods and tools already considering the technological evolution of energy supply mixes (especially electricity), but only in the calculation of operational impacts (B6) so far. The question arises as to how this can be dealt with in the future (1) in scientific studies or (2) requirements in the funding program, assessment systems or laws and whether, when and how dynamic considerations can be made for the embodied part, e.g. for replacements (B4).

Since there is already experience in this field, the guidance provided below advocates a gradual change to future energy mixes but following a conservative approach in the sense that a near future scenario shall be preferred, unless a future long-term scenario is thoroughly justified as reliable (Table 4.19).

To achieve consistency, although not currently the case in almost all methods, future energy supply mixes need to also be considered for replacements (B4) and refurbishment (B5) at the minimum. This presupposes that adapted LCI data of construction products are in place or simplified rules are provided by the method. Ideally, LCI data of construction products need to be also adapted to future (more efficient) manufacturing processes, among others, but the choice of such scenarios is subject to an even higher lack of consensus.

In the case of biogenic carbon accounting, considering the current state of climate science and the variability and uncertainty due to choices of scenarios and/or important (newly introduced) parameters in dynamic modelling of this aspect in LCA, as well as the lack of consensus on the latter, the here given guidance supports reliance on static considerations for regulations, standards and certification systems (Table 4.19).

Table 4.19: Rules on how to deal with different cross-cutting time-dependent issues in LCA

ISSUE(S)	RULE(S)
Shall the technical progress with respect to energy mix be considered?	1. The choice of the appropriate energy supply mixes (i.e. recent past mix, near future mix or long-term future mix) shall be made considering the (un)certainty of the information, the appropriateness of the mixes in a 50 to 60 years framework of building operation and whether or not temporal variations matter should be taken into account.
	2. For the operational part: At the minimum, the evolution of the electricity mix shall be considered as it is generally acknowledged that it has an important effect on the LCA results. Particularly, a near future (e.g. 5 years) or a realistic long-term future mix frequently updated (e.g. every 5 years in order to account for the real progress of energy transition while reducing the risk of under- or over estimating future impacts if the actual development is not on track compared to the scenario assumed) shall be considered. Electricity mix data from TSOs, utilities, ministries or administrations (e.g. energy or environment agencies) and national statistics are normally available for the past years, near future and long term future. The exact emission factors to be used shall be provided by the method. Note: This clearly would also entail an adjustment of the current existing benchmarks provided in a method.
Shall the technical progress with respect to transport services and manufacturing processes be considered?	3. This time-dependent effect shall be considered only if relevant adapted LCI data to future national scenarios are officially available in a country. If simplified conventions are considered, these shall be justified transparently, and official sources shall be cited to the extent possible.
How to account for biogenic carbon in bio-based materials?	**Inventory level** 4. The users of the method shall ensure that the biogenic carbon contained in construction products, building elements and buildings is physically accounted for over the life cycle. This may require significant adjustments in currently available life cycle inventories of materials based on renewable feedstocks such as wood. In particular, the allocation of raw material inputs shall reflect the physical flows irrespective of the allocation approach chosen. (Both 1 kg of wood beam and 1 kg of sawdust require an input of at least 1 kg of wood each.) 5. When construction products containing biogenic carbon are either expected to be recycled or landfilled at the end of life of the building or the building element, an amount of biogenic CO_2 emissions equivalent to the biogenic carbon content shall be accounted for[25]. Biogenic CO_2 safely and permanently removed and stored in dedicated underground storage facilities or permanently stored in carbonated cement used in concrete shall be treated differently[26]. 6. If an existing building is replaced by a new one, the biogenic carbon stored in the existing building and the subsequent release of biogenic CO_2 shall be taken into account, at least when monitoring the carbon content of building stocks of cities, communities and countries. See also related rule (3) in Section 4.6.4.

[25] This rule represents the majority of A72 experts' opinion.

[26] This rule represents the majority of A72 experts' opinion. In some countries like Australia and New Zealand landfilling is considered as a partly permanent CO2 storage, but in most countries, this is forbidden by law.

	7. When using bio-based products for the building, the users of the method shall ensure that natural flows of biogenic carbon in forests and on agricultural land (i.e. biogenic carbon not transferred into harvested products) left in forests such as branches, leaves and other residues are disregarded and not allocated to the products harvested. 8. The absorption of CO_2 shall not be accounted for, if the wood stems from forests which sold CO_2-emission certificates based on CO_2 absorption to third parties. **Impact assessment level** 9. Following IPCC's budget approach, the GWP of an emission of CO_2 shall be independent of time and equal 1 kg CO_2-eq per kg. Therefore, a static approach shall be preferred both to be in line with IPCC, the recent findings of climate physics[27] , and reduce uncertainty due to additional choices involved in dynamic approaches. 10. If opting for a time-dependent assessment of biogenic carbon flows, the time horizon shall at least be set to 100 years plus the final year of the reference study period (e.g. 50 or 60 years after the construction) and a fixed integration time of 100 years will be applied to quantify the relative radiative forcing of greenhouse gas emissions. With this time horizon, the results of the dynamic assessment and of the -1/+1 approach (if the carbon balance mentioned in rule 6 is assured) are identical. 11. The integration time (usually 100 years) used to determine the GWP and the global temperature increase potential (GTP) applies independently of the time of release of CO_2 and other greenhouse gases. The integration time on one hand and the reference study period and the lifetime of a building on the other are fully independent. A fixed time horizon (of e.g. 100 years) shall not be reasoned with the (fixed) integration time used to determine GWP and GTP.
How to account for carbonation of lime-containing products?	12. If natural carbonation of cement products is considered, the calculation method and assumptions, as well as the allocation of the effects to the different modules shall be clearly stated. If excluded, reasons for this decision shall be specified (See also Section 4.3.13-14). Time-dependent approaches are discouraged, see rules on biogenic carbon.
Shall future GHG emissions be discounted?	13. Physically discounting future emissions shall not be used[28]

[27] Matthews, H.D., Zickfeld, K., Dickau, M. et al. Temporary nature-based carbon removal can lower peak warming in a well-below 2 °C scenario. Commun Earth Environ 3, 65 (2022). https://doi.org/10.1038/s43247-022-00391-z)
[28] This rule represents the majority of A72 experts' opinion.

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Even if not currently opting for a dynamic approach regarding technological development of products and services, request the users to investigate such scenarios as a form of background information.

b. In addition to operation (B6), the future electricity mix also has important consequences for other use stage and EoL embodied impacts. If future mixes are only considered for B6 and not B4 the ratios of embodied/operational impacts will be skewed. If adapted LCI data for products and services (e.g. transport or waste processing) to consider the same energy mixes accounted for in B6 are not available, provide simplified conventions for the products with significant B4 impacts, such as PV systems.

c. Although physical discounting of future impacts is not recommended, in some approaches, monetization of environmental impacts is used (i.e. when there is need for a single indicator integrating various interests, See also Section 4.4.4-5). Once the environmental impacts are monetized, it is possible to apply discounting on the environmental external cost, but a zero or near zero (1% or less) discount rate is recommended.

Database developers (application / use case: F, see Table 1.2)

d. Provide LCI data for future construction product manufacture, transport services and energy services.

Researchers (application / use case: B, see Table 1.2)

e. long term future mixes may be useful, particularly in sensitivity studies. Use scenarios (e.g. Eurostat, the EU Roadmap 2050, national energy strategies), statistical models or economical models (e.g. TIMES) to test the sensitivity of your LCA results.

f. Electricity mixes (present, near future or future) with low environmental impacts may support buildings with low efficiencies and high specific electricity consumption. Perform sensitivity analyses with additional electricity mixes, for example long-term marginal electricity mixes (see also Section 4.3.25).

4.3.9 How to consider the product stage (modules A1−3): General

The product stage (A1-3) deals with the environmental impacts and resource use attributable to the cradle to gate processes; raw material supply (A1), transport (A2) and manufacturing (A3). Typically, material use in construction (A1-3) is responsible for the biggest environmental impacts from buildings, after operational energy use (B6), in a life cycle perspective. Furthermore, the processes covered by A1-3 frequently also occur in several steps building's life cycle as components need to be produced also for maintenance, repair, replacement and refurbishment activities (B2-5).

There are some special considerations when dealing with A1-3:

– in the case of prefabricated elements, the prefabrication itself is part of the manufacturing process (A3). Therefore, A3 module includes both manufacturing and assembly.
– Many data sources provide negative values for A1-3 of bio-based products as they follow the -1/+1 approach to the modelling of biogenic carbon. However, if a method does not include the end-of-life modules C3-4 in its reporting scope, data sources excluding biogenic carbon must be used.

The modelling of modules A1-3 is not under the responsibility of the environmental performance assessment method user for the building level; rather, the user is responsible for selecting appropriate environmental data for construction products, technical equipment, and processes (see the product data-focused A72 report by Chae and Kim (2022)). Therefore, the main task of methods in relation to A1-3 is to guide the users on how to assess data quality and which specific databases to use based on availability and design step in the design process. Methods are usually tied to specific national data sources, which can be national EPDs or national databases including a mixture of generic and product-specific data or generic data only. But it can be the case that no national data sources for specific product categories are in place. Methods need also rules in place on how to proceed in the absence of such data, e.g. the use of a specific commercial database can be recommended. The criteria and reasons of the choice of the recommended database(s) should be transparent.

Another question is how to handle the use of generic data not verified by third parties (due to lack of other data). For example, the Dutch approach GWW (SBK 2014) applies a multiplication factor of 1.3 to unverified generic data because experience shows that the environmental impact declared in unverified sources is oftentimes too low. Such rules can also form part of a method.

4.3.10 Modules A1-3: Conclusions and guidance

For mapping A1-A3 impacts, the government or other official service providers must provide quality-assured data in the form of databases that are suitable for lifecycle- based environmental performance assessment of buildings. It is also the responsibility of the users of the data or the developers of programs that integrate or link to such data to also check from their side their suitability. In any case, the method is important to clarify who is responsible for data quality and their correct application. The following rules (Table 4.20) and recommendations (grey box) apply to both new building projects and refurbishment projects and are based on these considerations.

Table 4.20: Rules for handling A1-3 information

ISSUE(S)		RULE(S)
How to support users in the selection of appropriate data sources?	1.	Suitable sources for embodied impact data for A1-3 shall be specified, both generic ones (for early design phases) and product-specific ones (for later design stages). 'Officially' approved and validated data sources by national authorities shall be preferred above all, if available, or a justification for the use of other sources shall be provided.
	2.	In the absence of data for specific product categories or products in the sources tied to the method (rule 1), minimum requirements that shall be fulfilled by data sources and/tools to support the method shall be listed. These shall include at the minimum completeness, transparency, adaptability to the national context, reliability/robustness and regular updates. Ideally, availability of information on the uncertainty of data shall also be a requirement.
How to handle negative values of A1-3 due to carbon absorbed in bio-based products?	3.	The -1/+1 approach to biogenic carbon accounting shall not be followed if C3-4 modules are excluded from the scope of the method. Hence, negative values of A1-3 shall not be used in isolation, but always together with C3-4 values.

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers/ providers of sustainability assessment systems (application / use case: C, see Table 1.2), currently relying on EN 15804+A1

a. Accelerate the process of transition from EN 15804+A1 to EN 15804+A2 aligned data, in particular because of the division into GWP fossil and GWP biogenic as well as the additional provision of biogenic carbon content of products. A timetable should be developed for the transition to A2 to ensure that by the time GWP fossil, GWP biogenic and GWP luluc (see also Section 4.4.2) are introduced at building level, these values for all construction products are available.

Database developers (application / use case: F, see Table 1.2), currently relying on EN 15804+A1

b. Make the switch from EN 15804+A1 to EN 15804+A2 compliance as quickly as possible.
c. Specify ranges of environmental values of types of products.
d. Specify in detail the quality of the data you provide.
e. Specify in detail how imported data is handled.

4.3.11 How to model transport processes (modules A4 and C2) and construction/deconstruction process (modules A5 and C1): General

Transport processes occur throughout various stages of the life cycle of a building. This section deals with post-gate transport processes, i.e. the delivery of products and systems to the construction site from construction product manufacturers, suppliers or storage facilities (module A4), transport of material and equipment on the construction site and manufacturing efforts (such as mortar mixing) during the construction process (module A5) and transport of waste products and equipment from the construction site to disposal or waste treatment facilities (module C2). An additional type of transport related to the building is the transport of workers (commuting) that is usually reported under A5, but its reporting is not mandatory and should be kept separate according to EN15978:2011 (currently under revision).

This section also discusses the construction and deconstruction processes that take place directly on the construction site and correspond to modules A5 and C1, respectively. The construction processes include the activities of constructing buildings or installing components and systems, while the deconstruction processes include the activities of deconstruction or dismantling. It is important to note that in the case of pre-fabricated building components, all pre-fabrication processes are assigned to module A3.

It is important to note that module B4 (replacement) includes the production of new products and underlaying materials (A1-A3) and their transport to building site (A4), the process of removing the old products and installing new products (similar to C1 + A5), as well as the transport of removed old products to disposal of waste processing facilities (C2) and the disposal of waste processing itself (C3 + C4). Therefore, transportation and (de-)construction processes occur also in connection to replacements (B4). The same applies to maintenance (B2), repair (B3) and planned refurbishment (B5). In B2 there are additional processes included like regular cleaning.

An overview of the activities related to transport and construction processes dealt with in this Section is provided in Table 4.21 and a related scheme in Figure 4.13.

Table 4.21: Scope of the activities related to transport and (de)-construction process discusses in this report and the correlation with the LCA modules.

Activity	Module(s) that fully or partly contain transport processes in their boundary	This section?
Activities related to transport processes		
Transport in the upstream chains	A2	No, see Section 4.3.9
Transport of construction and/or ancillary products from manufacturers, suppliers or storage facilities to the construction site	**A4**, B2, B3, B4, B5	Yes
Transport of construction site equipment to the construction site	**A4**, B4, B5	Yes
Transport of construction and/or ancillary products on the construction site	**A5**, B4, B5	Yes
Transport of construction workers to/ from the construction site	A5, (B2), (B3), B4, B5	No*
Transport from the construction site to disposal or waste processing facilities	B3, B4, B5, **C2**	Yes
Transport of building users during building operation (mobility)	B8	No, see Section 4.3.30
Transport on the waste processing and/or disposal facilities	C3, C4	No, see Section 4.3.32
Activities related to construction processes		
Preliminary works (excavation, earthworks, etc.)	**A5**	Yes
Installation of construction products and technical systems	**A5**, B3, B4, B5	Yes
Deinstallation of construction products and technical systems	B3, B4, B5, **C1**	Yes
(Re-)application of finishes (e.g. paint) or other products	B2, (B4), (B5)	No, see Section 4.3.15
Heating and lighting consumed on site	**A5**, (B4), (B5)	Yes

***** not mandatory in EN 15978:2011, and not significant in the context of this guideline

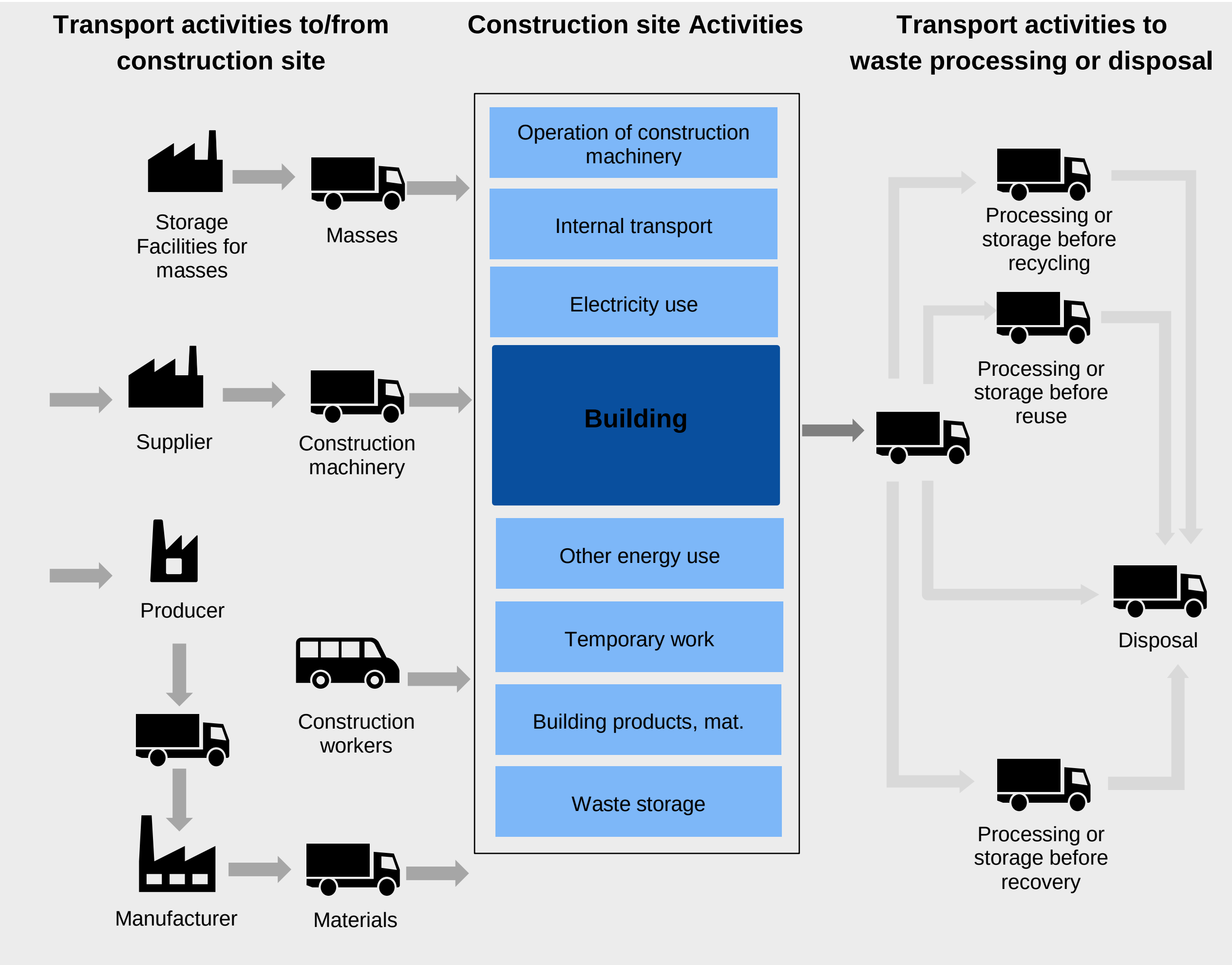


Figure 4.13: Scheme of the activities related to transport and (de)construction process (based on Brusselaers et al., 2020)

Modelling of transport processes: The environmental impacts associated with transport processes depend on several factors, such as the transport distance, the type of trip (without/with fully/with partially empty trips) and the means of transport. Assumptions on factors vary according to the type and quantity of product. For different means of transport, LCI data (at the minimum emission factors) are usually available for transport of goods in t km (tons kilometers) and for transport of people in p km (person kilometers).

The following questions arise in connection with transportation:

a. Which transport distances are taken into account, what is the starting point to the destination (i.e. construction site)? Possibilities for starting points include the manufacturers' plant, the building materials suppliers, or the temporary storage of construction companies. However, sometimes this information is not clearly reported in the EPDs. Also, imported goods with long transport distances need to be handled with particular attention.
b. The transport of which goods shall be documented? Shall methods request the complete documentation of all transports, or focus on the main building materials? Shall and can the transport of the construction site equipment be considered?
c. Shall transport of workers to/on/from the construction site be documented?
d. Shall a static or dynamic approach be followed for transport processes occurring far in the future, such as the ones during replacements (B4) or end-of-life stage (C2)? How can future transport options be considered? For example, an upcoming trend is the change of the transport industry to vehicles operated increasingly by electricity or hydrogen in the future (see Section 4.3.3 for a detailed discussion).

Regarding the handling of transport processes in existing literature and national methods, the options can be broadly categorised into the following four groups:

- Option 0: Not modelled/ Exclusion from life cycle scope
- Option 1: Generic modelling/ Use of default values (distances and means of transport)
- Option 2: Simplified modelling/ Use of simplified levels (such as local, regional, international) depending on the distances and means of transports.
- Option 3: Detailed modelling: (a) Use of information in material- or product-related EPDs (if available) and/or (b) model in detail and on a case-by-case basis at the building level.

Option 0 (not modelled): As the related A72 background report by Soust-Verdaguer et al. (2023) shows, if transported distances are not relevant (local or regional manufacturers) the modelling of transport is neglected (e.g. the Swiss SIA 2032 standard, in assessment methods in Germany, etc.). Imported materials and equipment may be treated differently (with transports into the country of use being included).

Option 1 (generic modelling): A generic approach uses one value/percentage for transport without distinguishing the materials. Therefore, it is possible using:

– absolute default values for A4 and/or C2 (e.g. the Finnish assessment standard[29])
– relative default values in% for A4 and/or C2 (e.g. A4 = 5% of A1-3)
– one average value for transport distance (and one type of transport vehicle) assumed for all building products (e.g. EeBGuide[30])

Option 2 (simplified modelling): A simplified approach defines average distances and means of transports depending on broad materials groups. Therefore, it is possible using:

– an average transport scenario (default distance, default means of transport, etc.) per main building material and essential building component.
– one absolute default/proxy value and/or assumption for the main factors (transport distance and means of transport) depending on the type of process (e.g. transport from manufacturer to site, transport from site to disposal, transport from site to recycling) (e.g. France[31])
– Definition of different groups or levels depending on the transportation distances and means of transports (e.g. see: RICS method[32]; case study 17 in A72 report by Birgisdóttir and Stranddorf (2022)
– average values for different groups of materials considering the most relevant cities and type of materials (Example: New Zealand[33]).

Option 3 (detailed modelling): A detailed approach can be followed where a detailed list of the specific materials/elements shipped to a building, the respective transport distances and means of transportation are used for the transport modelling (different distance and means of transport per product). Therefore, Option 3 defines more precise data for distances and means of transport (closer to real scenarios) of specific materials and it also could be the real fuel consumption (if available). Detailed modelling can also be considered where default values are provided by a method per product group and their derivation is based on distinct scenarios (but based on the national average market). Therefore, case-by-case scenarios are used where detailed default values can be used for early design stages and detailed specific values can be used at late design

[29] This method provides proxy values for life-cycle phases that may be time-consuming to investigate, but which have a marginal impact. The values provided for transport processes (A4/C2) are particularly10.2 kg CO_2 eq./m^2. This represents the mean value in Finland with an added 20% to consider uncertainty.

[30] The EeBGuide define National/European default parameters for transportation distance: 300 km, see: https://www.eebguide.eu/eebblog/wp-content/uploads/2012/10/EeBGuide-B-FINAL-PR_2012-10-29.pdf

[31] For example, the following default values are proposed in Pleiades LCA EQUER, and can be changed by the user: Distance from manufacture to building site, 100 km, Distance from Building site to landfill, 20 km, Distance from Building site to incineration, 20 km, Distance from Building site to recycling, 100 km. Transport by truck is considered. The French RE2020 regulation uses values provided in EPDs, which are also resulting from simplified modelling: they correspond to an average distance independently from the project location.

[32] Before specification of specific manufacturers, four levels are given as default: (1) Locally manufactured e.g. concrete, aggregate, earth 50km; (2) Nationally manufactured e.g. plasterboard, blockwork, insulation 300km; (3) European manufactured e.g. CLT, façade modules, carpet 1,500km by road; (4) Globally manufactured e.g. specialist stone cladding 200km by road, 10,000 km by sea.

[33] See: https://www.branz.co.nz/environment-zero-carbon-research/framework/data/

stages (see: Soust-Verdaguer et al. 2022). The national methods closer to detailed modelling are: (1) the Belgian method "Environmental profile of buildings" (Lam and Trigaux 2021) which defines default transport scenarios for ten main product groups, determining average transport distances and means of transport also according to whether the products were transported directly from the factory to the site, or from the factory to an intermediate supplier and from there to the building site; (2) the Swedish method which provides A4 GHG emissions in kgCO_2e/kg for every product in its Climate database[34] providing the background scenario used to derive these values in every case (means of transport, transport distance, type of fuel used, but no information on load factors and return trips is provided); when the climate declaration is to represent as-built, a distinction is made between using the product-specific default values in the database compared to using real-life data on how main construction materials were actually transported to site, and the distance. Most methods allow and recommend the use of specific data if the specific products are known, but such an approach is more possible for late design stages where information on A4 and C2 can also be obtained from manufacturer-specific EPDs (but they have to be checked for appropriateness at the specific building level).

It should be noted that either using default or specific scenarios for transport distances and means of transport, the impacts of A4 and C2 cannot be calculated if generic LCI data for different means of transport are not available in impact/kg (good)*km in a country. At the moment, such data can be found in Ökobau.dat and KBOB recommendation 2009/1:2022, among others (see the product data-focused A72 report by Chae and Kim 2022). It also should be noted that different options may be used for A4 and C2 transport processes. For example, simplified or detailed modelling may be used for A5 since this module belongs to upfront emissions and the calculated impacts can be confirmed with real fuel consumption obtained from contractors at post-handover, while generic modelling may be used for C2, as these processes occur far into the future and are highly uncertain to justify the effort associated with detailed modelling. Furthermore, different types of modelling may be chosen even within the same module; for example, a method may propose to focus the effort on detailed modelling options for transports of the three most relevant materials and components (greatest proportion of weight or volume) and use generic modelling for the rest of materials and components.

Modelling of construction processes: Construction processes can be modelled using data or assumptions in relation to:

- Type and duration of use of construction equipment including specific energy consumption and emissions.
- Type and duration of supply of heating, cooling, ventilation, humidity control, etc. during construction process.
- Type, scope, and duration of processes that generate noise and vibrations as well as emissions of dust and F-gases (E.g. CIBSE's calculation methodology on embodied impacts of building services recommends that C1 reporting should be mandatory for refrigerant-based system (Butcher (2021)).

Hence, the following questions arise in connection with (de)construction:

a. Which type of (de-) construction activities are considered (e.g. use of different types of machinery, internal transport)?
b. Which are the "systematic ways" for describing/including them? Shall the use of machinery construction and energy consumption for cost estimations be considered as a "systematic way"?
c. Similar for the transport, how can the changes in fossil fuel-based processes be considered in the future? For example, regarding the decarbonisation scenario for upcoming years, the use of fossil fuels in machinery and internal transports will change to a use of electricity or hydrogen. Shall a static or dynamic approach be followed for fossil fuels processes occurring far in the future? (see Section 4.3.3 for a detailed discussion)

Regarding the handling of (de-)construction processes processes in existing literature and national methods, similar options exist as in the case of transport processes:

- Option 0: Not modelled/ Exclusion from life cycle scope

[34] See: https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/climate-database/

– Option 1: Generic modelling/ Use of default values
– Option 2: Simplified modelling/ Use of average values for different main or structure material (e.g. concrete, steel).
– Option 3: Detailed modelling/ Use of information in material- or product-related EPDs (if available) and model in detail and on a case-by-case basis at the building level.

Option 0 (Not modelled): As the related A72 background report by Soust-Verdaguer et al. (2023) shows, if considered as of minor importance or data is missing, these processes are neglected, like in Switzerland (SIA 2032). Currently, in several countries, data on construction activities (A5) are collected from real case studies to derive reference values and consider their introduction in the national methods (e.g. Denmark and Norway (Fufa et al. 2019)).

Option 1 (Generic modelling): A generic approach uses one value/percentage for construction processes without distinguishing the materials/ components or degree of prefabrication. Therefore, it is possible using:
– absolute default values for A5 and/or C1 (e.g. the Finnish assessment standard[35])
– relative default values in % (e.g. A5 = 2%, 5% or 10%*A1-3) Examples: French design tool Pleiades LCA, the Belgian method "Environmental profile of buildings" (Lam and Trigaux 2021) or the study by Lavagna et al. (2018).

Option 2 (Simplified modelling): A simplified approach defines average electricity consumption and construction equipment depending on broad materials groups or construction activities. Therefore, it is possible using:
– average energy consumption of major construction equipment and construction site activities (e.g. lighting and heating) (Example: UK[36]).
– Use of average values for different types of construction activities and levels of building prefabrication (Example: Sweden[37] (Malmqvist et al. 2021, pg. 48))
– Use of different scenarios at building level (Examples: Soust-Verdaguer et al. 2018; Asdrubali et al. 2013).

Option 3 (Detailed modelling): A detailed approach can be followed where a detailed list of the specific (de-)construction activities per type of materials/elements are used for the modelling. Detailed modelling can also be considered where default values are provided by a method per product group and their derivation is based on distinct scenarios (but based on the national average market). Therefore, case-by-case scenarios are used where detailed default values can be used for early design stages and detailed specific (real or close to real) values can be used at late design stages or as-built declarations (e.g. French RE2020 regulation and Swedish climate declaration). It should be noted that either using default or specific scenarios for construction and deconstruction, the impacts of A5 and C1 cannot be calculated if generic LCI data for different machinery equipment is not available in a country. At the moment, such data can be found in Ökobau.dat and KBOB 2009/1:2022, among others (see the product data-focused A72 report by Chae and Kim 2022).

What can be expected in the background report by Soust-Verdaguer et al. (2023)?
1. It includes contributions from different Annex 72 countries participants, in relation to the national approaches to modelling transport and (de-)construction processes. The contributions were collected based on a structured survey and a systematic review of information included in existing product EPD.
2. Based on the survey, the main modelling options used in the different countries are identified and characterised into three main groups of options: generic, simplified, and detailed.
3. Recommendations are provided.

[35] The values provided for construction (A5) and deconstruction processes (C1) are 27.3 kg CO_2 eq/m^2 and 7.8 kg CO_2 eq/m^2 respectively. These represents the mean values in Finland, covering the consumption of energy and fuel on the worksite, with an added 20% to consider uncertainty.
[36] The average for building construction site emissions, in the absence of more specific information is 1400kgCO2e/£100k of project value.
[37] Swedish regulation requires that developers report the real case data in the climate declaration for as built conditions.

4.3.12 Modules A4-5 and C1-2: Conclusions and guidance

The obtained results contained within the A72 background report by Soust-Verdaguer et al. (2023), which includes a literature review and a survey within the Annex 72 countries participants, revealed a typology of the major possible options to model transport, construction and deconstruction processes and are summarized in the Table below (Table 4.22). The results also provide evidence that even though several methods do not currently consider these modules, there is a certain trend in newest methods to particularly include A4-5 in the minimum reporting, as together with A1-3 modules, they constitute the activities that can be controlled today.

Table 4.22: Summary of the broad range of possible options to deal with modelling of transport and (de-)construction processes.

Option	General definition of the modelling option	Modelling alternatives that can involve the modelling option
Option 0: Not modelled	No modelling of transport and/or (de-)construction process	– Not modelled due to missing data – Deliberately neglected because of their marginal importance
Option 1: Generic modelling	One or two generic values covering different building elements/components or building materials. Appropriate for: – When distances and means of transports are not relevant, the data is missing, or products stem from the same location. – Construction and deconstruction processes are not relevant, or the data is missing.	Consideration via default values
Option 2: Simplified modelling	Values for different building elements/components or building materials are grouped and modelled in a simplified way. Appropriate for: – When distances and means of transports can be grouped or simplified for similar products. – When the comparison of different materials and technical solution is relevant for the decision-making. – When construction and deconstruction process have similar characteristics for certain products.	Modelled at building level using different scenarios.
Option 3: Detailed modelling	Specific values for elements/components or building materials are used. Appropriate for: – When distances and means of transports are known / close to real scenario, for all the products and services. – When construction and deconstruction processes are known / close to real scenario, for all the products and services. – When transport scenarios in product-related EPDs are appropriate and consistent.	– Modelled in detail and on a case-by-case basis at the building level.

Moreover, to respond the questions raised earlier and propose possibilities to deal with them, it is important to highlight that beyond the questions themselves, which can be answered in different ways (as showed in the examples), the consideration and clear declaration of the aspects presented will increase transparency, prevent misunderstandings and undesirable mistakes.

It can be concluded that (at least at the moment) it is not possible to define one harmonized option to model transport, construction and deconstruction processes. It would be possible to define a range of options and provide some recommendations to define them, thus, two possible paths arise.

The FIRST one relates the definition of harmonized modelling options with the design phases, therefore, the generic and simplified modelling options can be applied in early design phases, and detailed modelling stages can be used at detail design phases, where detailed information about the building is already available. Especially requesting real-life data for as-built results provides incentives to consider reductions of transport and construction process modules (A4-5) in contrast to when using default values.

The SECOND path can relate the modelling of transport, construction and deconstruction processes with the element/component's representativeness in the building, and combines generic, simplified and detailed modelling options regarding their relevance in the building. Thus, detailed modelling options can be used for the main building materials/elements/components and generic and simplified for those that are less important (in terms of mass or costs). In this case, the accuracy of impact results of transport/ construction/ deconstruction can be proportional to the quantities of involved materials.

The following rules (Table 4.23) and recommendations (grey box) apply to both new building and refurbishment projects, and when necessary, a distinction between early and late design steps is made.

Table 4.23: Rules on how to deal with modelling transport, construction and deconstruction processes.

ISSUE(S)	RULE(S)
How to deal with transport related modules A4/C2, as well as construction process related modules A5/C1?	1. the scope of transport and construction activities covered by the method shall be clearly declared.
	2. In order to prevent misinterpretations when comparing variants with a high level of prefabrication with variants with assembling on the construction site, A1-5 shall be applied as part of minimum documentation requirements to cover all transports and processes at construction site and before.
	3. For early design stages generic or simplified modelling shall be allowed (see Option 1 and 2) and supported by providing default values and/or fixed assumptions to the users of the method. For late design stages detailed modelling shall be mandated for A4 at the minimum. There, a clear description on how to consider empty returns shall be included.
	4. The use of different data sources and databases can lead to different results; therefore, the method shall recommend specific allowable data sources or provide such values.
	5. If the inclusion of activities C1/C2 is mandated by a method for the sake of completeness, default values shall be provided per m^2 of building per kg of product (other units can also be used depending on the product). For far-future activities such as C1/C2 is unreasonable to mandate putting time and resources into calculating them even at late design stages. They are too uncertain.
	6. To increase transparency and provide a systematic approach for modelling complex processes A5-C1 specific guidelines for the data collection and data set shall be provided (e.g. list of activities and energy consumption per activity or building element).

Recommendations for action

Policy, regulation and law makers, developers / providers of sustainability assessment systems, national standardization bodies (application / use case: C, see Table 1.2)

a. include transport and construction processes (A4-5) in the minimum assessment scope and provide default values to compensate for possible lack of data and assist the method users during early design stages. These are activities to be controlled and verified today when new buildings are constructed, together with A1-3.
b. determine, publish, and periodically update LCA data for transport and construction processes.
c. determine, publish, and periodically update reference values for mean transport distances.
d. determine, publish, and periodically update LCA data for construction machinery, essential construction processes, the operation of the construction site equipment and typical construction site activities (e.g. pumping water, heating buildings).

Construction product manufacturers (application / use case: F, see Table 1.2)

e. In EPDs specify several variants for modules A4, A5, C1 and C2 or provide calculation rules for A4 and C2 (depending on transport distances and means of transport).

Researchers (application / use case: B, see Table 1.2)

f. Develop default values for modules A4-5 and C1-2 expressed per m^2 of building per kg of product (other units can also be used depending on the product).

4.3.13 How to deal with non-energy use- and non-water use-related environmental impacts occurring during building use (module B1): General

According to the standards (CEN TC 350 suite and ISO/TC 59/SC 17 suite) module B1 concerns the non-energy use- and non-water use-related environmental impacts connected with the building use. This might involve:

- fluorinated GHG emissions (the so-called F-gases, hydrofluorocarbons, HFC and others, (see gray box below) as a result of the use of refrigerants in various building-integrated technical systems[38]
- fluorinated GHG emissions as a result of the use of blowing agents in insulation materials
- emissions to air from painted surfaces, such as volatile Organic Compounds (VOCs).
- emissions to freshwater bodies from metal façades and roofs, such as copper ions.
- for concrete structures the effect of natural carbonation (i.e. CO_2 absorption when concrete surfaces are exposed to air) during the use stage.

Any further emissions to local environment like emissions to soil, water and outdoor air (see Table 4.33 in Section 4.4) if occurred during use, can also be assigned to this module.

Therefore, B1 is specifically relevant for materials or products emitting or binding GHGs and other pollutants in the use stage and such information can be available in EPDs and databases. However, to make such information transferrable to the building level scenarios shall define the internal and external conditions of use of the product. So far practice in academia and in industry is limited in terms of including B1 in building LCAs (see A72 background report by Balouktsi and Lützkendorf (2023b)) although especially F-gasses are detrimental to the climate. It is important to note that in general non-energy related GHG emissions can also be released during the manufacturing processes of some particular materials (e.g. calcination of concrete) but these are not addressed here as they are assigned to modules A1-A5 or B4. Some topic-specific terms are given below (gray box), as well as the importance of this type of emissions is explained in the following.

[38] In standardization there are currently discussions to allocate emissions of F-gases associated with technical systems to module B6 as they are related to building operation.

Key topic-specific definitions

F-gases: Synonym of fluorinated GHGs. Collective term for partially fluorinated hydrocarbons or hydrofluorocarbons (HFCs), perfluorinated hydrocarbons or perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The GWP values of these gases range from 4-12.400 (HFCs), 6.600-11.100 (PFCs), 23.500 (SF_6) and 16.100 (NF_3) according to IPCC AR5.

CFCs: Chlorofluorocarbons were used to make foams for furniture and buildings as well as in refrigerators but have been banned since the 1990s in the developed countries and 2010 in developing countries under the Montreal Protocol due to their ozone-depleting effect. Therefore, it is not allowed to use CFCs for new systems or insulation products.

HCFCs: Hydrochlorofluorocarbons were created to replace CFCs in refrigeration, air-conditioning and foam applications. They have a lower impact on ozone depletion, but they have a very high GWP. However, they were also banned under the Montreal Protocol because of the remaining impact on the ozone layer. In developed countries they have already been phased out (i.e. not used anymore for new systems and products), while their complete phase-out is expected for 2030 in developing countries (United Nations Environment Program, 2019).

HFCs: Hydrofluorocarbons, are predominantly used as refrigerants, though they can also be used as foaming agents. They have been used as substitutes for CFCs and HCFCs since they do not jeopardise the ozone layer. However, they generally still have a high GWP and thus will be phased out globally over time as a commitment to Kigali amendment to the Montreal Protocol. Two concrete initiatives towards achieving the Kigali goal are the Kigali Cooling Efficiency Programme[39] and the IEA Annex 54 of the Heat Pumping Technology Collaboration Programme[40].

HFO: Hydrofluoro-olefins constitute the fourth generation of fluorine-based gases. They are categorised as having zero ODP and low GWP and so offer a more environmentally friendly alternative to CFCs, HCFCs and HFCs. Several new HFO blends with lower GWP are listed in the European F-Gas Regulation.

Natural refrigerants: Natural refrigerants such as CO_2, ammonia, water and hydrocarbons (i.e. propane, isobutane and propylene) have substantially lower or zero GWPs and zero ODP but may have other health and safety implications. There is increasing interest and development going into heat pumps using CO_2 as a refrigerant with a GWP of 1 kg CO_2 eq/kg.

Volatile Organic Compounds (VOC): They are a large group of carbon-based chemicals that easily evaporate at room temperature. Some VOCs are dangerous to human health or cause harm to the environment. The most frequently monitored indoor VOCs coming from building materials are BTEX (benzene, toluene, ethylbenzene and xylenes), terpenes (α-pinene and d-limonene) and aldehydes (formaldehyde, acetaldehyde and benzaldehyde) (Harčárová et al., 2020).

Fluorinated GHG emissions from refrigerants in HVAC systems and heat pumps. The problem with building-integrated units using refrigerants is that they lose a percentage of them during operation over their useful life through leaks, as well as during deconstruction. Causes may be weakened joints over time due to on-going pressure in the system or damaged joints due to poor frost protection, vibrations (e.g. due to non-well-isolated or balanced fan or compressor transmitting vibration into the pipework), and corrosion of the copper pipework over time, among others. Therefore, to calculate the quantity of halocarbons released into the atmosphere, assumptions or data on the annual leakage rate and the recovery rate at EoL are needed (in addition to the mass of the refrigerant and its lifetime). Depending on the type of product and the care

[39] See: https://www.unep.org/ozonaction/kigali-cooling-efficiency-programme
[40] See: https://heatpumpingtechnologies.org/annex54/

taken during its installation and maintenance, representative annual leakage rates are in the order of 1-10%, while for the EoL the best scenarios assume 100% recovery and the more pessimistic ones assume 85% recovery for split systems (Hamot et al., 2020). The general leakage scenarios proposed by CIBSE (2021) to be used as a default are shown in Table 4.24. Although the leak rate values do not change much from country to country, the recovery rates provided by CIBSE are more representative of the UK market; other countries have much lower recovery rates (e.g. see values from Germany in Table 4.25).

The climate gases currently commercially available and used in HVAC systems and heat pumps in different areas around the world are shown in Table 4.26. The most relevant standards dealing with refrigerants and their characteristics are ISO 5149 (2014)[41], ISO 817 (2014)[42], EN 378 (2016)[43], and the ANSI/ASHRAE Standards 34, 15 and 147 (2019). Currently, a step-by step HFC-phase down is organised in developed and developing countries which have committed in 2019 under Kigali Amendment to the Montreal Protocol to progressively decrease HFC consumption so that their consumption level by 2036 will be 15% of 2019 level. This means that in the medium- and long-term future all new systems will be using natural refrigerants or other low GWP alternatives. For the short-term, this gradual ban of HFC refrigerants of different speeds in different countries means that HFC products of high GWP may continue to be used in new installations over the next few years.

Table 4.24: Refrigerant leakage scenarios proposed by CIBSE (2021).

Product	Annual leak rate to be used in B1 (use)	EoL recovery rate to be used in C1 (deconstruction)
Package heat pump or chiller, where no refrigerant is managed on site (type 1)	2%	99%
Heat pump or chiller where some works to refrigerant pipework are carried out on site (type 2)	4%	98%
VRF systems where a large amount of refrigerant pipework is installed and filled on site (type 3)	6%	97%

Table 4.25: Refrigerant leakage and recovery rate of selected cooling and heat pump systems provided by the Federal Environment Agency of Germany (2021).

Product	Annual leak rate	EoL recovery rate
Mono split air conditioning	5%	61,5%
Multi split air-conditioning	4,6%	79%
VRF system	5,3%	79%
Heat pumps	2,5%	71,5

[41] ISO 5149 (2014) Refrigeration and Systems and Heat Pumps- Safety and Environmental Requirements which comprise three parts, Part 1 (Definitions, classification and selection criteria), Part 2 (Design, construction, testing, marking and documentation) and Part 3 (Installation site)
[42] It deals with “Refrigerants- Designation and Safety Classification”.
[43] It deals with “Refrigerating Systems and heat pumps – Safety and environmental requirements”

Table 4.26: Information on refrigerants used in building-integrated systems. Note: the list is not exhaustive. ODP = 0 for all products listed here. (Source: Hamot et al., 2020). In general, the ranking of refrigerants by GWP follows the order: CFC>>HCFC>>HFC>>HFO >HC/Natural.

Product	GWP	Heat pumps	HVACs	Comment
HFC - R410a	2088	X	X	Very widely available. Mostly found in VRF system and systems with scroll compressor. Its step-by-step phase down is now considered and regulated in several countries due to its high GWP[44].
HFC - R407c	1744	X	X	Widely available. Mostly found in chiller installations and some heat pumps. Also subject to a step-by-step phase down.
HFC – R134a	1430	X	X	Widely available. Mostly applied in large chillers and heat pumps with screw or centrifugal compressors. Also subject to a step-by-step phase down.
HFC - R32	675	X	X	Commonly used in Japan, and more and more in Europe. Mostly found in higher pressure systems.
HFO - R513a (XP10)	631		X	Relatively new to market but appears to be widely distributed. Mostly found in chillers
HFO - R1234ze	6		X	Manufactured by several companies. Suitable for low pressure HVAC systems
HFO – R1234yf	4		X	Manufactured by several companies. Suitable for low pressure HVAC systems
PROPANE - R290	3	X	X	Available, but not very common in the US so far.
CO_2 - R744	1	X	X	Manufactured by several companies.

As shown in the case study example in Figure 4.14 the continuation of the practice as usual may lead to GHG emissions from refrigerant leakage making up one third of direct emissions occurring during operation. Therefore, these emissions need to be understood and drastically reduced. Furthermore, given the increasing demand for air conditioning worldwide due to improved socio-economic conditions in many countries coupled with a decreasing cost of equipment, as well as due to climate change causing rising temperatures among others the effect of these gases will intensify. Concurrently, the decarbonization of electricity grids drives further the application of electric heating systems such as heat pumps (HP) over traditional fossil fuel-powered systems. Against this background, CIBSE (2021) recommends that calculations of the annually leaked refrigerants under B1 (as well as the disposal-related leakage under C1) should be mandatory even for the most basic assessments. Alternatively, in some methods, the importance of this type of emissions is expressed by the inclusion of a separate criterion/indicator, but without being assigned to any specific module (e.g. DGNB, the indicator “Halogenated hydrocarbons in refrigerants”, rewarding the implementation of cooling without halogenated/partially halogenated refrigerants).

[44] See the Aim Act in the US and the F-Gas Regulation (EC) No. 517/2014 in Europe

Figure 4.14: Whole life carbon emissions over 30 years of a US low energy office building (2,000 m^2) using a VRF system. Depending on the refrigerant used, its leakage rate and recovery at end of life, refrigerant can have a different impact on global warming. (Source: Hamot et al., 2020).

Fluorinated GHG emissions from blowing agents in insulation materials: HFCs are also found in blowing agents used in the manufacturing of spray foam roof adhesive and insulation products such as extruded Polystyrene (XPS) and Spray Polyurethane Foam (SPF). These HFCs are released into the atmosphere during the lifetime of the product, and, depending upon the type, sometimes almost completely in two decades or more. They are mainly released during the use phase of the building's lifecycle. The use of F-gases as an expanding agent in polyurethane foam has been banned in the EU since 2008, and by 2005, 85 % of production had already been shifted to hydrocarbons (having a much lower GWP) (IPCC, 2014). Similar actions have also been taken more recently also in other parts of the world such as Canada and several U.S. states which adopted new environmental regulations on January 2021 to eliminate the use of blowing agents with a GWP higher than 150[45]. HFCs and in some cases also HCFCs are still used in some Asian countries but they are also in the process of being phased out. Furthermore, in these countries, it is expected that demand for use in insulation materials will grow in the future. Existing life cycle carbon or embodied carbon analyses for buildings tends to miss or ignore the GHG emissions from use phase of insulation materials, which contain XPS or SPF. However, if considered, the emissions of these insulation materials would be much larger due to emission from use phase.

VOC emissions from paints: Some construction building materials such as paints are major contributors to indoor emissions of volatile organic compounds (VOCs) that have the potential to deteriorate indoor air quality and increase people's risk to health problems. Additionally, some VOCs can contribute to the formation of photochemical ozone under sun exposure. Some studies dealing with this topic are by Cheng et al. (2015), Klinger and Savi (2016) and Burkhardt et al. (2020).

CO_2-binding by natural carbonation of cementious and lime-based products: This topic is discussed in Section 4.3.6. In general, recent research has shown that carbonation of cement seems to play a minor role at the building level (Resch et al. 2020; Alig et al. 2020). Other studies find that carbonation can be important (about 75% of the CO_2 released during the calcination of concrete) if assumed that crushed concrete is exposed to air for over four months before being used as a ground filling material (Piccardo and Gustavsson 2021). In any case, if reported, the carbonation effect is usually allocated to modules B1 and C3-4. In Europe, an approach for a rough estimation is described in the standard EN 16757. However, no specification is provided in this standard in relation to the time of carbonation to be assumed at the EoL, which is what defines the level of overall importance of this effect.

[45] See: https://www.aia.org/articles/6397732-what-aec-pros-should-know-about-new-enviro

4.3.14 Module B1: Conclusions and guidance

At the moment, the life cycle emissions of a building affected by fluorocarbon gas, either used as a refrigerant in various building-integrated systems or as blowing agents in insulation materials, may be considerable, although their phase down and replacement with low-GWP alternatives is already regulated to change in the short-term. From a methodological point of view, the currently updated European standards consider these emissions as embodied and assign them under module B1. Further types of emissions considered in B1 are the indoor emissions from different types of materials, as well as the effects of natural carbonation of cementious products. In the past, what should be reported under B1 was more unclear and therefore the way these gasses are considered in national methods differs. The following needs are derived from this:

– For methods: the specification of relevance/significance of such emissions in relation to whole life cycle emissions and their inclusion in net zero GHG emission balances, as well as whether these emissions are assigned to the embodied or operational part (however, this is irrelevant for a life cycle-based net zero balance).
– Data: information on construction products and systems must contain (scenario dependent) information on the substances used and the rates of their release

The following rules (Table 4.27) and recommendations (grey box) apply to both new building projects and refurbishment projects, and when necessary, a distinction between early and late design stages is made.

Table 4.27: Rules on how to deal with non-energy and non-water-related emissions occurring during building use

ISSUE(S)	RULE(S)
How to deal with F-gasses, HFC emissions and VOCs released from specific types of products during building's use?	1. Any substantial amount of GHG-emissions arising from refrigerants, insulation blowing agents and paints (among others) over the life cycle of the building shall be accounted for.
	2. Refrigerants with low GWP (i.e. <150 kg CO_2 eq/kg) and acceptable refrigerant leakage rates shall be specified in the method.
	3. Default scenarios shall be specified in relation to refrigerant leakage of different types of equipment (such as Tables 4.22-23) to allow the calculation in early design stages in the absence of specific data. In late detailed design, data on refrigerant leakage thresholds shall be provided by the Mechanical, Electrical and Plumbing (MEP) consultant in accordance with relevant regulations. Data from EPDs, other type of manufacturers' declarations and other relevant specialist documentation can be used.
How to deal with carbonation process?	4. If natural carbonation of cement products is considered, the calculation method and assumptions, as well as the allocation of the effects to the different modules shall be clearly stated. The method shall consider all relevant aspects that influence the level or carbonation. If excluded, reasons for this decision shall be specified. 5. If natural carbonation of cement products is considered, it shall be reported separately (e.g. from the other B1 results).

Recommendations for action

Policy, regulation and law makers (application / use case: C, see Table 1.2)

a. Prohibit the use of climate-damaging refrigerants in building equipment.
b. Restrict and prohibit the use of climate-damaging blowing agents for insulating materials.
c. Establish a database of recommended hydrofluorocarbon-free cooling equipment. An international example is: https://cooltechnologies.org/

National standardization bodies (application / use case: C, see Table 1.2)

d. Publish standards for environmentally/ climate-friendly refrigerants.
e. Name and list halocarbon emissions that are harmful to the climate

Developers / providers of sustainability assessment systems,

f. Check the refrigerants used in the assessment system and appropriately consider them.
g. When insulating materials are used, check and assess whether they are produced with blowing agents that are harmful to the climate.

Construction product manufacturers (application / use case: F, see Table 1.2)

h. Provide detailed assumptions and scenarios for B1 data

Designers (use case D, see Table 1.2)

i. Be aware of the environmental impacts associated with refrigerant use and particular types of paint

4.3.15 How to deal with maintenance and repair tasks (modules B2 and B3): General

Buildings have a long lifespan. Their technical and functional performance must therefore be maintained, restored or adapted and/or improved over the technical service life or economic useful life. In the life cycle model of buildings standardized in international and European standards the modules for this are maintenance (module B2), repair (module B3), replacement (module B4) and refurbishment (B5). These modules serve to cover the impacts related to the full spectrum of possible activities necessary to maintain and/or improve of the technical and functional performance of building components and/or the whole building during a building's life cycle; from a small maintenance activity to a larger refurbishment.

However, in theory and practice, it is not always easy to clearly distinguish between these activities or the corresponding modules, which allows for many different interpretations in LCA studies and methods from different countries. Particularly difficult is to determine whether an activity should be considered as maintenance (B2), repair (B3), or replacement (B4). These are mainly activities at construction product, technical system and/or building component level. Planned refurbishment (B5) is mostly related to the building component and/or building level (see Section 4.3.19). As the distinction between B2-4 is not straightforward, the following principles can be applied:

– **Maintenance** should encompass all planned actions related to maintaining the usability or the technical/functional performance of a product or building part/component, such as planned periodic maintenance and cleaning operations. Maintenance should be understood as the set of context-related operations performed under normal conditions (e.g. a product could have different maintenance requirements in different climates).
– **Repair** should encompass product modification and activities caused by accidents, improper installation or handling, unforeseeable events, etc. and therefore related to restoring the usability or technical/functional performance of a product. This includes, for example, corrective maintenance such as the replacement of a broken component or part due to damage (e.g. a broken windowpane). Repair module may also apply to complex product systems consisting of components, whose service life is shorter than the overall product system.

– **Replacement** should encompass the activities related to replacing an entire product due to damage or at the end of its service life.

Example of differences: Replacing the ventilation engine of a ventilation machine due to failure instead of replacing the entire machine (module B4) is considered as repair (module B3). However, replacing the engine is not part of general maintenance (module B2) in the way that replacing the filter would be.

It becomes clear that a distinction must be made between
– Maintenance of building components and technical systems (cleaning, maintenance, replacement of auxiliary materials such as oil, filters, ...)
– Repair of building components and technical systems by exchange of product components
– Replacement of building components and technical systems by exchange with product, component or system of equal characteristics

To include these modules in an assessment, in addition to define the types of activities included in each individual module, one also needs to define the quantity of materials and products needed to perform each activity as well as the periodicity of each activity – i.e. maintenance, repair and replacement cycles per type of material and/or product.

Current status of methods: B4 is a significant module and is already considered by almost all methods according to an A72 survey (Balouktsi & Lützkendorf, 2023b), therefore issues related to it are dealt with in an individual section (see 4.3.17). B4 should also be dealt with separately in the future to enable a parallel approach to life cycle costing (LCC). There replacement cost is strictly separated from maintenance cost.

On the other hand, B2 and B3 are typically considered unimportant in most of the cases in LCA, but not in LCC. A significant number of methods includes B2 (maintenance), but the boundaries of what activities are part of it differ among them: some methods by B2 strictly refer to cleaning processes of the interior and exterior of the building and report this module only for a limited number of indicators, others additionally include activities such as masonry repainting, coatings reapplications and equipment maintenance. Maintenance scenarios can be drawn from several studies (e.g. Hershfield 2002; BRANZ 2013), if these do not form part of product EPDs themselves[46]. In any case, to define realistic maintenance scenarios one needs to know the finishes, furnishing and equipment installed in a building and these elements should be in general part of the assessment scope (see Section 4.1.6 discussing the “physical building scope”).

On the other hand, the majority of methods do not consider B3 (repair). Repair (module B3) includes repair of damaged products or building components in order to restore them to their expected performance level (e g windowpane replacement in a broken window). This is easily confused with maintenance in module B2 and is very difficult to draw up realistic scenarios for as this involves tricky predictions. In general, including repair (B3) would require construction damage statistics of an adequate detail so as a calculation method to be considered robust (Boverket 2020). In most countries detailed damage statistics are currently not available. This means that, at the moment, the calculations for this module are not robust enough to justify its inclusion in official voluntary or regulatory frameworks. Indeed, A72 survey showed that most methods considering B3 are of an academic nature. In summary, national assessment methods primarily follow one of the four approaches for repair (B3):
– **Approach 0**: B3 is excluded for lack of clarity in the standards. Example: in the currently drafted Swedish law for the Climate Declaration of buildings only B2 and B4 will be included in 2027 after being specified in greater detail in the related Swedish standard (Boverket 2020);
– **Approach 1**: is seen as part of / or in combination with maintenance (B2) – therefore, B2-3 are summarized. Example: Dutch method GWW (SBK 2014);

[46] Products usually come with special «maintenance and care instructions». “Maintenance contracts” are often attached.

– **Approach 2**: is seen as part of / or in combination with replacement (B4) – therefore, B3-4 are summarized. Example: Finnish method (Kuittinen et al. 2020);
– **Approach 3**: if cannot be based on EPDs or any other data, it is assumed as equivalent to a certain per cent of B2 or B4 or A+C impacts. Example 1: B3 = B2*25% in RICS method if no data is available (2019); Example 2: B3 = B4*10% in the assessment method applied by the Budapest University of Technology and Economics if no data is available; Example 3: B3 = (A+C)*10% for technical equipment in CIBSE guideline on embodied carbon calculation (2021).

Various ways of handling the use stage modules are currently discussed in the revision of the European standards - see Figure 4.15. The draft European standard prEN 15978-1:2021 offers the possibility to summarize the modules B2 and B3 in the presentation of assessment results, but to keep the basic structure.

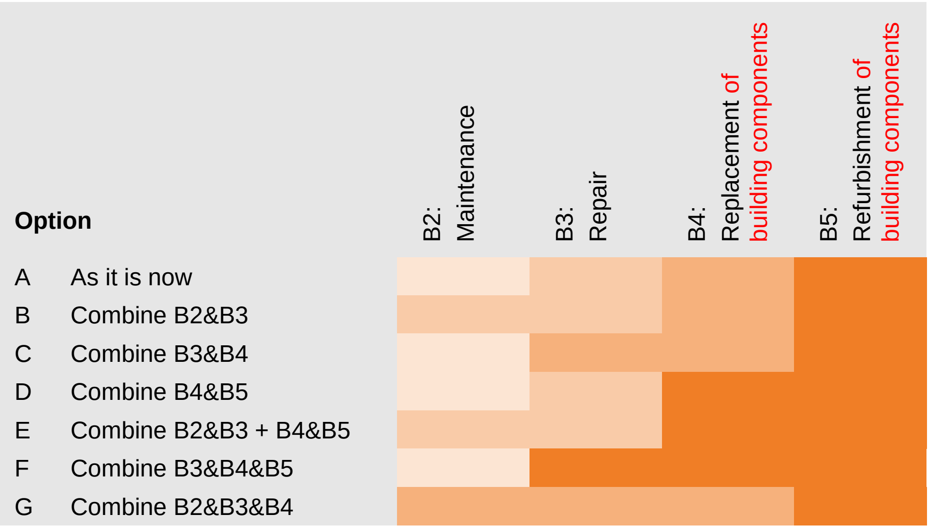


Figure 4.15: Different options currently discussed in standardisation process in CEN TC 350. The trend is towards Option B.

4.3.16 Modules B2-3: Conclusions and guidance

Dealing with B2, B3 and B4 in environmental performance assessment should be based on the same procedure followed for economic performance assessment, and therefore be aligned with the structure of LCC. It is desirable that life cycle models for economic and environmental considerations largely agree. Annex 72 advocates **approach 1** (option B in Figure 4.14), therefore, to summarise B2-3 and always keep B4 separate, if B2-3 impacts are included at all. Therefore, rules and recommendations for B2/B3 modules are summarized in this section. In any case, in future, this information needs to be provided by the construction product manufacturer in the EPD. The following rules and recommendations for action are aimed at supporting the establishment of a common national basis for the treatment of maintenance and repair tasks in building LCAs (Table 4.28 and gray box below).

Table 4.28: Rules on how to deal with maintenance and repair tasks

ISSUE(S)	RULE(S)
How to model small maintenance activities?	1. Whether and how maintenance and repair are dealt with in the method shall be clearly shown.
	2. Clear descriptions of, and distinctions between, modules B2, B3 and B4 shall be provided, if B2/B3 are included in the prescribed assessment scope. The use of real examples of activities and their categorisation under these 3 modules would help.
	3. B2 shall always be included in an assessment scope, if external and internal finishes, as well fittings are also part of the assessment scope. If not, B2 can be considered as irrelevant.

4. Clear and well-justified maintenance scenarios per material/product type (i.e. information on type, quantity and frequency of maintenance) shall be provided based on literature, in case B2/B3 information is not provided by product manufacturers.

Recommendations for action

Policy, regulation and law makers (application / use case: C, see Table 1.2)

a. Give the appropriate political importance to the issue of systematic maintenance of buildings. Maintenance is necessary to extend the useful life of buildings and therefore to conserve resources and avoid environmental impacts that are caused by undertaking major refurbishments of buildings in bad condition or replacing them with new ones.

National standardisation bodies (application / use case: C, see Table 1.2)

b. regulate the type, scope and cycle of maintenance work per building product type.

Developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

c. allow a summary of B2/B3 in the presentation of the results.

Researchers (application / use case: B, see Table 1.2)

d. develop and publish default values for maintenance per product type (impact/m^2 or impact/item)

Construction product manufacturers (application / use case: F, see Table 1.2)

e. provide information on maintenance, cleaning, and repair (type of activity, material use, cycle) under different conditions.

4.3.17 How to model replacements of building components, construction products and/or technical systems during a building's life cycle (module B4): General

The impact of replacement of a building component/ construction product/ technical system equals the impacts associated with its production, construction and end of life processes (i.e. B4 = A1-A5 + C1-C4). Any recycling/reuse/recovery potential resulting from B4 processes is reported in module D (D1 in Europe) together with the "potentials" of elements not needing any replacement during a building's life cycle. What is important for the modelling of B4 is the definition of the replacement cycles of building elements. To do so data on the service lives are needed. At the same time, Module B4 can become the subject of time-dependent considerations such as the technological development in relation to production and recycling processes, as well as transport processes - see Section 4.3.4. It important to highlight that what distinguishes planned replacements (B4) from a planned refurbishment (B5) is that, in the present authors' interpretation, B4 only corresponds to replacements of like-for-like materials, building components and technical systems.; a planned exchange for higher-quality products and systems is assigned to B5 (discussed in Section 4.3.19). B4 can only be modelled on the basis of information on components' service life.

Variations in service life values: The definition of service lives values is a context specific problem. Multiple studies, as stated in (Silvestre et al. 2015), have identified the deterministic (Factor Method as defined in ISO 15686-1, ISO 15686-2 and ISO 15686-8 standards), the probabilistic and the engineering method (combination of the previous two), as possible ways to determine and predict the service life. In practice, the service life constitutes a quite complex material parameter, which is affected by a variety of different factors, not necessarily technical. Even the effects of climate change can be considered in its prediction (Loli et al., 2020). Variability exists within a country (different sources available) but also between the countries (different construction technologies, practices, reasons to replace an element). As different definitions and contexts of use are identified in the literature (see A72 background report by Lasvaux et al. (2023)), it is interesting to separate the service life data according to their context of use. As an illustration, Figure 4.16 shows the descriptive statistics for the same building elements, using all the data gathered in the DUREE database during the Swiss DUREE project (Goulouti et al., 2020a). The sample was separated in three source types, i.e. service lives used for LCA calculations[47], the ones used for LCC and the other ones used by building owners among others (called “management”). In the next result, the Annex 72 data are filling the different samples (mostly the LCA one and sometimes the LCC one if the service lives are also used for LCC calculations).

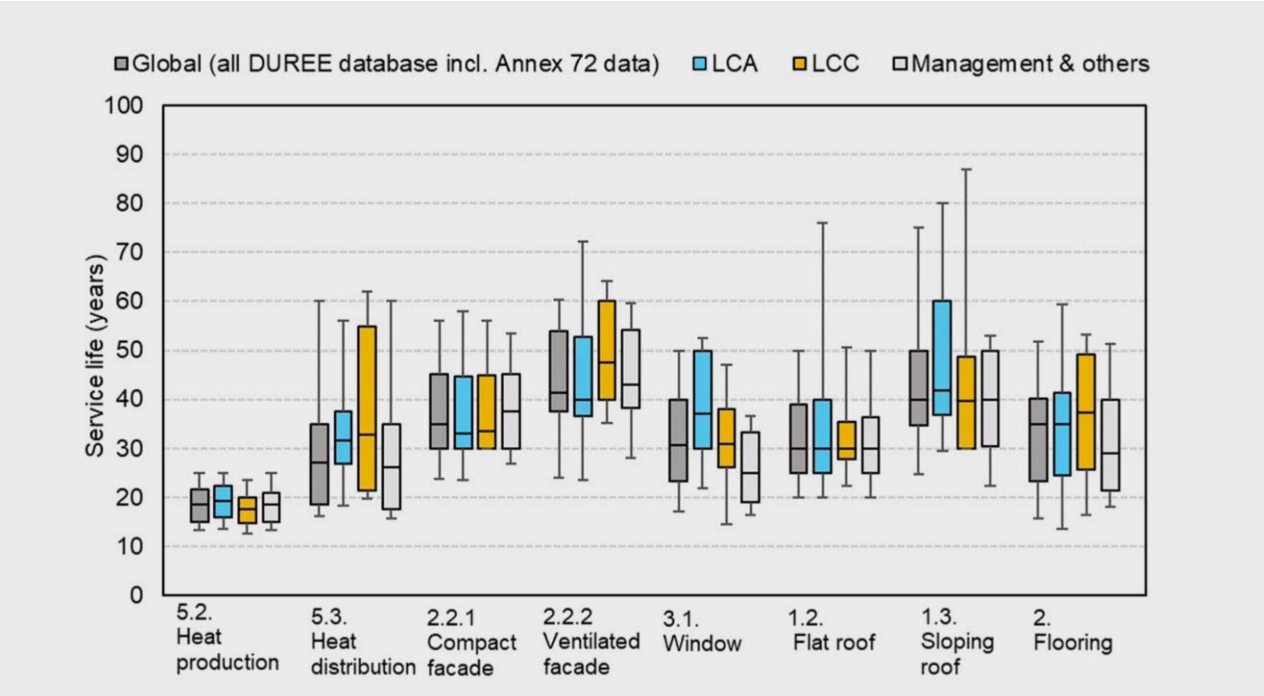


Figure 4.16: Example of reported values in the literature used for different purposes (LCA calculations, LCC calculations and other sources like professional building owners) (Source: A72 background report by Lasvaux et al. (2023)).

The results confirm the inherent variability in the collected values. A substantial spread of service lives’ can be observed for the eight building elements while it is possible to rank the elements by median service lives values from the heat producer with about 15-20 years to the ventilated façade with about (45-50 years). Median SL values for the other elements fall in-between. It can be concluded that there is no source type that presents systematically lower or higher service life data. However, the overlap of intervals in the figure show that the data considered in LCA, LCC and other are comparable. More information can be retrieved from the DUREE report (Lasvaux et al., 2019).

Structures have been studied by (Palacios et al., 2019): applying degradation models of reinforced concrete structures, the life span of for instance an external beam is higher than 200 years in new constructions. In this case, the expected service life is longer than the RSP. For estimated average values for the service life of components, the statement "greater than the reference study period" is then sufficient.

How the wide ranges in service lives translate into the final LCA result? With the use of Global Sensitivity Analysis and on the basis of three case studies, Goulouti et al. (2020b) concluded that six building elements (out of the sixteen examined) are the most influential on the LCA uncertainty. These are the compact façade, windows, sloping roof, flooring, wall covering and ceiling (see also Lasvaux et al. (2022) for a similar analysis). This means that special attention should be given when defining the service lives for these building elements in further LCA calculations. Goulouti et al. (2020b) also concluded that this result is valid, independently of the building typology, as the latter only affects the ranking of the six most influential building elements.

[47] And energy calculations

Replacement rate calculation: Currently there are mainly two different approaches on how to deal with replacements in the life cycle inventory of a building:

- **Approach A**: Annualised impacts per building element;
- **Approach R**: Rounded up number of replacements of building elements.
- **Approach S**: Simulation of the building life cycle[48]

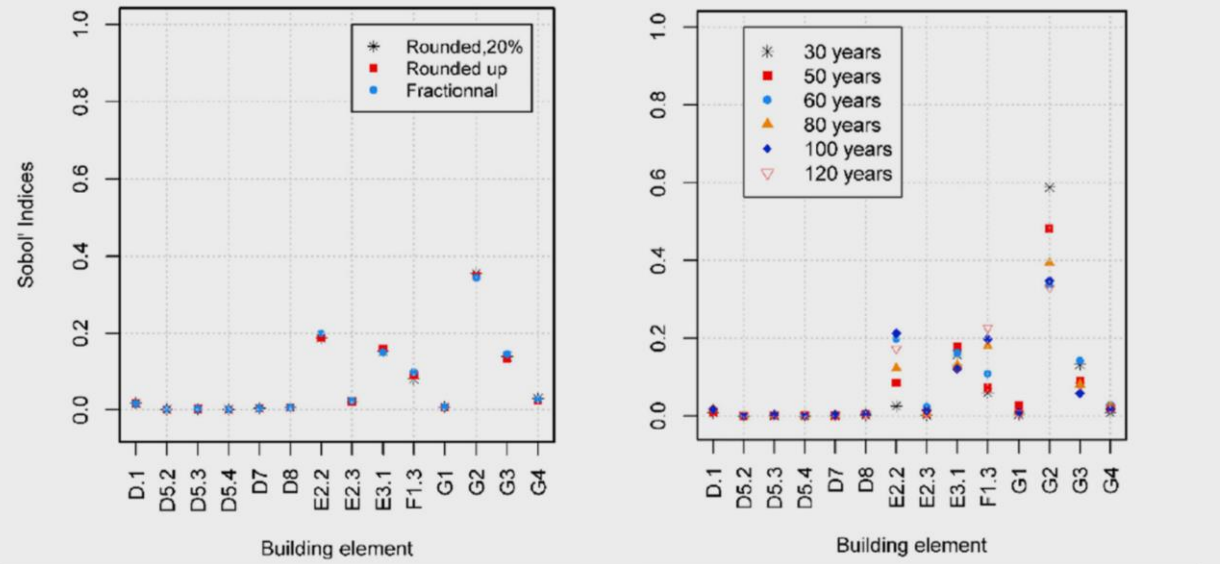
Approach A, Annualised impacts per building element – The annualised environmental impacts of a building element are calculated taking into account the service life (or the reference service life (RSL) or the adjusted expected service life) of the element. First, the environmental impacts of manufacturing a particular building element (e.g. a window) are determined. Secondly, the environmental impacts are divided by the reference service life (RSL) of this building element (e.g. 30 years). These two steps are repeated for all the building elements, which compose the building under assessment. Finally, all resulting values, per year, are added up, a sum which corresponds to the annual environmental impacts of the building under consideration. This approach is applied in Switzerland in the technical bulletins SIA 2032 (SIA 2020) and SIA 2040 (SIA 2017), in which the distinction between initial efforts and efforts due to replacements are of little interest and the residual values are simply neglected.

Approach R1, Rounded up number of replacements – First, the number of replacements of a particular building element (e.g. a window) is determined by dividing the reference service life (reference study period) of the building (e.g. 60 years) by its reference service life time (e.g. 30 years) minus 1. In this example, the windows will be replaced only once during the service life of the building. In case that the RSP of the building is 50 years, the exact number of replacements would be 0.67. Since fractional replacements are not possible, these values are rounded up to the next integral number (in the example: 1). Secondly, the environmental impacts of manufacturing a particular building element (e.g. a window) are determined. Thirdly, the environmental impacts of manufacturing all building elements of a building are added up to get the environmental impacts of the product stage (Modules A1-A3). Fourthly, the environmental impacts of manufacturing all building elements of a building are multiplied by the number of replacements and then added up to get the environmental impacts of replacements during the use stage (Module B4). Fifthly, the total environmental impacts of the product and the use stage are divided by the RSP of the building under assessment. This approach is required by the CEN standard on the assessment of the environmental performance of buildings.

Approach R2, rounded up number of replacements with a certain condition – This approach distinguishes the obtained values for the calculated number of replacements depending on a threshold. If the replacement rate is higher than a percentage (e.g., 20%) of its integer value it is rounded up, otherwise it is rounded down[49]. Like that, overestimation of the replacement rate can be avoided, in case is the number of replacements is very small, e.g. 1.05 times. Practically, this means that if the end of life of a building element is close to the end of the building RSP, this is no replacement.

However, even if Approach R1 and R2 reflect better the reality of the replacement rate, the use of the fractional one presents a negligible influence on the building LCA results, especially compared to the choice of the RSP value (see the consequences of this aspect in Figure 4.17). More details are given in the A72 background report by Lasvaux et al. (2023). This conclusion is also in line with older investigations in literature (Werner & Frischknecht, 2018). The question of which approach to use to calculate the replacement rate can be more relevant for the building component level but more investigations are necessary (Francart & Malmqvist, 2020).

[48] currently only in the case of research projects
[49] Such calculation rule is currently implemented in existing building LCA tools



Name of element types			
D1. Electrical installations	D5.4 Heat emission	E2.3 Ventilated façade (insulation & cladding)	G1. Internal partitions
D5.2 Heat production	D7. Ventilation	E3.1 Windows	G2. Flooring
D5.2 Solar collector	D8. Sanitary installations	F1.2 Flat roof	G3. Wall coverings
D5.3 Heat distribution	E2.2 Compact façade (external insulation & rendering)	F1.3 Sloping roof	G4. Ceiling coverings

Figure 4.17: Sobol' Indices for the three aforementioned types of replacement rate, as well as for different RSPs ranging from 30 to 120 years for the indicator GHG emissions (Goulouti et al., 2020b). Note: The order of the building elements with the highest impact on the LCA uncertainty remain the same in the left graph, while this order changes in the right graph, but the top six elements in terms of influence remain consistent.

Approach R3, component-specific rounded up – The analysis of the aging process of real buildings shows that the replacement rate in the case of components is often overestimated[50]. Most of building components often turn out to be more robust than expected, or the building owners are more tolerant of an aged state. An approach can be that for such building components, the calculated number of replacements is always rounded down and no replacement is assumed in the last 5-10 years of the life cycle model. However, the situation is different with technical equipment that is critical for safety and efficient operation. In these cases, since a planned replacement must always be carried out, and often is mandatory, the number of replacements can be rounded up. This leads to a component-differentiated approach which so far is not seen applied in any of the national methods, tools, but is presented as a possibility in the draft of upcoming EN 15978.

Approach S: Simulation of the building life cycle – A simulation process accounts for environmental impacts using a one-year time step[51]. Each building element has an age counter, incremented each year. When the age reaches the life span, impacts corresponding to the replacement processes are added. Replacement is not considered anymore after 90% of the building life span.

Levels of details for fixing the service live of a building element: The service life of a building element can be defined at different levels of details. However, as a building element gather different components with different functions, it is not appropriate to define a single service life for a multi-layered element. The service life is thus defined for each component (or layer). If more product-specific data are available, the service life can also be defined even further for specific product using the information of reference service life (RSL) in

[50] See: Ritter, F. (2011). Lebensdauer von Bauteilen und Bauelementen-Modellierung und praxisnahe Prognose (Vol. 22). TU Darmstadt.
[51] E.g. Pleiades ACV EQUER, see Polster, B., Peuportier, B., Blanc Sommereux, I., Diaz Pedregal, P., Gobin C. and Durand, E. Evaluation of the environmental quality of buildings - a step towards a more environmentally conscious design, Solar Energy vol. 57 n°3, pp 219-230, 1996

the Environmental Product Declaration (EPD). Indeed, the definition of the service life in practice will be a function of two “limiting” criteria:

– First, representative renovation practices[52] should be considered in order to avoid misleading service lives definition. For example, in practice, if the rendering and the external insulation are replaced at the same time, the two components should not be distinguished in the view of their service lives even if literature sources provide a service life for the rendering and the insulation. The same problem exists with the windows (glazing and framing). They are generally replaced as a single component and thus define different service lives does not correspond to reality.
– Second, possible lack of service lives data for very specific elements or for innovative products may not allow attributing service lives in a higher level of detail.

What can be expected in the background report by Lasvaux et al. (2023)?

1. Discussion on service lives definitions and values of building elements and their related uncertainties and variabilities based on values found in literature as well as default values used in A72 countries (data collected based on a survey among A72 experts).
2. Illustration of consequences/ influence on the result of the variability of service life values of building components, the replacement rate calculation method and the reference study period on the basis of case studies
3. Provision of recommendations

4.3.18 Module B4: Conclusions and guidance

Module B4 makes a significant contribution to the results of a building LCA. Components and systems that are either replaced very frequently or cause high environmental impacts (initially and when replaced) are important. For the modelling of B4, there are different methodological questions for which methods need to provide answers. First, the definition of the service lives for different types of building elements is unavoidable. Special attention should be given to building elements whose uncertainty may have an important impact on the final LCA result. Second, there are several approaches to calculate the replacement rate based on components’ service lives. Third, a matter of question is at what level of detail the service life of a component comprised of several layers of varied service lives must be fixed. Rules and recommendations for action are provided below to support the handling of such calculations in building LCAs (Table 4.29 and gray box below).

Table 4.29: Rules on how to model replacements

ISSUE(S)	RULE(S)	
How to deal with the uncertainty of building elements’ service lives?	1.	Default values for the service lives of all possible construction products and technical equipment shall be provided
	2.	For fixing the default values for the most influential service lives of building elements on the total LCA result, uncertainties shall be handled, robustness of results shall be checked (through ranges)
How to calculate the replacement rate of building elements?	3.	It shall be clearly stated whether Approach A (Annualised impacts per building element), approaches R1, R2 or R3 (rounded up approaches) or S (simulation) shall be followed when calculating the replacement rate. Particularly, for approach R3, it shall be made clear for which components, products and equipment the number shall be always rounded up (never rounded down) including a justification.
At which level of detail shall the service life of a building element be defined?	4.	If two products/layers are typically replaced at the same time, the two components shall not be distinguished in the view of their service lives even if literature sources provide different service live for these two products. At least, the lowest service life shall be used for both materials (layers).

[52] And representative of the reference context of use as mentioned in EN 15804 and EN 15978.

Recommendations for action

National standardisation bodies (application / use case: C, see Table 1.2)

a. Develop and provide tables with default service life values for building elements and construction products
b. Provide service life ranges for influential building elements based on empirical evidence to assist designers to examine the robustness of the LCA results following a probabilistic approach

Developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

c. use the default service life values for building elements provided by your national standards.

Researchers (application / use case: B, see Table 1.2)

d. run sensitivity analyses to investigate the significance of effects of various service life ranges for different components on the final LCA outcome
e. provide empirical evidence on the actual service life of building components under different conditions of use

Construction product manufacturers (application / use case: F, see Table 1.2)

f. provide different default values for service life according to different conditions of use

4.3.19 How to model planned refurbishment (module B5): General

In this report a distinction is made between planned (anticipatory) refurbishment or repurposing of a building and unforeseen/not according to initial plan (reactive) refurbishment or repurposing (Figure 4.18). In a planned refurbishment, a new building still under design becomes the object of assessment. Examples are the planned repurposing of exhibition and Olympic game buildings or the refurbishment of a building to make it net zero in a prepared second step. This option is represented by module B5 as part of the life cycle model of a new building design according to the CEN TC 350 and ISO TC 59 SC 17 standards and becomes part of the functional equivalent. In the case of building concepts without refurbishment already planned at the time of design, module B5 becomes irrelevant, but modules B2, B3 and B4 must still be processed.

In an unforeseen refurbishment, at first an existing building, later the design for refurbishment and at the very end the refurbished building become the object of assessment. This means that the type and time of refurbishment was not yet known during the initial design and the need for improvement and/or adaptation to a new type of use emerged during use. The way of assessing these two cases differs, and thus the latter case which is the most significant is addressed in an own section (4.6).

It is important to note that planned refurbishment corresponds to a process of continuous improvement and can involve:

a. refurbishment/retrofit of the present building components to increase energy efficiency, i.e. entire components can be replaced/substituted with better ones (change windows with more innovative ones), or additional layers can be added to a component (e.g. additional layer of insulation); It is important to note that, in this guideline, what distinguishes the replacements undertaken under B5 from B4 is that the latter use like-for-like materials and products.
b. installation of entirely new components which are not present from the start, such as PV panels in the case of a net zero refurbishment.

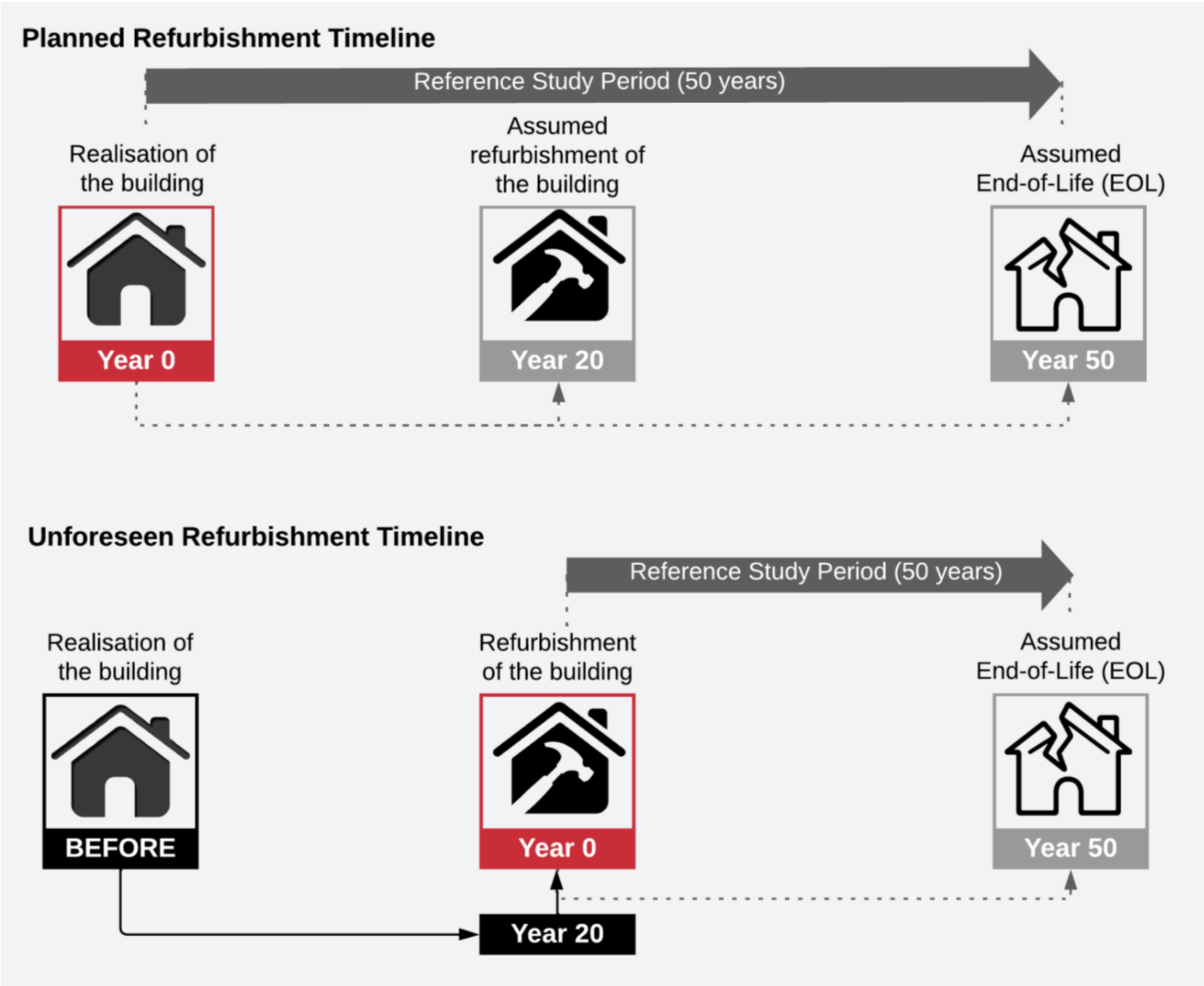


Figure 4.18: Difference in timeline for planned and unforeseen refurbishment.

In case (a), the forecast of technical progress and/or the change of policies that will come with new requirements is particularly challenging (missing knowledge). Less challenging is the variant in which the best available technology is not yet used in the new building, e.g. for cost reasons, but it is already known. In this case, the impacts and benefits associated with the replacement of components with a technically/functionally improved variant in the context of a planned refurbishment can be estimated without any problems.

A particularity of (b) is that the building may be designed from the start to accept additional elements, and this also may involve additional impacts, which are present before the refurbishment (B5) itself occurs. For example, in the case of solar systems planned to be installed at a later stage, empty pipes may be already defined and incorporated during design that can then accommodate components of the system to be installed at a later stage. Impacts associated with the pipes should be part of overall LCA. Therefore, it would make sense to document any additional efforts taking place at the time of refurbishment/repurposing as part of B5, while additional efforts in relation to the future use incorporated already in the initial design are part of A1-5, later also B4, C1-C4 and, in addition, B1. This is also an aspect not currently mentioned in the standards.

Most methods do not include B5 in their life cycle scope, although, depending on the depth of the refurbishment/adaptation and type of building, its magnitude in the whole life embodied impacts can be two thirds of A1-3 impacts (Rasmussen et al., 2020). It also significantly influences post-refurbishment operation processes (B6 and B7) if one carries out an energy-efficient and water-saving refurbishment. It is expected that the call for extending the life of buildings through adaptable/flexible designs will lead to upgrade the importance of module B5 (and B4). At the same time life extension (e.g. by 50 %) may lead to lower annualized environmental impacts, dividing all environmental impacts by 75 years instead of 50 years.

4.3.20 Module B5: Conclusions and guidance

As seen, the inclusion of B5 necessitates complex assumptions. Therefore, when included in an assessment the question naturally arises as to the credibility of the assumptions made and the probability of their actual realization. There is a risk of manipulation. It would be helpful to develop the basis for voluntary commitments or contractual guarantees. For example, Level(s) system in its rules for scenario development of future refurbishment/adaptability requires that, if LCA results are to be publicly reported, an independent critical review of the assumptions shall be carried out by a property market specialist with knowledge of the local and regional conditions and his or her opinion appended to the reporting (Dodd et al., 2021). Against this background, related rules (Table 4.30) and recommendations (gray box) are provided in the following.

Table 4.30: Rules on how to model planned refurbishment

ISSUE(S)	RULE(S)
How to deal with the embodied impacts of a planned refurbishment or repurposing already in the design of a new building?	1. All impacts associated with either a planned future refurbishment or planned repurposing of a new building assessed today shall be documented under module B5. In this case, the planned refurbishment/repurposing shall already be part of the functional equivalent.
	2. If benchmarks within an assessment method do not include B5 (most likely case), the overall LCA result of a building shall exclude B5 only when compared to the benchmark (B5 shall be shown as additional information only). If a method includes B5 in its assessment scope, this presupposes specific benchmarks including B5 are also provided to cover this special case.
	3. If B5 is included in the scope, an independent critical review of the assumptions shall be requested by a specialist with knowledge of the local and regional conditions and his or her opinion appended to the result.

Recommendations for action

Policy, regulation and law makers (application / use case: C, see Table 1.2)

a. regulate whether there may be an obligation to refurbish in the future (e.g. later installation of solar systems, elevators, or systems to support older people). For many concepts, there are specifications for how to achieve 'readiness' - this can indicate an option for future planned refurbishments

Developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

b. Make the documentation of B5 mandatory for adaptable building concepts, since adaptability is associated with additional effort, which lies in the future. B5 impacts are activated only if the building is indeed adapted in the future (an option) and should thus be reported separately from the rest of A-C impacts.

Researchers (application / use case: B, see Table 1.2)

c. There can be various scenarios for B5; investigate how this should be presented.

4.3.21 How to model operational energy use (module B6): General

The calculation, assessment and reduction of the energy consumption of buildings in connection with operational energy use (B6) is a typical design task. The basic principles for its calculations are largely regulated around the world. Internationally there is ISO 52000-1 (ISO 2017), while in Europe, the Energy Performance Building Directive (EPBD, current draft from 12/2021) provides the basis. In many countries there are specific calculation bases, requirements and even software tools to assist designers in this task. A distinction is usually made between calculations to prove compliance with legal requirements under standardized boundary conditions for local climate and user patterns and the prediction of the specific energy demand under specific use conditions.

The international standards ISO 16745-1 and ISO 16745-2 (ISO 2017) exist for the determination and verification of energy-related GHG emissions during buildings' operation. Among other things, different system boundaries for operational GHG emissions are provided in those standards distinguishing between CM1 (carbon metric 1) which is the sum of annual GHG emissions, from building-related energy use and CM2 (carbon metric 2) the sum of annual GHG emissions from building- and user-related energy use.

Built on the distinction between the building-related part and the user-related part of energy consumption, along with a distinction between what services are typically regulated within national regulations and what not, in Europe, the discussion on the system boundary of the operational energy consumption has led to the introduction of a broad breakdown of module B6 into three parts: B6.1 regulated building-related energy consumption, B6.2 unregulated building-related energy consumption and B6.3 (unregulated) user-related energy consumption. EN 15643:2021 and the upcoming version of EN 15978 (preliminary version in 2022) regulate further details (see also Table 4.8 previously shown).

The determination of the operational energy consumption (demand for new buildings, consumption for existing buildings) is usually carried out in two steps: (a) determination of the demand side: i.e. the final energy demand based on which parts (B6.1-3) are covered and (b) determination of the supply side: i.e. the type of sources selected to cover each type of energy demand including its resource and emission intensity. Both parts need to be determined and assessed and lead to different types of choices and actions.

Demand side (a): A general discussion on the necessity to expand the scope of B6 in energy calculation and assessment considerations is discussed in Section 4.3.22. Delving into the details, the following influencing factors are normally considered:
- For module B6.1: a1 quality of the building envelope, a2 quality of building services, a3 quality of servicing and maintenance, a4 climate, a5 user behavior
- For module B6.2: a2 quality of building services, a3 quality of servicing and maintenance, a5 user behavior
- For module B6.3: a7 type and number of appliances, a5 user behavior

It can be said that B6.1 is associated with the 'quality' of the building and its services to a great extent. The latter also influences B6.2. While designers and services engineers can ensure that the building envelope and the technology installed is as efficient as possible, they cannot predict under what conditions the building will be ultimately operated. That is why the specification of assumptions in relation to a4 (climate) and a5 (user behaviour) is the responsibility of the method. Some pressing current questions are whether and how to consider the already changing climate as a result of global warming, as well as how to improve user behaviour prediction and consideration of the changing preferences and conditions. These two aspects are explained in detail in Sections 4.3.23 and 4.3.24.

Supply side (b): The following influencing factors are normally considered for (b):
- b1 Type and proportion of renewable energy generated on site
- b2 Type, mix (where applicable) and amount of energy purchased

While the designers and services engineers, in collaboration with clients/ tenants (e.g. green leases), can ensure that the building is using as much clean energy as possible to cover its energy needs, and preferably renewable energy generated on-site to increase robustness, they are not responsible for modelling the effects of energy supply and derive the primary and emission factors associated with different energy supply sources. The specification of which factors to be used for each energy source and under which context is the responsibility of the method. Sometimes, for the same source of e.g. electricity supply different emission factors are provided by energy authorities following different modelling choices. The choice of intensity factors can have an important effect on B6 results. Furthermore, often, parts of the on-site generated/produced renewable energy is exported to third parties (e.g. grid). The way to allocate the environmental impacts associated with exported energy raises a number of methodological issues. These two topics are further discussed in Sections 4.3.25 and 4.3.26. Therefore, in addition to b1 and b2 the reporting of the following inventorying information also become important:

– Type and amount of self-consumed energy generated on site
– Type and amount of energy exported to third parties
– Emissions potentially avoided by third parties (indication as Module D2)

4.3.22 Module B6: Expanding the typical scope

Acknowledging the considerable complexities and risks involved in predicting total energy demand of buildings, and in particular the unregulated part of it, most methods focus on the calculation and assessment of regulated part (B6.1). However, this does not represent an accurate reflection of reality. As discussed earlier (see Section 4.1.8) B6.2 (building-related unregulated part) and B6.3 (user-related unregulated part) can make up more than 50% of total energy demand collectively. Often, this also becomes evident during the verification of the calculated building energy demand after the building's completion (e.g. by measuring energy use during the first year(s) of operation). If the verification is based on utility bills, the separation of the different uses of electricity is often not visible[53]. This leads to the measured values of consumed electricity and the related bills to be much higher than expected.

For the building industry, it is essential to gain a better understanding of the total operational energy use and related emissions by including B6.2 and B6.3 in the minimum documentation scope. This is now acknowledged in some countries which have started including the unregulated part of operational energy use in their calculation scope and benchmarks[54]. Some examples are (a) the UK Future Homes Standard / Future Buildings Standard (2025) which provides an overall design target of 35-40 kWh/m^2/yr for all energy use of new buildings from 2025; (b) the German quality label QNG (2021). Although it can be argued that building design cannot influence unregulated energy use, especially B6.3, as it is highly influenced by user behaviour, extending the scope of methods can:

– provide a better picture of the internal heat gains within the building.
– improve the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity.
– fulfil the clients' expectation of what truly matters to them: the real-life energy use and related running costs of their buildings. Being concerned with minimising the running costs among others, clients have a high interest in understanding how buildings are expected to perform, so that they can target control alterations and user behaviour-change programs in a more efficient way (and avoid rebound effects).

It makes sense, therefore, to consider the intricacies of regulated and unregulated energy use early in the design process. As this is complex, methods need to consider providing default values for B6.2 and B6.3 to assist designers in providing a comprehensive picture to third parties. An example, of such values can be seen below in Figure 4.19 (taken from the German quality label QNG).

[53] It depends on the national context and type of building.
[54] the Swedish tool Miljöbyggnad has one indicator in which all energy shall be calculated already since 2008.

a) Default values for B6.2

Energy efficiency class	Load kg	Speed m/s	Use category of elevator (kWh/year)				
			1 0,2h	2 0,5h	3 1,5h	4 3h	5 6h
A	630	1,0	527	661	1.106	1.774	3.110
		1,6	583	800	1.523	2.608	4.779
B	630	1,0	1.008	1.205	1.864	2.853	4.829
		1,6	1.091	1.414	2.490	4.104	7.333
C	630	1,0	1.946	2.237	3.207	4.662	7.572
		1,6	2.071	2.550	4.146	6.540	11.327
D	630	1,0	3.788	4.213	5.632	7.760	12.015
		1,6	3.975	4.683	7.040	10.576	17.648
A	1600	1,0	670	1.018	2.177	3.915	7.393
		1,6	811	1.371	3.236	6.035	11.631
B	1600	1,0	1.222	1.741	3.470	6.065	11.253
		1,6	1.434	2.271	5.060	9.243	17.611
C	1600	1,0	2.267	3.040	5.616	9.480	17.208
		1,6	2.585	3.835	8.000	14.248	26.745
D	1600	1,0	4.270	5.418	9.245	14.987	26.469
		1,6	4.746	6.610	12.821	22.139	40.774

b) Default values for B6.3

Zone	kWh/m²*year
Individual office	10.5
Group office	10.5
Open plan office	15.0
Meeting room	2.0
Lecture hall, auditorium	4.0
Canteen (dining area)	3.6
Restaurant	2.5
Kitchen	4.2
Kitchen - preparation	540.0
WC and sanitary rooms	54.0
Other recreation rooms	0
Ancillary areas	2.0
Traffic area	0
Warehouse, technology room	0
Data centre	657.0
Exhibition hall	0
Library	0
Sports hall	0
Fitness room	8.8

Figure 4.19: Default B6.2 and B6.3 values provided in Germany as part of the label QNG[55].

4.3.23 Module B6: Consideration of changing climate

A basis for determining and assessing the operational greenhouse gas emissions of buildings (module B6) already during design is the realistic prognosis of the energy demand. Important input variables are the outside temperatures during the heating and cooling periods as well as the thermal comfort requirements. As a result of the already occurring global warming, changes in the local climate will occur.

Heating and cooling needs are strongly associated with local weather conditions. Due to climate change, global and local weather conditions are expected to change, which will lead to evolving annual heating and cooling requirements for the building stock in the future. Specifically, the energy consumption linked to winter heating is expected to decrease, while needs related to summer cooling are expected to increase. This will potentially result in a reduced use of natural gas and other fossil fuels combusted for heating and, at the same time, in the increase in electricity demand used to power cooling systems.

Although the international scientific community dealing with energy demand of buildings has already analysed the close relationship between climate change, energy demand and GHG emissions, most methods follow a static approach: they assume the climate unchanged over the building service life. Practitioners usually work with weather data files only valid for the current time and buildings have a rather long lifespan: this means that designing buildings only for "today", might mean that the weather conditions in the future might be largely different than what the building is designed to withstand. This could translate into increased energy uses, longer periods of thermal discomfort with higher PPD and fundamentally a building design which cannot adapt to climate change related future scenarios.

For a building energy analysis corresponding to future climate conditions, weather files describing the future climate situation for each location need to be created. Creating future climate weather files is challenging, since one first needs to define the future carbon emission scenarios as a first step. Over the last two decades, IPCC has released a set of different emissions scenarios based on different assumptions regarding population increase, economic development and rate of use different technologies. The latest assessment report (AR5) adopted four GHG concentration tracks, called "Representative Concentration Pathways (RCPs)", for future climate anticipation by the end of this century (see brief description in Figure 4.20): RCP2.6 (very low), RCP4.5 (low), RCP6 (medium), and RCP8.5 (high), where the specific nomenclature used in the definition of the scenarios refers to the radiative forcing implemented in the modelling, defined as the change in net radiative flux (measured in Watts/m^2) at the tropopause or top of atmosphere due to a change in an external

[55] See pg. 15-17 of the current manual, available at: https://www.nachhaltigesbauen.de/fileadmin/pdf/QNG-BEG/QNG_Handbuch_Anlage3_Anhang3212_LCA_Anforderungswert_Nichtwohngeb%C3%A4ude.pdf

driver of climate change, such as (and most prominently so) the concentration of carbon dioxide. The scenarios range from assumptions of large decarbonisation actions and substantial reduction in carbon-intensive practices (RCP2.6) to 'business as usual' (RCP8.5). These scenarios are generally developed in time and extend also beyond the end of the XXII century.

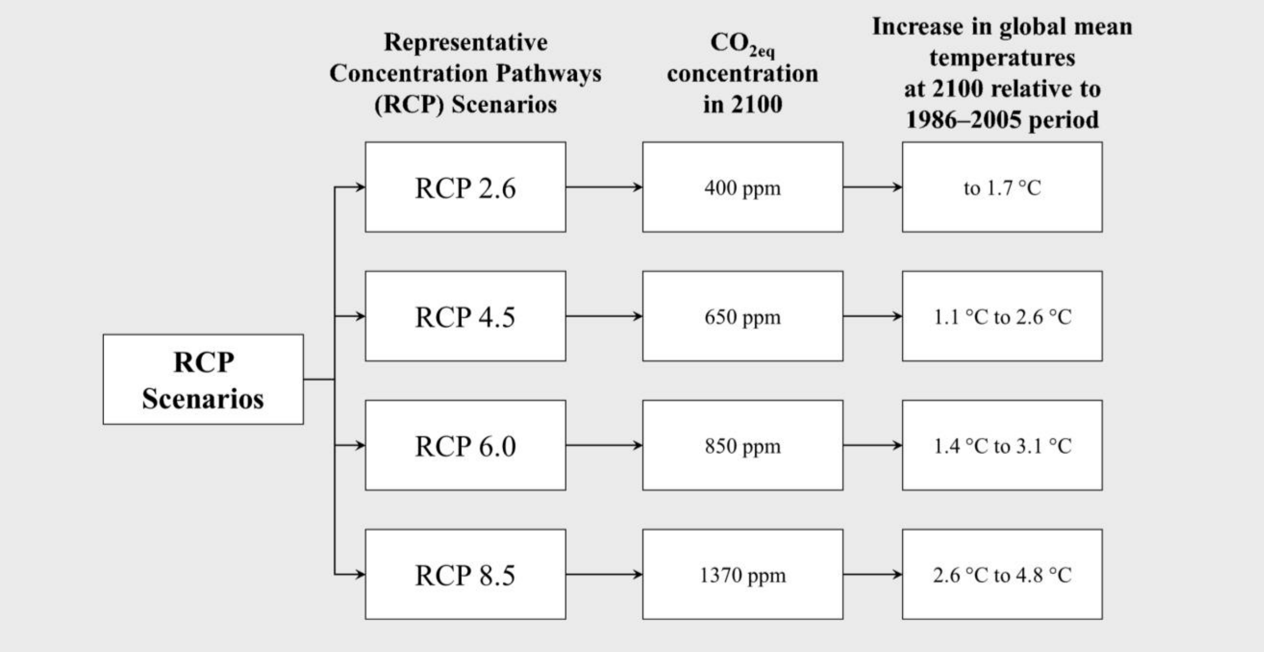


Figure 4.20: Representative Concentration Pathways IPCC scenarios (IPCC, 2013).

Key topic-specific definitions

Global Circulation Models (GCM): they are numerical models of the main physical process in the atmosphere, oceans and land surface and represent the state of the art of the modeling and simulation of the global climate system in response to the increase of the concentration of greenhouse gases in the atmosphere. GCMs are usually based on three dimensional grids with resolution higher than 250 km, thus calculating and simulating the physics of the airflow of air and water masses: energy balances, wind flow and speed, water currents and temperature, precipitations etc.

Regional Circulation Models (RCM): RCM models are based on limited areas and use a much denser concentration of grid points for the numerical modeling and simulation, thus being able to catch specific local microclimate trends and variations, which can often be very impactful in the performances of buildings. They can usually be combined with GCMs as they use boundaries conditions deriving from GCMs.

While RCPs give an overview and aggregated information on what to expect as the perspective of global warming is concerned, these scenarios and models do not per se include climate change predictions, but rather investigate the variation of the main variables affecting climate change. The approach towards the modelling of the effects of climate change is usually performed through the use of specific modelling techniques (e.g. use of GCMs "downscaled", or, in other words, transposed to spatial and temporal scales lower than those provided by the original GCMs), mostly developed within climate science research with large resolution. Specific techniques of downscaling can derive averaged values for use in more specific applications for site specific analyses, otherwise other techniques involving more refined and detailed meshing and calculations are available and usable, either making a combined use of Global Circulation Models (GCM) and Regional Circulation Models (RCM) or through statistical trend analyses and future projections.

However, as the focus is to develop tools and weather data files usable by energy models for the building sector, data generated from GCMs cannot be used directly in future building energy uses predictions. Thus, usually two different approaches are available: statistical (e.g., interpolation of the main climate related variables) and building simulation approaches (i.e. use of specific tools and methodologies aimed at performing climate change predictions that can be combined with building simulation). For the latter, usually two approaches are available:

– the combination of climate projections with weather "generator" approaches, that basically generate a new, future weather data file.
– morphing of existing and available datasets: "Morphing" methods apply the monthly data from GCM or RCM to hourly pre-existing weather data files, through operations of "shift", "stretch" and a combination of them.

The different approaches tend to be recognized as effective in different domains: it is generally accepted that the morphing method is particularly effective provided the original weather data are detailed enough and able to adequately describe the variability of the local climate. However, since most commonly climate data used in building practice uses average and conservative values, statistical and stochastic approaches tend to be more effective in the description of extreme climate change events, thus often causing higher peak power estimations for heating and cooling, although more computationally intensive (Moazami et al., 2019). A morphing method was used in building LCA linked with energy simulation (Roux et al., 2016a), whereas downscaled GCMs provide prospective data that can be used as an alternative (Le Roy et al., 2021).

Temperature change trends and consequences for building energy use: Variation trends on temperature and the main climatic parameters in different regions have been shown in various studies, as well as corresponding variations in energy uses for heating and cooling. For example, Cellura et al. (2018) focus on the European context and use some of the techniques mentioned in the previous paragraphs. The study develops a wide range of parametric analyses on a set of different cities across Europe, choosing specific envelope features for a modelled non-residential building and performs a downscaling of GCM data (CESM1(Cam5)) using the morphing method to the currently available weather data files based on the climate forecasts for 2035, 2065, 2090 of the IPCC. Important variations on air temperature occur which of course have implications on the expected heating and cooling energy uses in buildings (see A72 background report by Guarino et al. (2023) for detailed results). For example, the expected heating and cooling demand for the year 2035 and scenarios RCP 4.5 and RCP 8.5 can be traced throughout Table 4.31, which shows very variable results: the simulations for 2035 identify a high increase in cooling (e.g. reaching up to 130%), if compared to current standards. A similar but reversed trend is seen for heating demand (e.g. with reductions up to about 40%). In the report by Guarino et al. (2022) the examination of more cities, more scenarios (i.e. RCP 2.6 and 6.0) and future years (i.e. 2065 and 2090) can found.

Table 4.31: Future cooling and heating energy demand for selected cities according to selected RCP scenarios for the year 2035. Note: See the A72 background report by Guarino et al. (2023) for the results according to more RCPs and future years (adapted from Cellura et al. 2018).

European city	Today		2035					
	Cooling [kWh/m²]	Heating [kWh/m²]	Cooling [%]		Heating [%]		Total demand [%]	
			RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Marseille	24.98	43.33	+87%	+92%	-25%	-27%	+62%	+65
Montpellier	18.78	43.80	+122%	+128%	-21%	-26%	+101%	+102%
Nice	16.33	30.97	+114%	+128%	-35%	-39%	+79%	+89%
Athens	35.65	33.18	+76%	+75%	-28%	-33%	+48%	+42%
Thessaloniki	26.04	59.88	+77%	+113%	-24%	-26%	+53%	+87%
Genoa	17.71	33.36	+121%	+130%	-15%	-13%	+106%	117%
Messina	34.71	14.51	+47%	+55%	-40%	-41%	+7%	+14%

Other studies similar to the one proposed are available in literature (e.g. Zou et al., 2021; Liu et al., 2020; Moazami et al., 2019; Kikumoto et al., 2015; Jentsch et al., 2013), but regardless of building sizing and modelling assumptions, the common perspective is that cooling in buildings is going to have a more relevant impact on building energy performances in the next decades than today. Cooling requirements may double or triple if compared to current trends, with corresponding reductions in heating requirements. This will potentially result in a reduced use of natural gas and other fossil fuels combusted for heating and, at the same time, in the increase in electricity demand used to power cooling systems. For countries with a predominantly coal-based electricity mix, this evolution will lead to increasing levels of GHG emissions associated with building operation, if the current carbon intensity of their mix remains unchanged in the future.

These trends can also have unforeseen consequences. It is possible to expect i.e. relevant cooling in traditionally "cold" countries, with unexpected increases also of embodied impacts tied to the production and acquisition of new cooling machines and HVAC systems. Also, in the case of severely cold areas calculating with current data an effect can be that more embodied impacts may be caused for thicker than necessary (in the future) insulation. This will also result in other impacts related to the ongoing global warming, resulting a vicious cycle that may lead to increase of carbon emissions and heat island effect pushed by an increase in cooling demand and thus further contributing to global warming.

Uncertainty in relation to the choice of circulation model: Along with the provisional nature of the studies discussed above, another relevant aspect within the methodologies of energy use assessments and in particular within morphing modelling is that several models exist, within the GCM approaches. Choosing one model over another means to have a second layer of uncertainty at the GCM modelling stage, which is translated into the air temperature provisional trends and the energy consumption calculations. The A72 background report by Guarino et al. (2023) shows an example of the monthly future projections developed by different GCM (ACCESS 1.3 and 3.3, HadGEM2-AO and HadGEM2-CC). What can be observed is that while the trend in air temperature is rather common among all results from the alternative models, relevant differences can be traced up to +2°C between the outputs of different models Furthermore, the same substantial variability between energy uses for heating and cooling can be traced (e.g., RCP 4.5 results can vary as much as 35% simply by choosing one data source or another, if cooling is concerned). Without aiming at giving substantial and quantitative indications on the aforementioned models, this example highlights that these uncertainties need to be taken in consideration.

What can be expected in the background report by Guarino et al. (2023)?

1. It includes the description of the most used techniques for the introduction of global warming expected climate variations within the context of building energy simulation through the downscaling of existing global circulation models' outputs and the manipulation of existing weather data files.
2. It discusses future provisional assessments of the air temperature variations throughout the current century as well as the analysis of existing literature that estimates potential energy use variation in heating and cooling throughout different climate zones in the world.
3. Recommendations are provided.

4.3.24 Module B6: Consideration of changing user behaviour

Several studies have showed that occupant behaviours affect the operational energy consumption largely and are the main cause of the gap between the predicted and actual energy performance of buildings, especially the residential ones (Martinaitis et al., 2015; Ramos et al., 2015, Yan et al., 2015). Although most of the calculations are based on an "average user behaviour" with regard to different parameters inputted in a performance simulation such as air changes through ventilation and room air temperature, real user behaviour shows great differences. Often, the real number of users is also different from what was assumed. For example, Andersen et al. (2012), who analyzed the energy consumption of a block of 35 almost identical apartments and 290 dwellings in terms of orientation, building systems and building envelope composition located near Copenhagen concluded that differences in household behaviour might lead to differences in energy consumption by a factor of three, without considering the extreme cases (Figure 4.21). Gram-Hanssen (2010) attempted to understand the reasons behind differences in user behaviour based on interviews.

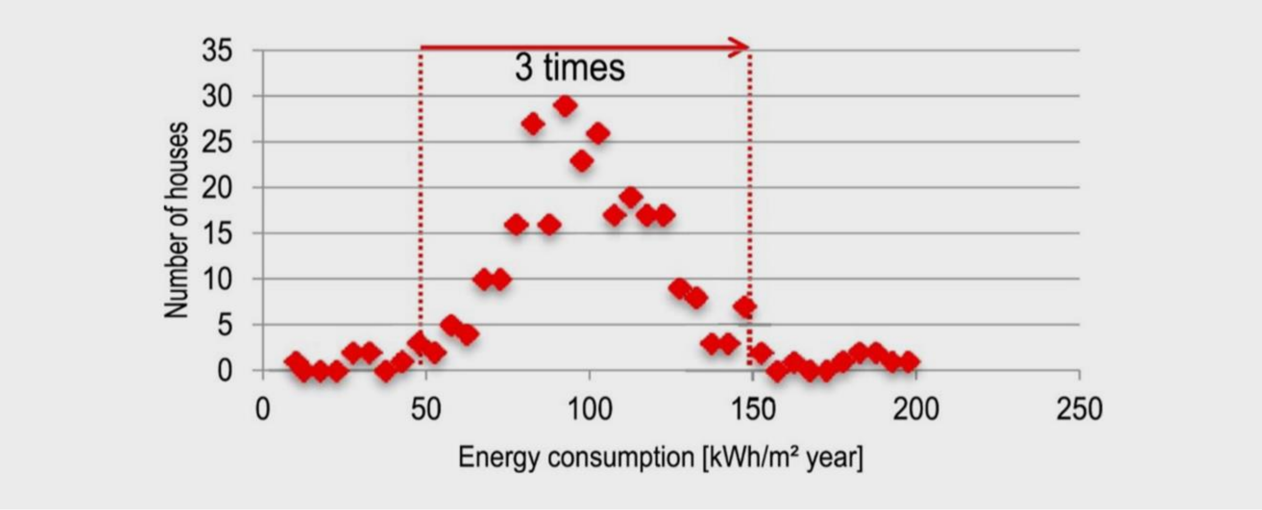


Figure 4.21: The influence of occupants' behaviour on energy consumption investigated in 290 identical dwellings and in 35 apartments (Adapted from Andersen et al. (2012) and Corgnati (2014))

This highlights the usefulness to integrate stochastic behavioural models in energy simulations to increase the relevance of simulation results (in terms of energy consumption and thermal comfort), avoid design errors and represent behavioural diversity. In general, changes in user behavior may be associated with various parameters such as:

– Thermal comfort level
– Energy-consciousness level
– Presence time of users (pattern of use)
– Space per person
– Household size/type

Thermal comfort level: The acceptable comfort levels during summer and winter differ by geography and sometimes even by building type. For example, acceptable summer comfort levels addressed in building codes and related studies around the world can range from 17-30 degrees for residential and office buildings (Yang et al., 2014). The tolerance towards highest temperatures is seen in warmer regions. Considering that user behaviour is not static (in reality), but adaptive to different discomfort levels, it is possible to assume that the population will eventually acclimatize to a warmer climate. This will lead to the 'set point' temperature be increased in line with mean temperatures. However, an opposite effect may also be seen in developing countries in the future: the increase in human development index in certain areas around the world can lead to unwillingness to accept low thermal comfort.

Energy-consciousness level: It is not sufficient to just incorporate high efficiency systems into buildings if the occupants interact with them in a careless way. It can be assumed that the high awareness of climate change and the need to save energy will also increase the knowledge level of building occupants on how to operate efficiently the different building systems. In other words, it is expected that the level of energy-consciousness will further increase in the future. For example, Figure 4.22 shows the positive consequences of energy-conscious behaviour in combination with energy-efficient systems for a typical (in terms of construction and mode of operation) Egyptian office building (Elharidi et al., 2018). To capture the likely variation in occupant behaviour three scenarios were used (energy-conscious behaviour; typical/normal behaviour; energy careless behaviour) without varying the seasonal adaption in clothing levels between the scenarios.

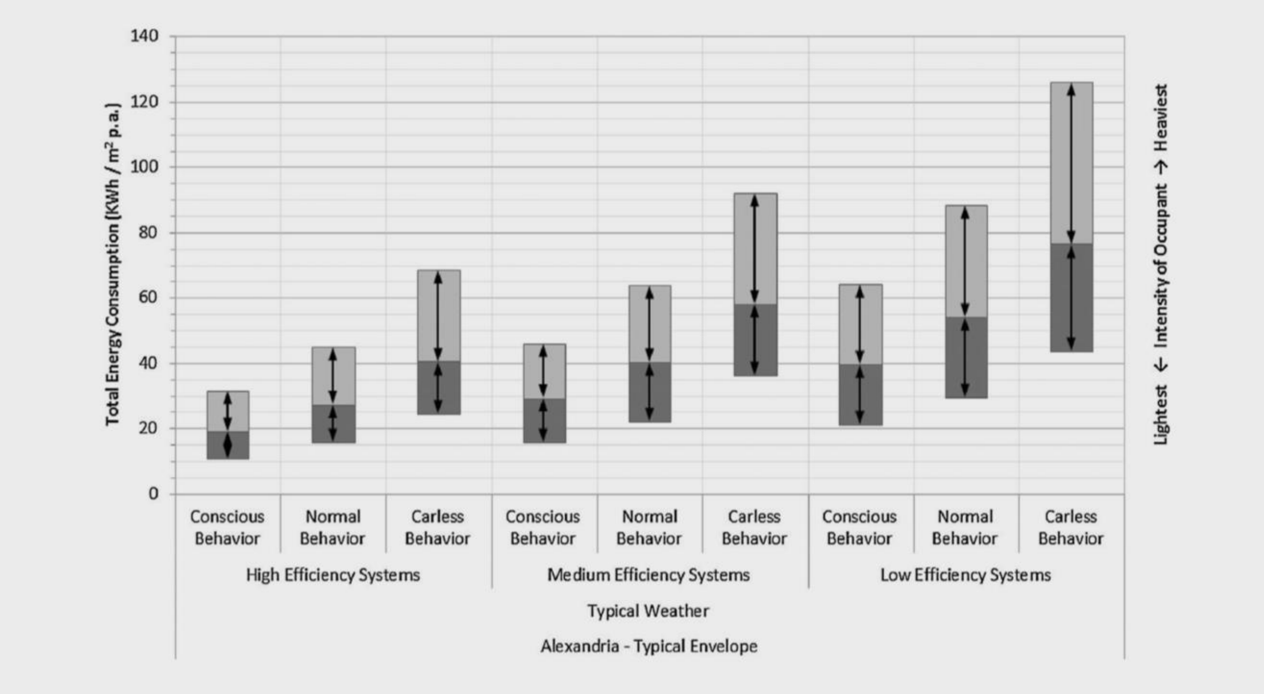


Figure 4.22: Total annual energy consumption per unit area for Alexandria (Typical Construction, Typical Weather) (Elharidi et al., 2018). Note: The behaviour parameters considered are: colling set point, heating set point, occupant control (lights and equipment) and HVAC operation period, among others.

It is shown that a careless behaviour in interaction with high efficiency systems can result in as high energy consumption as a conscious behaviour in a building with low efficiency systems for the same construction, weather conditions and intensity of operations. This leads to a crucial conclusion that failure of a human component in how the technology is operated can block the whole mission in the energy efficiency increasing efforts. That is why many countries have not only passed legislation and provided incentives to encourage adoption of high efficiency systems but also launched initiatives to encourage more energy efficient behaviour. An energy-conscious behaviour will lead to the 'set point' temperature be increased during summer and decreased during winter.

If future scenarios considering the possibility of more energy-conscious user behaviour are adopted, a clear distinction should be made between residential and non-residential buildings. There are different social dynamics and factors influencing the behaviour in the home and the workplace behaviour. For example, employees neither have economic motives for adopting a more energy-conscious behaviour nor the means to track the building's energy consumption. In principle, possibilities for strategic interventions to influence energy consumption in non-residential buildings are more limited than in households and, therefore, theories of behavioural change generated in a domestic building setting cannot be readily used as the basis for scenarios dealing with future behaviour in the workplace.

Presence time of users (pattern of use): The world is already experiencing a trend of increased home office (more hours of use of our homes) and a shift to hybrid work.

Space per person: Developed areas in the world may orient themselves towards sufficiency.

Household size/type: The number of persons in the same dwelling may vary across time: for example, a four persons household with two children occupying a dwelling may change to a two persons household when children leave. This influences the overall energy consumption significantly.

Current situation in relation to deterministic vs stochastic models: Although an important topic due to its significant effect on the final results, the application of a stochastic approach for this topic in regulatory or certification methods is challenging, especially if national or international user behaviour models are not in place (as is, for example, the case with electricity mix models or climate change models). This is why all or most official methods at the moment follow a deterministic approach. However, it should be acknowledged that default occupancy profiles may overestimate or underestimate occupancy and occupant-related loads and using default use profiles may therefore lead to selecting sub-optimal design alternatives. It is useful for design tools to allow detailed occupant modelling using stochastic models, so that designers can identify designs that have greater robustness by considering uncertainty due to occupants during building design.

For example, Vorger et al. (2014) proposes a comprehensive stochastic model of occupants' behaviour in residential buildings, which integrates an original model for the creation of virtual individuals described by a set of socio-demographic parameters. This allows a high degree of refinement in the generation of schedules and in the attribution of equipment to households according to statistical data. The use of appliances and lighting is modelled on the basis of inhabitants' activities with a higher accuracy than existing models from the literature, through data from several large measurement campaigns. A reference model for interactions of occupants with windows was adapted. The whole model is coupled to a dynamic BES tool with no more necessary input than the building description (but any available information on inhabitants' characteristics or equipment can be filled by the user). The distribution of the simulation outputs is than obtained using the Monte-Carlo method. Alternately, an average occupancy scenario can be derived from the stochastic model and used in any simulation, avoiding performing many simulations as required by the Monte-Carlo approach.

4.3.25 Module B6: Assessment of energy supply with a focus on electricity

The relative importance of the environmental impact of operational energy consumption in the life cycle of buildings does not only depend on the building envelope, efficiency of systems and user behaviour, but also on the impact intensity (e.g. GHG emission intensity) of the energy sources used. One of the most important sources is electricity and the provenience and the technologies used to generate it are key determining factors for its GHG intensity. For example, the assessment of one, rather energy efficient, building with electricity being the only energy carrier consumed during its operation by several research organisations using their respective national method revealed two things: firstly, the operation phase contributes at least one third to the total GHG emissions; secondly, the differences in life cycle greenhouse gas emissions vary by a factor of more than 5 (see Figure 4.23, Frischknecht et al., 2019).

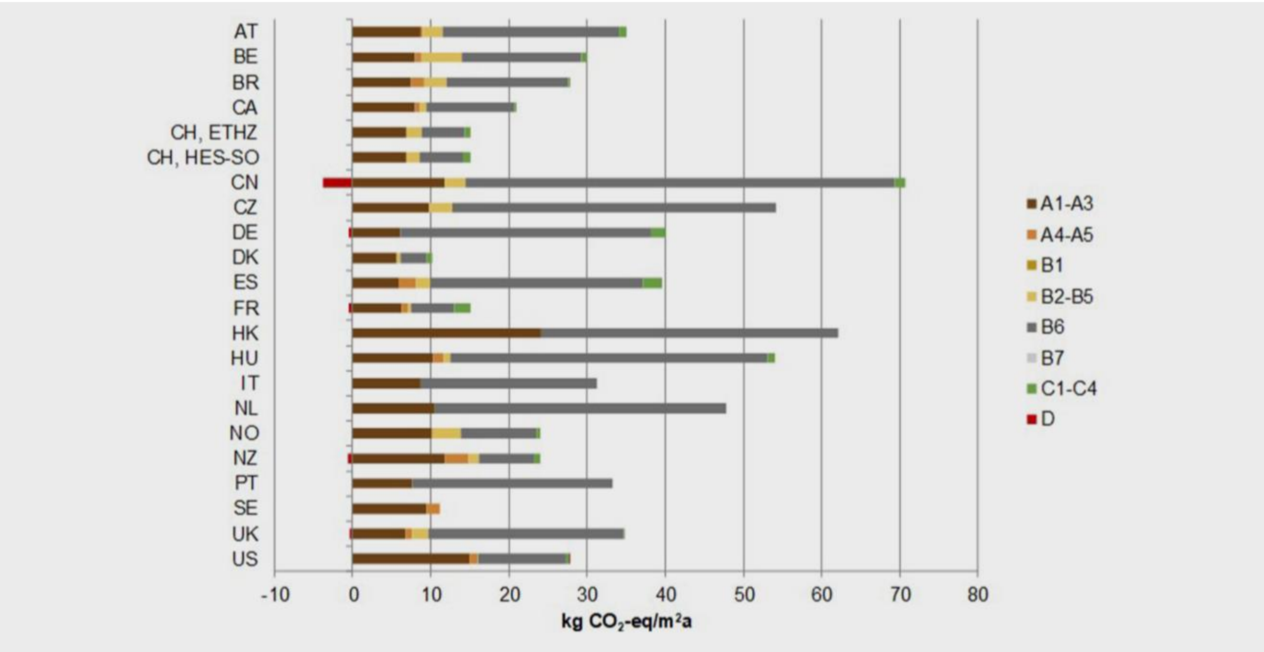


Figure 4.23: Greenhouse gas emissions in kg CO2-eq. per m2 and year of the reference building “be2226” assessed according to the national/regional approaches of the countries listed (Frischknecht et al., 2019).

That is why it is considered very important to choose the most appropriate electricity model in the life cycle assessment of buildings. There are different electricity mix modelling possibilities, which are discussed in the following, focusing on the following choices:

1. Generic or provider-specific electricity mix
2. Geographic scope (i.e. national, regional or continental scale)
3. Type of mix (i.e. production mix or supply mix)
4. Nature of trade flows (physical flows, flows based on contracts, flows based on GO or combination of approaches)
5. Modelling choice for the supply mix (production + import, production – export + import, national electricity declaration)
6. End uses dependence (universal electricity mix or use-specific electricity mix)
7. Time dimension (historical, present, near future or future mix)
8. LCA modelling approach (average or marginal mix)
9. Time granularity (annual, seasonal or hourly mix)

Key topic-specific definitions

Electricity production mix: % of different processes from which electricity is produced. For instance, the global world electricity production mix in 2020 is[56] : 35% coal, 29% renewables, 23% gas, 10% nuclear and 3% others.

Electricity supply mix: % of different processes from which supplied electricity is produced (a domestic supply mix may be different from the domestic production mix due to imports and exports).

Specific mix: supply mix of a specific electricity provider

Generic mix: average supply mix of all electricity providers

Use-specific mix: supply mix for a specific use (e.g. heating, cooling, lighting…)

Universal mix: average supply mix for all uses

Guarantee of origin (GO): an electronic document which proves that energy originates from renewable energy sources, in accordance with objective, transparent and non-discriminatory criteria.

The discussion that follows addresses electricity related impacts. Methodological choices should be consistent across energy sources. Thus, the following reasoning of different choices applied on fuels as well. For instance, if a future renewable scenario is applied for electricity production, the same level of ambition should preferably be applied for gas (future supply with biogas and/or synthetic gases produced with biogenic carbon and renewable electricity), liquid fuels and district heating and cooling.

1. **Generic vs provider-specific electricity mix**

The choice of an electricity provider has a large influence on environmental impacts. However, in the design phase of a building the occupant is generally not known and neither the electricity provider. Therefore, a generic mix is commonly appropriate for a method (as part of voluntary certification or regulation) because a specific mix cannot be identified. Methods can however have in place specific rules for cases the occupant is known (e.g. in case of a household or a company developing a project for their own use) or if a long term contract exists with an energy provider. For example, one of the Swiss methods (2000 W society) considers the specific mix of a known provider but only for 50% of the total consumption in order to account for the risk that this situation may change during the actual building use[57].

[56] See: https://www.iea.org/data-and-statistics/charts/global-electricity-generation-mix-2010-2020
[57] Such rules always depend on the context: in a country like Sweden when district heating is one of the most common ways to heat buildings, there is a situation when the builder knows what company the provider will be as soon as the municipality to build in is de-

On the other hand, if the goal of the life cycle-based environmental performance assessment is to compare various electricity providers in order to advise a facility manager or owner of an existing building, using a specific mix is more reasonable. This presupposes that the specific emission factors are provided in EPDs or other verified sources.

It should be noted that, in the exploratory phase, it is often useful to show the importance of users' choices in the environmental performance of buildings, and therefore also the choice of an electricity provider. A cooperative gathering renewable electricity producers proposes 100% renewable electricity to clients, and it is therefore interesting to perform a sensitivity study comparing the generic and 100% renewable mixes.

2. **Geographic scope**

The electricity network is highly interconnected, which makes the modelling of electricity challenging from a geographical scope. Usually a national scale is considered, because the choice of some production technologies (energy transition towards renewables) is related to a national political process. However, other options are also investigated in standards, tools and research, such as the use of continental or regional mixes, sometimes in the form of a sensitivity analyses to investigate the influence of this choice on the results.

For example, the Norwegian standard NS3720:2018 ("Method for greenhouse gas calculations for buildings") requires that calculations are performed using two scenarios for GHG emissions of electricity supply: scenario 1 (Norwegian electricity mix) and scenario 2 (European electricity mix). Studies shows that this choice can have a significant influence on the results (Lolli and Hestnes 2014; Moschetti and Brattebø 2017; Nydahl et al. 2019). One issue with averaging a continental mix is that this would lead to consider a percentage of nuclear or coal power plants even in countries having decided to abandon such technologies. As an intermediate solution, assessment methods and tools may choose to apply a regional mix if a group of countries share the same market (e.g. the Tidstegen assessment tool[58] is based on a Nordic electricity mix, due to the fact that Nordic countries share a common market, i.e. Nordpool).

3. **Production mix vs supply mix**

Once the geographical scope of the grid has been decided, the composition of the mix needs to be defined. Considering that electricity is often traded, various modelling approaches are available for this (Itten et al., 2014; Ménard et al., 1998; see also A72 background report by Peuportier et al. (2023)). First, a broad distinction should be made between domestic production mix and supply mix. The domestic electricity production mix represents the production of different power plants within a geographical boundary, without electricity trading considered. This can be an acceptable simplification in countries with a low share of import/export (i.e. in such cases, production mix ≈ supply mix). On the other hand, the electricity supply mix consists of the different processes from which supplied electricity is produced. Since several countries are trading a considerable amount of electricity with the neighbouring countries, applying the supply mix is sensible in a method, as it corresponds to the electricity delivered to a country's consumers, including buildings. In case of a supply mix considering imports and/or exports, more detailed questions about its modelling occur such as whether the electricity trade is modelled using "commercial flows" or "physical flows" (see §4),

4. **Nature of trade flows**

The current electricity market distinguishes between the physical electricity and the quality of the electricity (described by guarantees of origin), which are traded separately (see Figure 4.24). As a consequence, the certified quality of the electricity purchased and consumed by a country, or a building may significantly deviate from the physical electricity mix purchased and consumed. This deviation occurs when the electricity qualities

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cided. Hence, the emission factors from the relevant district heating provider are used. Therefore, a key issue in Building LCA in Sweden related to module B6 is whether the emission factors for electricity and district heating will steer towards the choice of district heating or a ground heat pump to heat a building.

[58] See: (1) Gode, J., Lätt, A., Ekvall, T., Martinsson, F., Adolfsson, I., & Lindblom, J. (2015). Miljövärdering av energilösningar i byggnader - metod för konsekvensanalys. Stockholm.; (2) https://www.ivl.se/sidor/vara-omraden/miljodata/verktyget-tidstegen-for-klimatbedomning-av-energiatgarder.html

(GOs) are purchased independently of the physical amounts, the latter being purchased on a spot market with no information about their provenience. Using guarantees of origin (GOs) purchased independently of purchasing the electricity is problematic because fossil or nuclear production may be artificially transformed into renewable electricity (a company could use electricity produced with coal or nuclear power but purchase GOs of renewable electricity to claim that it uses renewable power). It is likely to lead to double counting of renewable electricity (building LCAs in Switzerland and Norway both claim (partly) GOs of Norwegian hydro-electric power) because GOs are a voluntary means of communication (see A72 background report by Peuportier et al. (2023) for a more detailed discussion).

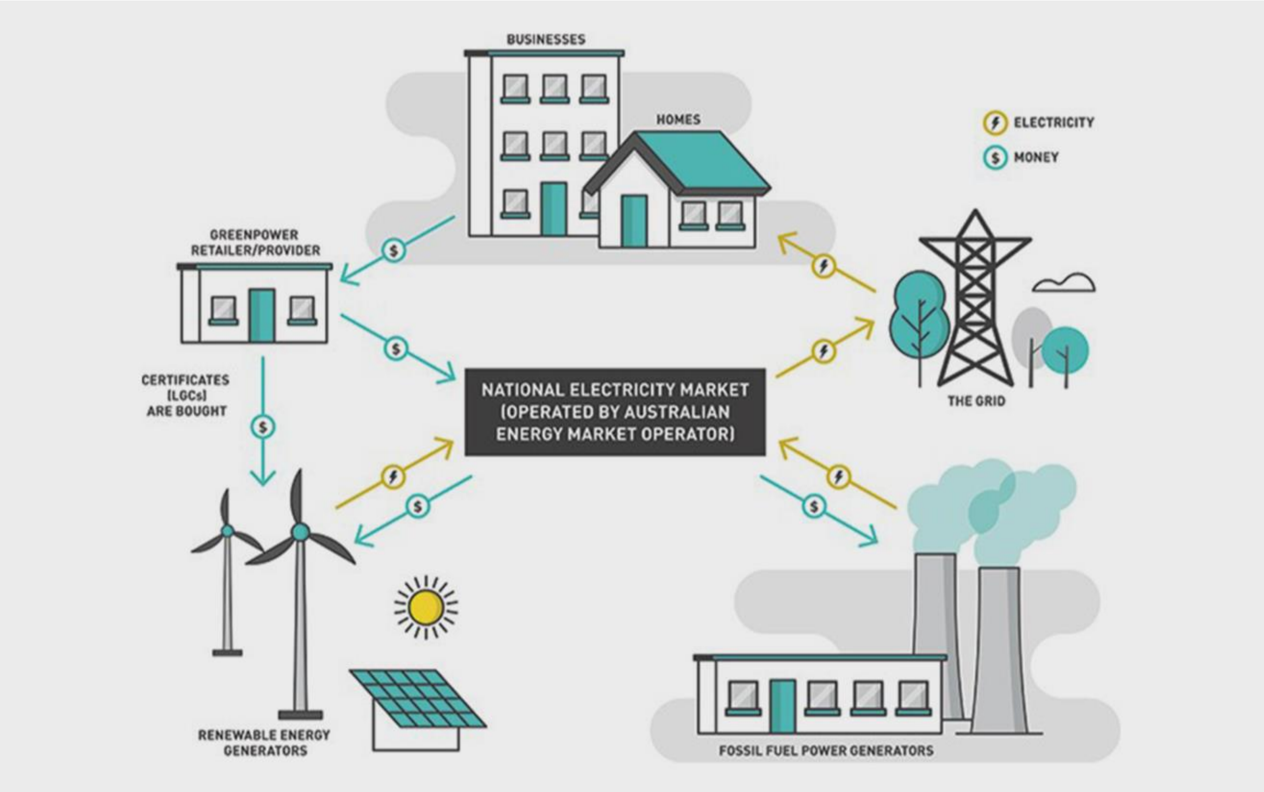

Figure 4.24: System of guarantees of origin and certificates explained in an Australian context; Source: https://www.choice.com.au

Method developers may either use “commercial flows” or “physical flows” to model electricity trade with neighbouring countries, reported on a transparency platform such as ENTSO-E in Europe (see the implication in §5).

Reasoning for commercial trade: LCA is a method that complements economic information about products, services and technologies with information on their environmental impacts. That is why life cycle inventory models are supposed to describe or at least approximate economic realities. Data on commercial trade is chosen (and preferred to physical exchanges) because it better reflects the economic realities of electricity trade.

Reasoning for physical trade: The physical trade approach models the real exchanges and underlines an overall stability of the electricity supply at every time step which is part of the analysed service for the electricity consumption mixes. The “physical flow” approach can be used if the goal is to optimize the global energy balance of production/consumption in a country. It is also relevant to be used for analysing demand-side management strategies using hourly data to check if the consumption occurs during the best period of time in terms of GHG emissions).

The 2019 suggested update of the European Product Environmental Footprint (Zampori and Pant 2019) method proposes to select in priority supplier specific electricity product based on GOs, which has been discussed in §1, and otherwise a "residual grid mix" defined as characterizing the unclaimed, untracked or publicly shared electricity. As reasoned above methods based on GOs are generally not recommended.

When LCA is applied to building research, physical and commercial trade can be compared to check whether or not differences are substantial.

5. **Modelling choice for the supply mix**

There are different choices for the supply mix:

– domestic production + imports (P+I). This model does not differentiate between electricity exported and electricity supplied to the domestic market.
– domestic production – exports + imports (P-E+I). This model assumes that the exported electricity is produced by the domestic power plants and the imported electricity is used exclusively for electricity supply within the importing country. This model does not take into account that the imported electricity can be re-exported to other countries.
– domestic production + net imports/exports. This model assumes that simultaneous, physically measured imports and exports is transit trade. This may deviate from the economic realities.
– consumer mix. The electricity mix of the domestic supply is modelled according to the integration of the electricity declarations of all electric utilities in a country. The declaration includes a differentiation according to technology and whether or not the electricity is produced domestically or abroad.

There is no "right" and "wrong" modelling approach, as there is a different "philosophy" behind each modeling approach. The appropriateness of each approach depends on context of use.

Reasoning for P-E+I: It is rare for a country to import electricity in order to export it further to another country, in particular in larger countries such as Germany, France or Poland. There are some transit contracts, which however are not part of the commercial trade data in the ENTSO-E transparency platform. Hence, it is safe to assume that all exported electricity stems from domestic production. It is also generally more precise because the % of import is related to the national consumption volume.

Reasoning for P+I: The exported electricity from the assessed country is considered equivalent to the electricity supplied to domestic customers. In addition, the P+I model is able to attribute the environmental responsibility of consuming the electricity in the assessed country not only to the direct "first level[59]" neighbouring countries but also to the "second level" countries (in a view of ensuring at every hour grid stability) even if there are no direct economical trade flows from the assessed countries and the second level countries contributing to the LCA of the consumption mix of the assessed country.

In both approaches, it is important to check that imports and exports do not include transit flows because this may lead to a bias if a large amount of imported electricity is not consumed in the country but readily re-exported. If the transit flows can be identified, they may be subtracted from both export and import. A gross balance should be used because import and export electricity mixes are generally different so that import and export flows do not compensate (even if the physical flow is zero, see §4).

6. **End uses dependence**

In relation to the different uses considered under B6, there are two possibilities: To apply an average supply mix for all uses (i.e. universal mix) or to apply end-use specific supply mixes (e.g. heating, cooling, lighting…). Most methods apply universal mixes. This is an appropriate choice if seasonal variation of the electricity consumption in buildings is similar to the seasonal variation of national consumption. A method applying end-use specific supply mixes is the French building regulation. The reason is that electric heating induces a peak

[59] For instance of a country A exports to a country B exporting to a country C, country B is first level and country A is second level for country C

load and higher CO_2 emissions in winter, whereas e.g. domestic hot water is produced in the night and stored in tanks. Different CO_2 emissions per kWh are therefore considered according to each use, but this is not really science based. It is rather the result of a negotiation between e.g. gas and electricity lobbies.

7. **Time dimension**

The choice of a present annual electricity mix or a future annual electricity mix depends of the availability of expected future data points and scenarios as well as the uncertainty of these scenarios. This topic was already discussed in Section 4.3.2 and related rules and recommendations were provided in Section 4.3.8. As a summary it can be said that although electricity mix data from TSOs, utilities, ministries or administrations (e.g. energy or environment agencies) and national statistics are normally available for not only the past years, but also near future and long term future, it is not common yet to include such future scenarios in building LCA in several countries.

8. **LCA modelling approach**

A new construction increases the electricity demand, while renovating a building usually aims at reducing this demand. In attributional LCA, an average electricity mix is considered when evaluating the corresponding environmental impacts. In consequential LCA, a marginal mix may be considered instead, in order to account for the consequences of the studied system (building) on the background system (including electricity production).

Marginal electricity mixes depend on the time scale and may be defined on a short term for particular time during a day (e.g. peak loads during cold and hot days, respectively), or during a season (e.g. reduced electricity consumption during the winter season caused by the replacement of direct heating systems with heat pumps) and they may be defined on a long term to capture long term changes in electricity demand due to national energy policy measures (affecting both the demand and energy efficiency in housing, industry, mobility, etc.).

Furthermore, electricity mixes usable in consequential LCA may be based on 1) economic models, 2) policy scenarios quantifying the annual average (and seasonal) production of electricity, 3) a “thinking model”. (see A72 background report by Peuporter et al. (2023) for more information)

Reasoning for attributional mix: Buildings are just one (admittedly important) group of electricity consumers among many. The evolution of the electricity demand of buildings is the result of a mixture of efficiency gains in existing buildings, additional demand by new buildings on greenfields, change in demand by new buildings replacing old ones. It is hard to substantiate and to determine why new and refurbished buildings should be linked to additional power production and not to the average electricity production volume. An attributional mix treats all electricity consumers equally.

Reasoning for long-term marginal mix: Future scenarios of electricity demand and production are based on assumptions about the energy efficiency of buildings, cars, industrial processes etc. Existing buildings may reduce their operational environmental impacts by switching to electric heat pumps operated with renewable energies without improving the energy efficiency. Such refurbished old buildings may contribute to a demand for electricity which exceeds the production capacity of the ambitious future scenario. In such situations long-term marginal mixes, established as the difference of the future electricity mixes in a business-as-usual and in an ambitious energy scenario, are useful to test the resilience of refurbishment measures to the electricity mix in scenario analyses.

Reasoning for short term marginal mix: Replacing gas or fuel boilers by electric heating or heat pumps is often proposed to reduce GHG emissions. But this will create a high peak demand during cold winter days. This supplementary demand requires peak production techniques which may be different from average production because such capacities will be used only a limited time of the year. High CAPEX techniques would not be economical, so that older or cheaper capacities (e.g. gas or coal thermal plants) may be used. In such a case a short-term marginal mix is appropriate. Identifying a marginal mix is based upon an assumption (e.g. 10% top of the merit order) or requires a model of the electric system in order to identify which production process is added when adding a supplementary demand corresponding to the studied building consumption or energy use. This approach can be applied to a present situation, or a future prospective scenario, e.g. using a market allocation model (e.g. TIMES), i.e. a bottom-up linear optimization model that computes a least cost pathway for a system of interest subject to the satisfaction of specified service demands and user specified constraints. Results can be averaged according to a typical load profile corresponding to a certain use (e.g. space heating, domestic hot water...) allowing simpler annual calculation to be performed in e.g. a regulation or certification scheme (e.g. in the French E+C- method 210 g CO_2/kWh heating, 83 g CO_2/kWh domestic hot water).

Studying the environmental benefit of smart buildings is an example research topic for which a con-sequential approach considering both short-term and long-term aspects is relevant. Buildings consume a large share of the total electricity production in many countries, so that accounting for interaction between this sector and the electric system is useful towards a higher global environmental performance.

9. **Time granularity**

The data of electricity mix can be of different time granularity (hourly, monthly, seasonal, annual). Temporal variation of the electricity production mix and related impacts may be large in some countries. For instance, in France CO_2 emissions are higher during peak demand due to the operation of thermal power plants during these periods. Figure 4.25 (Roux et al. 2016b) shows the difference in environmental impacts per m^2 and year of electricity use in a so called “plus energy house” when applying an hourly mix (plain line) and a yearly average mix method (dotted line), respectively in the case of electric space heating (a) and all uses including a PV production (b). Compared to modelling electricity supply on a yearly average basis, an hourly based electricity mix increases the space heating related CO_2 emissions of the building per m^2 and year by 20% in graph a) and the whole electricity related emissions with PV production by 40% in graph b). The difference is more pronounced with building integrated PV because more PV electricity is produced than consumed in summer and the excess production is fed into the grid (which potentially gives rise for avoided emissions[60]) and more electricity is consumed than produced in winter and the GHG emission intensity of the avoided electricity mix during summer is lower than that of the consumption during winter.

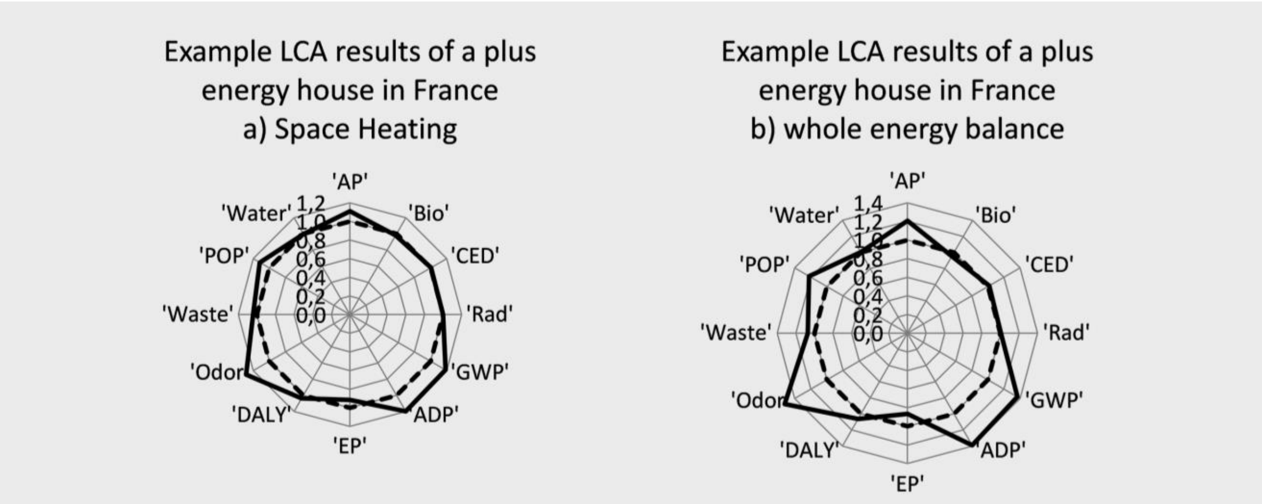

Figure 4.25: Impacts of electricity use in a Plus energy house in France (Roux et al. 2016b), Comparison between an hourly mix (plain line) and a yearly average mix method (dotted line).

[60] This is one possible modelling option, see Section 4.3.25 on « exported energy » for a discussion on the various approaches.

There are different reasons for choosing an annual mix:
– electricity products and hence the technology shares purchased are usually bought on an annual basis;
– In case the use profiles of residential and office buildings do not significantly deviate from the national use profile, this reduces the need for hourly mixes;
– many design tools are not able to model operational electricity demand nor supply on an hourly basis.
– long-term future electricity mixes presented in official future scenarios are annual, sometimes additionally seasonal but not hourly.

Reasoning for hourly mix:
– The electricity demand varies according to the hour of the day (it is lower at night), the day of the week (it is lower during weekends) and the season (it is higher during hot days due to cooling, and during cold days if electric heating is used).
– Thermal mass allows storing heat which may reduce the demand during peak hours and the related environmental impacts, but impacts are produced for the fabrication of such materials.
– Hourly calculation allows a trade-off, which is useful in a design tool and does not add complexity for users if energy calculation is also performed hourly.

Results of an hourly calculation can be averaged over a year so that a simpler annual calculation can be performed in a regulation or certification method, accounting for a typical hourly profile corresponding to specific uses like heating, cooling etc. Developing control systems algorithms or demand side management in terms of environmental impacts, i.e. in order to use the electricity when its carbon footprint will be lower and/or minimized, is an example research question where hourly calculation is appropriate.

Summary

All the above-described choices (1-9) lead to different impact factors for electricity. Depending on the purpose of the use of a method and with the precondition that different factors are available in a country, the following choices (Table 4.32) are recommended by A72 experts.

Table 4.32: Recommended modelling choices for electricity mix per application case (A72 background report by Peuportier et al. (2023)). "Gray" indicates than no specific choice is recommended.

Type of choice	Application cases			
	Regulation/ certification	Design tool	Facility assessment	Research
1_Generic vs provider-specific electricity mix	generic	generic	specific	
2_Geographic scope	national	national	national	
3_Production mix vs supply mix	supply mix	supply mix	supply mix	
4_Nature of trade flows	commercial or physical flows, explain the choice			
5_Modelling choice for the supply mix	production-export+import or production+import, explain the choice			
6_End uses dependence	universal if same temporal variation in buildings as national consumption, use-specific recommended otherwise (e.g. winter peak demand for heating)			
7_Time dimension	present, near future or long-term future mix, explain the choice			
8_LCA modelling approach	average, short-term marginal or long-term marginal, explain the choice			
9_Time granularity	annual or hourly, explain the choice			

4.3.26 Module B6: Treatment of renewable energy generated on site

One approach to achieve sustainable development goals in the area of conserving resources and reducing undesirable impacts on the local and global environment is to increase the generation and use of renewable energy. By generating and using renewable energy in the building and/or on the property, buildings can contribution to this. This can not only reduce resource consumption and environmental impacts in the operation of the building itself, but also reduce the environmental burden caused by third parties in case parts of the generated energy is exported and consumed by them. In addition to the increasing self-sufficiency with renewable energy, the aim is therefore to contribute to the decarbonisation of the energy supply through the "export" of energy beyond the system boundaries of the own building. In this way, buildings are transformed from “consumers” of energy into “producers / suppliers” of renewable energy.

The generation and export of renewable energy is not an end in itself. Expected environmental benefits only occur when there is a demand for renewable energy and this substitutes conventionally generated energy. The "substituted" energy is evaluated with special primary energy and emission factors. The strain on the networks must be also considered; in particular, a "network-friendly" feed should take place. This requires controlling the scope and time of personal use, provide energy storage in the building and export parts of all of energy generated, if required or desired. The relationship between self-use and export is influenced by local and national characteristics as well as by economic considerations.

The (renewable) energy generated on-site and is being self-used or exported or partially both, is not free from environmental impacts. A number of methodological issues are raised with respect to how to treat the energy and material flows associated with exported energy in a building’s environmental performance assessment. These are discussed below, and rules and recommendations are provided in Section 4.3.26.
There are three main allocation approaches for electricity produced on site (photovoltaics, but also wind) exported to the grid:

– **Approach 1:** A share of the life cycle-based environmental impacts of on-site electricity production corresponding to the proportion of self-consumed electricity is accounted for in the building LCA. The rest of the impacts, corresponding to exported electricity, is accounted for in the electricity mix of the buyer of the electricity (This is illustrated in Figure 4.26). This represents the “Step A” approach according to ISO 52’000-1 (clause 9.6.6) and is identical to approach B of the draft version of the revised EN 15978 standard.
– **Approach 2**: All life cycle-based impacts of the on-site renewable energy generating system are allocated to the building. The building LCA also includes the potentially avoided impacts from exporting electricity to the national grid (or e.g. future European mix). In the grid mix of the one purchasing the exported electricity, the exported electricity bears the environmental impacts of the national grid (or future European mix). This correspond s to Step B” approach according to ISO 52’000-1 (clause 9.6.6) and is illustrated in Figure 4.27. It is important to stress that in this approach, the avoided impacts have to be evaluated according to an electricity mix which can either correspond to attributional LCA (average mix) or consequential LCA (marginal mix), using hourly, seasonal or annual time step, recent past or future mix etc. (see the previous §).
– **Approach 3**: All life cycle-based impacts of the on-site renewable energy generating system are allocated to the building, and potentially avoided impacts from electricity export are reported as additional information in module D2, which is outside of the building LCA boundaries and therefore not accounted for in the building LCA result contrarily to **Approach 2**. This is identical to Approach A of EN 15978 standard (Figure 4.28).

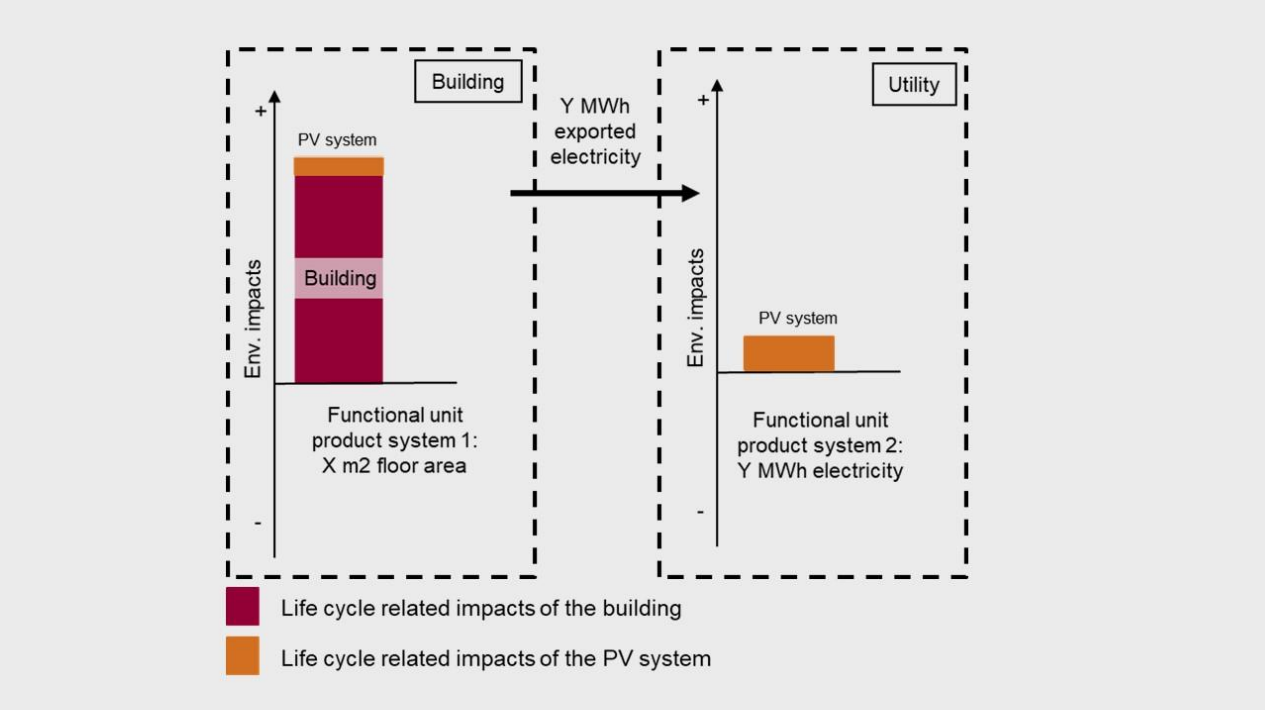

Figure 4.26: Approach 1 (Step A in ISO 52000-1; and approach B of draft EN 15978): Allocation of environmental impacts caused by onsite energy production between the building and the energy exported based on the share of self-consumed energy produced onsite. Note: The main elements of this approach are: (a) impacts related to the self-consumed share of PV electricity attributed to building; (b) impacts related to the exported share of PV electricity attributed to exported electricity; (c) Overall sum of environmental impacts equals the observed environmental impacts.

Reasoning for Approach 1: This approach ensures that electricity produced on-site and exported to the grid shows the environmental performance of the technology used to produce it (e.g. PV, wind, combined heat and power plant). The share of environmental impacts of manufacturing, operating and dismantling the energy producing technology attributed to the building corresponds to the share of self-consumption. Building integrated PV systems may be subdivided into the parts needed for weather protection (front glass, supporting structure; attributed to the building's LCA) and the parts needed to produce electricity (panel except front glass, cabling, inverter; attributed to electricity production). The building's environmental performance depends on the share of self-consumption.

This approach may be implemented in two different ways:

– **Approach 1a**: 100 % of the construction and manufacturing efforts (including replacements and end of life treatment) of the energy technology (such as (BI)PV) are attributed to the building in Module A and the pro rata environmental impacts of exported energy are subtracted in Module B6. In other words, the total embodied impacts of the renewable energy technology are initially fully assigned to the building and later proportionally reassigned in the event that energy is sold to third parties.
– **Approach 1b**: the share of self-consumption is determined and only this share of construction and manufacturing efforts of the energy technology is attributed to the building in Module A. No further (negative) environmental impacts shall nor need to be accounted for in Module B6, see Table 2 Example application of step A approach

This approach ensures that the environmental impacts of renewable energy are only accounted once: the self-consumed part is attributed to the building's LCA; the exported part is attributed to the utility or third party purchasing the renewable electricity. No potentially avoided impacts (grid mix electricity) are accounted for in the building's LCA which would imply that the exported electricity must bear the environmental impacts of the grid mix (corresponding to the avoided impacts).

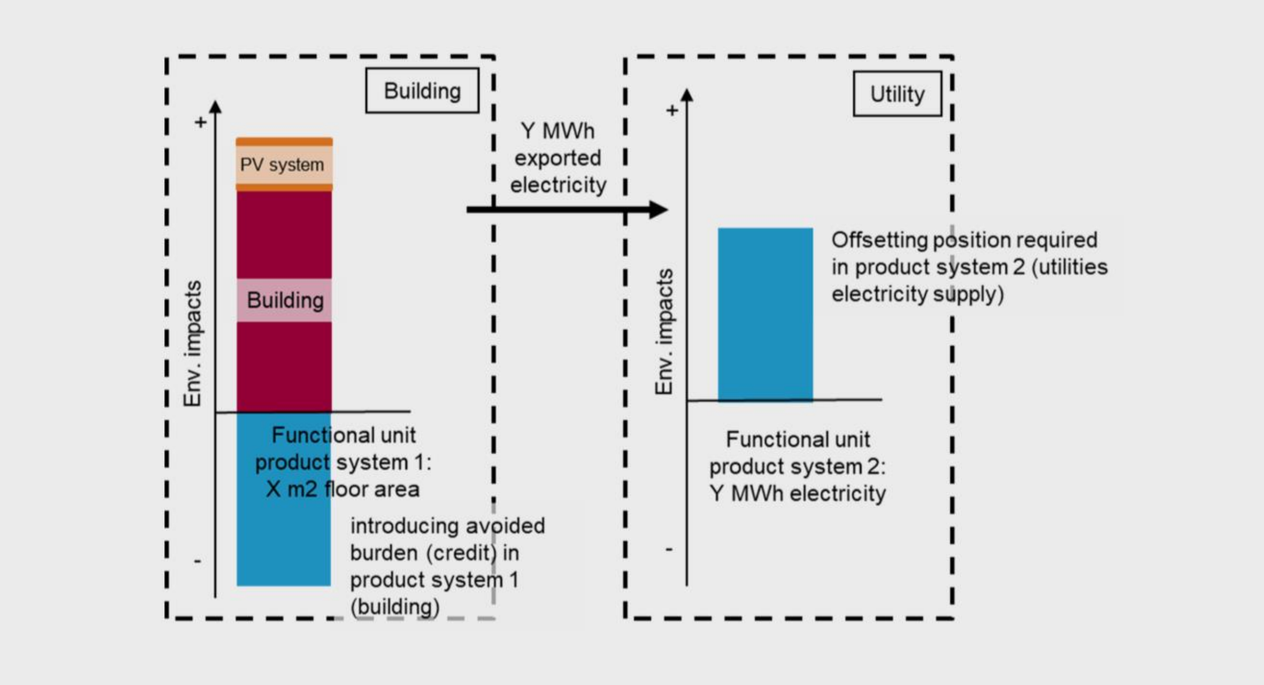

Figure 4.27 Approach 2 (Step B in ISO 52000-1): Allocation of 100 % of the environmental impacts of onsite energy production and 100 % of potentially avoided emissions outside the system boundary to the building. Note: The main elements of this approach are: (a) Potentially avoided burdens (credits), determined with grid mix environmental impacts and amount of electricity exported, are accounted for in building LCA; (b) (equivalent) off-setting position in utility's LCA of electricity required to avoid double counting; (c) Overall sum of environmental impacts equals the observed environmental impacts, only if off-setting position is booked in utility's LCA.

How the environmental impacts of a building with and a building without (BI)PV compare shall be assessed by comparing the LCA of a building with and a building without (BI)PV and not by including avoided burdens into the assessment of the building with (BI)PV.

Reasoning for Approach 2: A building exporting locally produced renewable electricity corresponds to a system with two co-products: the building and an electricity production. Evaluating the part of impacts related to the building is an allocation problem. The environmental benefit of a renewable production compared to the standard grid (avoided impacts) can be allocated to the consumer or to the producer. Installing a PV roof requires more effort (investment, time) than just consuming renewable energy produced by others. The whole roof is part of the property, and not only the self-consumption % of the PV roof. This is why Approach 1 accounts for this benefit in the environmental value of the property. Also, this benefit is a consequence of a design decision, so that it is accounted for when comparing a building with and without PV. There is no double counting of this benefit because if the exported renewable electricity is included in the grid mix, the benefit of the local renewable production is lower. The LCA results remain consistent if the scale of the evaluation is expanded at the neighbourhood level: neighbour buildings may consume exported electricity so that the self-consumption % is larger than modelling each building separately, but the environmental impact of a building remains the same using this approach. The results are also consistent regarding the environmental payback time of e.g. PV modules.

Reasoning for Approach 3: The reason for attributing all the impacts of the renewable energy producing unit to the building is the same as for **Approach 2**. Namely that the unit is part of the building (site). It is a conscious choice of the building owner/designer to place the energy producing unit (sometimes for economic reasons), so he or she should know which impact this generates.

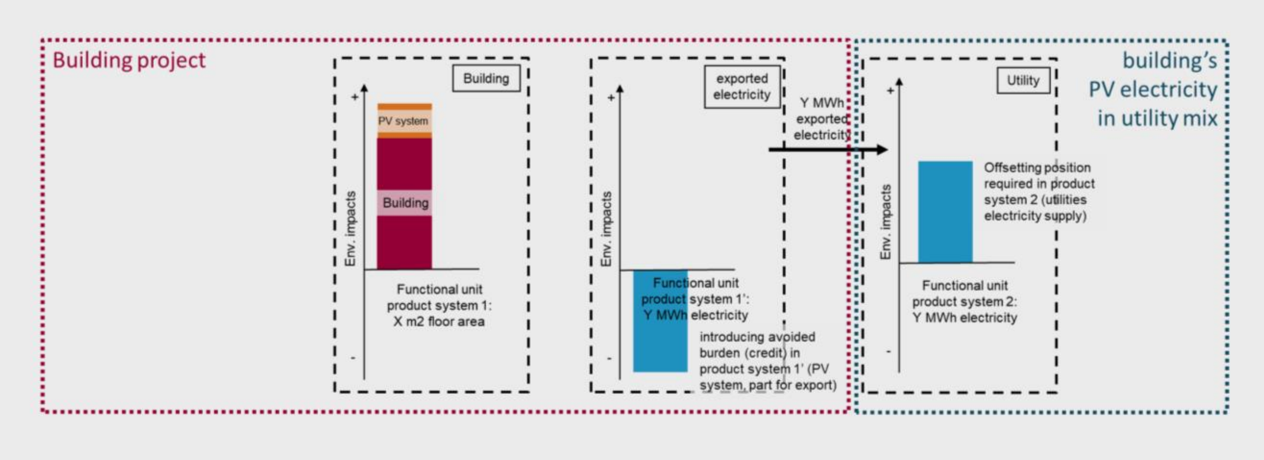

Figure 4.28: Approach 3: Allocation of 100 % of the environmental impacts of onsite energy production and 100 % of potentially avoided emissions in Module D2, outside the system boundary of the building but as part of the building project.

Reporting the potential benefits from exported energy in module D (outside of the system boundaries) is consistent with the recycled content approach at material level (prescribed by ISO 21930 and EN 15804). In both cases potential benefits occurring outside of the system boundaries are reported separately, as additional information and shall not be summed up with modules A-C results. In the European standardization, module D2 was introduced to document effects in connection with exported energy - see EN 15643. This prevents uncertain benefits (e.g. the choice of the grid mix used to model the avoided impact from exported electricity is prone to discussion and likely to evolve over the life cycle of the building) from being credited against impacts that occur today (production of the energy producing unit) and from being accounted twice (in the building LCA and in the LCA of the grid mix of the utility purchasing the exported electricity).

4.3.27 Module B6: Conclusions and guidance

Although the focus has so far predominantly been on the regulated part of the operational energy consumption, for the building industry, it is essential to gain a better understanding of the total operational energy use and related emissions by including B6.2 and B6.3 in the minimum documentation scope of methods. Although it can be argued that building design cannot influence unregulated energy use, especially B6.3, as it is highly influenced by user behaviour, extending the scope of methods can provide a better picture of the internal heat gains within the building and improve the dimensioning of PV systems and the determination of the degree of self-use of solar-generated electricity. As it is complex to predict the unregulated part, methods need to consider providing default values for B6.2 and B6.3 to assist designers in providing a comprehensive picture to third parties. There are examples of recent methods which are going in this direction. Based on all these considerations, related rules (Table 4.33) and recommendations (gray box) are drawn.

Table 4.33: Rules on how to define the scope of B6

ISSUE(S)	RULE(S)
How the minimum scope of B6 shall be specified?	The scope and the assumptions used for the calculation of B6 shall be specified in detail. If B6.2 and B6.3 are excluded, clear reasons shall be given.

Recommendations for action

Recommendations for policy, regulation and law makers (application / use case: C, see Table 1.2)

a. Include more aspects of energy use in the regulated part (integration of B6.2 into B6.1 for a start). Furthermore, determine basic principles, methods and calculation values to take into account the user-related energy consumption (B6.3).

National standardisation bodies (application / use case: C, see Table 1.2)

b. Analyse which proportions of the user-related energy consumption (module B6.3) lead to usable internal energy gains and must therefore be taken into account in the energy balance in any case. Possibly, a distinction should be made between B6.3a (with influence on internal gains) and B6.3b (without influence on internal gains).

Developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

c. Update documentation requirements for assumptions and boundary conditions important for the determination and assessment of B6 so that they are declared more precisely than today.

Developers / providers of calculation tools (application / use case: G, see Table 1.2)

d. Provide the possibility to users to include B6.2 and B6.3 modules

Researchers (application / use case: B, see Table 1.2)

e. Develop default values for B6.2 and B6.3 to assist method developers and provides in expanding their typical scope of assessment.

Even within a defined scope, the calculation and assessment of the operational energy use (B6) of buildings is influenced by several input parameters describing the external and internal conditions under which the building operates, which are usually assumed as fixed/standardised despite their dynamic nature, such as local climate and user patterns.

However, the local climate is subject to future changes due to global warming. Predicting the evolution of global warming in the next decades is by itself a very complicated matter with considerable implications and potential ramifications for the political, technical, environmental domains. The application to the construction and real estate sector of climate change analyses are paramount: since buildings usually have an expected life span of around a century, meaning what is being built today needs to be able to withstand the evolution of climate in the coming decades/century, meaning that climate resilience considerations need to be integrated and considered in building and energy systems design for the future. There are techniques already used for future climate assessment in the building sector but predominantly in the context of research investigations. While it is now in most cases accepted that the constraints coming from global warming should be included in the design of buildings, these are concerns in which the practitioner's community do not properly invest. This is for sure due to the limited availability of easy to use (and not time-consuming) tools that may allow practitioners to simply implement these kinds of analyses into their design.

When it comes to user behaviour during building operation, predicting it is a very complex task, therefore official methods are predominantly working with default use profiles. It is widely acknowledged that default occupancy profiles may overestimate or underestimate occupancy and occupant-related loads which in consequence may lead to selecting sub-optimal. While for the purpose of legal requirements, certification and benchmarking using default use profiles is indispensable to handle method-related uncertainty, it is useful for design tools to allow detailed occupant modelling using stochastic models, so that designers can identify designs that have greater robustness by considering uncertainty due to occupants' behaviour during building design.

Based on all these considerations, related rules (Table 4.34) and recommendations (gray box) are drawn.

Table 4.34: Rules on how to model operational energy use in relation to climate change and user behaviour

ISSUE(S)	RULE(S)	
How to incorporate climate change in B6 related aspects in LCA of buildings?	1.	The impact of climate change on the energy performance of buildings, according to projections of future weather data, is relevant and shall be considered in building LCA (particularly B6.1). In this context, providers and users of calculation rules and assessment methods shall be requested to apply future climate data for determining the B6 operational energy demand, with the precondition that such data is available by an official national body. If such future climate data are not available, at the minimum, current (recent time ranges) climate data shall be used.
	2.	Benchmarks provided by the method shall not be affected by future climate data. A building design is resilient when it is robust enough to fulfil all mandatory requirements by the method (withstand) also during extreme climate conditions.
How to incorporate the user behaviour in B6 related aspects in LCA of buildings?	3.	To define the impacts caused by the behaviour of the users on the building-related operational energy use (subdivided into regulated building-related part B6.1, building-related unregulated part B6.2 and user-related part B6.3), scenarios shall be developed and described in a comprehensive manner. As far as possible, a selection of scenarios shall allow the assumptions to be adapted as precisely as possible to the expected reality.
	4.	Additionally, a best- and worst-case scenario shall be provided per indicator[61] to allow the method users to examine this type of uncertainty in a concise way and provide such calculations as background information.

[61] Best- and worst-case scenarios may be different for different indicators, e.g. more electricity consumption for appliances reduces the heating need, inducing higher primary energy but lower CO2 in the case of gas heating.

Recommendations for action

Recommendations for policy, regulation and law makers (application / use case: C, see Table 1.2)

a. Make a more pronounced distinction between these two use cases: a) calculation to show the fulfilment of legal or other requirements using average conditions for climate, user behaviour, energy supply and other input parameters; b) creation of a forecast for the expected real performance based on specific expected conditions of climate, user behaviour, energy supply and other input parameters.

National standardisation bodies (application / use case: C, see Table 1.2)

b. Develop and provide scenarios and corresponding datasets for the future development of the climate. The datasets (e.g. weather files) should look a reasonable distance into the future (e.g. 30 years from today) and consider a worst-case scenario to help ensure the buildings' resilience regardless of the global emission reduction measures that are put in place.
c. Develop and provide realistic scenarios for user behaviour per building type

Developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

d. Same as recommendation (a)
e. Update documentation requirements for assumptions and boundary conditions important for the determination and assessment of B6 so that they are declared more precisely than today.

Developers/providers of calculation tools (application / use case: G, see Table 1.2)

f. Provide the possibility to users to switch between different data sets on climate and user behavior.
g. Incorporate interfaces able to read in the result of an energy performance calculation (usually B6.1), if necessary also able to read in the results of a simulation of a PV system.

Researchers (application / use case: B, see Table 1.2)

h. In case studies, consider a best-case and worst-case climate change forecasting scenario via downscaling (respectively). A thorough study based on a worst case and best-case scenario can already provide relevant information about the most sensitive components of the building LCA model (investigating multiple scenarios can be time consuming).
i. In case studies, consider different user behaviour profiles to provide insights about the most sensitive components of the building LCA model and how robustness can be improved.

The relative importance of the environmental impact of B6 in the life cycle of buildings does not only depend on the building and system characteristics and user behaviour, but also on the impact intensity (e.g. GHG emission intensity) of the energy sources used. As there are different modelling approaches to energy supply, different impact intensity factors occur. Sometimes, for the same source different emission factors are provided by energy authorities following different modelling choices. It is of paramount importance to select the right source for each respective purpose of an environmental performance assessment. Furthermore, often, parts of the on-site generated/produced renewable energy is exported to third parties (e.g. grid). The way to allocate the environmental impacts associated with exported energy raises a number of methodological issues. Rules (Table 4.35) and recommendations for how to handle the "supply side" of operational energy consumption are provided below.

Table 4.35: Rules on what type of emission factors to use for energy supply and how to allocate exported energy.

ISSUE(S)	RULE(S)
How to deal with the various sources of information for assessment of energy supply?	1. In the case of a static approach clearly defined sources shall be given for primary energy-, impact- and emission factors for different types of energy supply. The factors shall be regularly updated.
	2. In the case of a dynamic approach, scenarios shall be given for the current stage and further development of primary energy-, impact- and emission factors.
	3. The use of generic national supply mixes shall be preferred, unless the method is also applied to the “in-use” building phase, where the use of a provider-specific factor shall be allowed. The other modelling choices behind the primary energy and emission factors of the national supply mix depend on the context and shall be explained and justified as background information (see Table 4.32).
How to deal with the boundary conditions of energy demand?	4. It shall be declared precisely under which assumptions and system boundary conditions the energy demand was determined. It shall be shown separately for B6.1-B6.3.
	5. When comparing supply variants, it shall be ensured that all emission and impact factors include upstream activities (upstream supply chains).
How to allocate the renewable energy generated on site?	6. The effects of the self-consumed renewable energy generated via technologies mounted on the building and/or on the building site shall be considered in the calculation of B6; this leads to a reduction in the amount of energy used in the building supplied from external energy services and, as a result, the associated resource use and environmental impact.
	7. In the case of exported renewable energy to third parties, it shall be declared how the embodied impacts associated with life cycle of the building-integrated or on-site located renewable energy system are allocated to the overall LCA of the building. These can be either (see Section 4.3.26): – proportionally allocated to the building according to the share of energy used in the building in relation to the total amount of energy produced (Approach 1b); – initially fully assigned to the building and later proportionally reassigned to it in the event that energy is sold to third parties (Approach 1a); – fully assigned to the building (Approach 2 & 3)
	8. In the case of exported renewable energy to third parties, it shall be declared whether and how the potentially avoided emissions due to exported energy are allocated to the overall LCA of the building or reported separately. Any choice (Approach 1-3) shall be justified.
	9. Regardless of the allocation approach followed (see Section 4.3.26), the following additional information shall be provided under module B6 to improve transparency: (1) amount of renewable energy produced on site; (2) degree of self-sufficiency/ self-use; (3) amount of exported energy in terms of supplying energy to third parties; Note: It is possible to display surface areas that are potentially suitable for the generation of renewable energy on the building and the degree of their utilization. (Analyses of “solar potential”)

4.3.28 How to model operational water consumption (module B7)

According to the international (ISO 21931-1:2022) and European standards (EN 15978:2011, under revision) module B7 "operational water use" covers the impacts associated with all water used during a building's operation. Particularly, module B7 intends to capture all impacts related to the water supply (and its pre-use treatment) and wastewater treatment during the use stage, but excluding water use in relation to maintenance and cleaning (B2), repair (B3), replacement (B4) and/or refurbishment (B5) that are reported in the related modules. Furthermore, although impacts (including from energy use) associated with the supply and treatment of water (both before and after use) occurring outside the building boundary are included in B7, any impacts associated with energy use from water-related systems within the building, e.g. provision of domestic hot water, operation of pumps are reported under module B6. Regarding the reporting of those impacts, similar to module B6, the draft European standard (prEN 15978-1:2021) proposes to separate B7 into two categories, distinguishing water used by building integrated systems, such as drinking water supply, water for sanitation, domestic hot water, irrigation of landscape areas, green roofs, etc. (B7.1) and water used by non-building integrated systems (appliances), such as dishwashers and washing machines (B7.2).

In general, one can look at the impacts associated with **operational water use and wastewater treatment** in three stages: (1) water treatment and distribution; (2) water use in buildings; (3) wastewater treatment (Figure 4.29). Particularly what drives the LCA impacts related to these three stages is that:

- each one of them requires energy (and therefore is also indirectly associated with GHG emissions among other impacts). If the energy is consumed within the building site (e.g. energy needed to operate a building-integrated wastewater treatment), this becomes part of B6.
- wastewater treatment results in direct GHG emissions from biological processes.
- Chemicals are consumed in water and wastewater treatment which are associate with embodied impacts (production + transportation)
- Wastewater treatment results in sludge disposal which contributes to ecotoxicity
- The final affluent of the entire process contributes to eutrophication.

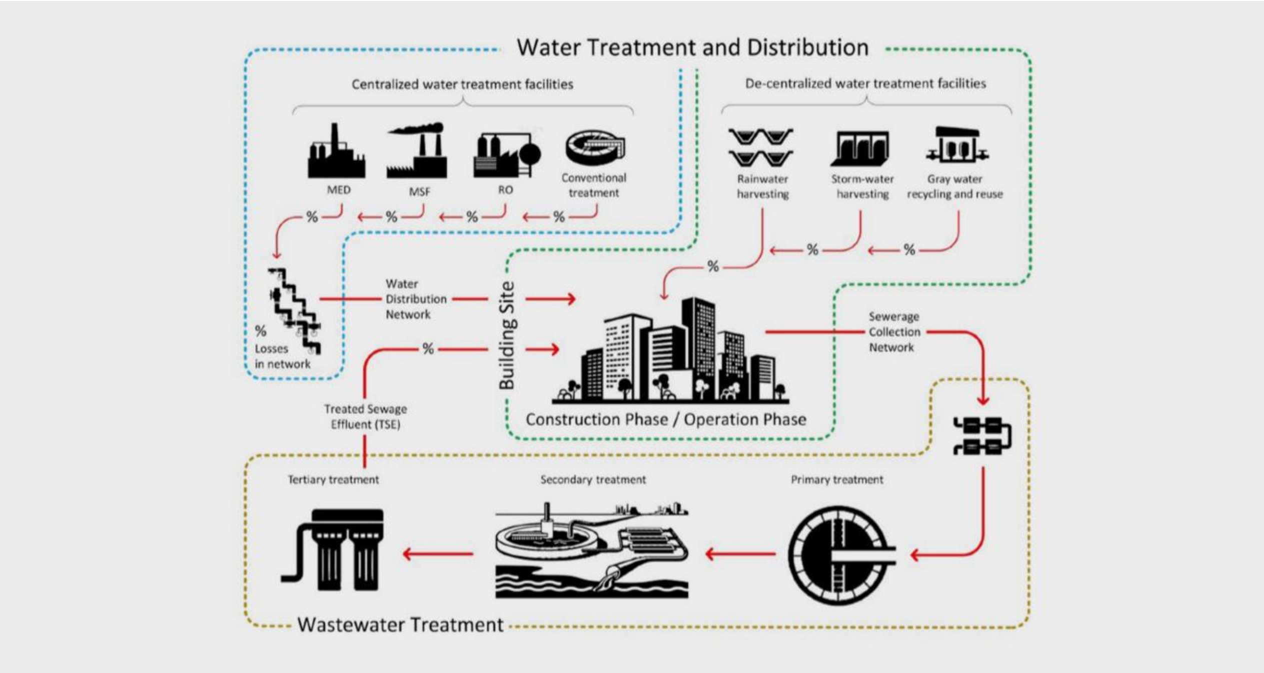

Figure 4.29: Main stages of the built environment hydraulic cycle: water treatment and distribution, water use and wastewater treatment. (Source: Mannan and Al-Ghamdi (2020)).

In order to consider the consumption of resources in water supply and disposal, an LCA of these processes is required in the narrower sense. Indeed, a study provided by eTool[62] shows that, along with freshwater depletion, the indicators to which B7 may have a non-negligible contribution are terrestrial aquatic ecotoxicity, eutrophication potential, **global warming potential** and acidification potential[63]. It should be here noted that water deprivation potential has only been recently discussed as a core environmental impact indicator in the CEN TC 350 standards – see Section 4.5 for more details.

To calculate these impacts would require the following inputs:

– The amount of water from all sources (potable water, greywater, rainwater etc.) entering the building on the basis of the calculated/estimated or the measured annual amount of water used to meet the different needs associated with defined uses of the building. It is important to avoid double counting where any water is recycled and reused within the building.
– Impact conversion factors for water use and treatment as published by the local water supplier or, if unavailable, generic conversion factors from an appropriate source.
– An assumed % wastewater volume of water supply volume (e.g. wastewater volume is 95% of water supply volume)
– Impact conversion factors for wastewater treatment as published by the local supplier or, if unavailable, generic conversion factors from an appropriate source.

Current status of methods: Not many methods include B7, and most of them just account water demand and not the supply chain impacts of water supply and its pre- and post-treatment. Examples of methods including both upstream and downstream processes (i.e. wasterwater) are the Belgian method “Environmental profile of buildings” (Lam and Trigaux 2021) and the French Pleiades LCA approach[64], while only the upstream supply chains are considered by the e.g. UK RICS methodology[65]. The exclusion of B7 and especially of its life cycle-based consideration can be attributed to lack of LCA data for these processes and especially wastewater treatment. Examples of national data for freshwater supply and treatment processes are Ökobau.dat[66] and BEIS[67].

However, Australia already includes scope 3 emissions from water supply, wastewater treatment and waste in the emission boundary of its carbon neutral building standard (Commonwealth of Australia, 2020). In future, carbon impacts from water consumption during operation and use will also be included in other net zero assessments. For example, LEED Zero Carbon certification will expand in the future its system boundary to incorporate carbon caused from water consumption, (along with waste generation, and the embodied carbon of materials used) into the carbon balance (USGBC 2020).

The water consumption during operation is a partial water footprint. With a full consideration of the resource consumption and all environmental impacts, a water footprint of the full life cycle of a building can be determined. Since A72 does not only deals with primary energy and GHG emissions, but also other environmental aspects, there is medium-term interest in including the use of water over the entire life cycle and, in this respect, also considering the water consumption and pollution during the production of building materials and the execution of construction processes. The methodical basis to be used for this is provided by the product water footprint (e.g. Gerbens-Leenes et al. 2018).

[62] See: http://etoolglobal.com/wp-content/uploads/2015/06/International-Residential-Benchmark-Weighted-x10-dwellings-v28.pdf
[63] Some tools like Equer provide the possibility to choose compost toilets, with less eutrophication impact
[64] using generic ecoinvent data. See: Online users manual of Pleiades LCA (EQUER), see https://docs.izuba.fr/v4/fr/index.php/Projet_/_Eau?toc-id=1085 Please note that in the model the functional unit for wastewater treatment is not per m3 but per person because reducing the quantity of water does not reduce the quantity of soap and other pollutants.
[65] based on BEIS 2016 Government GHG conversion factors although it is important to note that B7 is not mandatory in RICS methodology
[66] See: https://oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=ce3057d1-3371-47b4-a982-a1c42c2c6a85&version=20.19.120&stock=OBD_2021_I&lang=de

[67] See: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016

4.3.29 Module B7: Conclusions and guidance

So far, the life cycle-related environmental impacts associated with operational water use have been neglected by most methods and tools. This can be attributed to the unclarity surrounding this module in the standards. Like module B6, B7 involves the calculation of the demand side (building-related and user-related water demand which can be expressed in per person or m^2 and can be an indicator by itself) and the determination of impacts associated with the supply side (upstream and downstream impacts of water supply and wastewater treatment). The water use without upstream and downstream impacts has been so far in focus due to the perception that supply side impacts can be negligible on building level or the lack of data. With the inclusion of the life cycle indicator "water deprivation potential" as a core indicator in the CEN TC 350 standards, it is expected that B7 will also gain in importance. This indicator is not only relevant for B7 but also for the manufacturing of products (A1-3) and other modules of the life cycle but B7 will be a critical module for this. The contribution of B7 to GHG emissions has also started to be observed for inclusion in different "net zero" approaches. The following rules (Table 4.36) and recommendations (grey box) apply to both new construction projects and refurbishment projects and are aimed at improving transparency.

Table 4.36: Rules on how to model operational water use

ISSUE(S)	RULE(S)
How to model the life cycle-related impacts and resource use of operational water use?	1. Whether and how module B7 is taken into account shall be clearly described. What water uses are included in the scope of B7 shall be clearly stated, especially if irrigation of green roofs and outdoor facilities is included/excluded. If possible, a distinction shall be made between water used by building integrated systems (B7.1) and water used by non-building integrated systems (B7.2).
	2. Whether the energy consumption and GHG emissions for water heating and water transport in the building are assigned to module B6 or module B7 shall be stated clearly.
	3. Users shall be requested to declare the exact quantity of drinking water replaced by rainwater.
	4. Users shall be requested to declare the exact quantity of drinking water replaced by greywater, as well as how high the impacts of the water treatment for this are. Where this is allocated shall be clearly stated.
	5. Users shall be requested to declare whether the water is drawn from the network or from an own well.
	6. Users shall be requested to declare how much water is discharged into the sewer on site, or seeps away, treated or stored.
	7. A comparison must be made with cost calculation values.
	8. Whether B7 includes/excludes the supply chain impacts shall be clearly stated.

Recommendations for action

Data providers (application / use case: F, see Table 1.2)

a. Provide LCI data for water supply and wastewater treatment

Researchers (application / use case: B, see Table 1.2)

b. Carry out LCA-based research to examine all the impacts of building's water use. Ideally, develop LCA data for different types of water supply and treatment, as well as wastewater treatment (including emerging technologies).

4.3.30 How to model building-induced mobility (possibly covered in informative module B8)

In the scope of operational impacts, the current considerations go beyond the inclusion of the user- and building-related energy consumption. The recent update of standard EN 15643 already includes an additional module B8 for “Users activities” in the list of information modules describing the model of the life cycle. However, this module is still open to interpretation and therefore still optional. National methods which have already attempted to incorporate mobility triggered by the location of the building in their scope can form the starting point for this, e.g.:

– The Swiss standard SIA 2040 includes guide values for everyday mobility, in addition to operation and construction. The calculation methodology for mobility is based on SIA 2039 and is based on assumptions about the travel distance per capita, access to public transport systems, retail shops, schools etc. and modal split of the different modes of transport. It is based on “well-to-wheel’’ emission factors that include infrastructure and the whole life cycle of the vehicle and fuel productions of different modes of transport. A corresponding Excel tool is available for the calculations.
– The Norwegian standard NS 3720 already includes the so-called “B8 transport in use”, and it is based on “well-to-wheel’’ emission factors that include infrastructure and the whole life cycle of the vehicle and fuel productions of different modes of transport.
– LEED Zero Carbon standard accounts as part of the carbon balance not only the GHG emissions caused from energy consumption but also occupant transportation.
– The French Pleiades ACV (EQUER)[68] design tool accounts for impacts related to home-work and home-shops transportation, making it possible to compare various building sites[69] during early design.

The GHG emissions connected with building-induced mobility can be significant. The life cycle assessment performed by Lausselet et al. (2019), indicated that operational mobility GHG emissions could contribute up to 15% of the total GHG emissions coming from the life cycle of a (net) zero GHG emissions neighbourhood in Bergen city, Norway. The daily distance travelled by inhabitants was found to be one of the critical parameters influencing the mobility GHG emissions.

4.3.31 Module B8: Conclusions and guidance

B8 is an “optional” add-on module. It can be used for aspects of user-related energy requirements not covered in B6.3, as well as building-induced mobility including the energy requirements of electric cars charged on site. It therefore makes sense to further subdivide B8 in the future (B8.1, B8.2, etc.). The exact content of this module is still unclear in the standards, therefore the rules (Table 4.37) provided below target at increasing transparency.

Table 4.37: Rules on how to model B8

ISSUE(S)	RULE(S)
How to model building-induced mobility?	1. Whether and how module B8 is taken into account shall be clearly described.
	2. If taken into account, module B8 shall be always reported separately from B6.
	3. If taken into account, whether the resource use and environmental impact factors used for B8 include/exclude the supply chain impacts shall be clearly stated.

4.3.32 How to deal with waste treatment and disposal processes (module C3-4)

Building materials have individual End-of-Life (EoL) treatments when the building comes at the end of its service life. Some proportion of building materials will be landfilled, while others will be incinerated and yet others will be prepared for recycling or reuse. These processes are represented by modules C3 and C4 in

[68] See: Online users manual of Pleiades LCA (EQUER), see https://docs.izuba.fr/v4/fr/index.php/Projet_/_Transports?toc-id=1087
[69] EQUER tool also includes domestic waste management in its calculation as another important aspect when comparing building sites.

the European and international standards. Particularly, for materials and/or components intended to be recovered and reused or recycled after the EoL of the building, any environmental impacts associated with their treatment and processing prior to reaching the end-of-waste state shall be included in module C3. For materials not being recovered for reuse and/or recycling the impacts resulting from any processing required pre-disposal and from the degradation and/or incineration of landfilled materials is reported under module C4.

Based on this, it is important for methods to provide such EoL scenarios for different types of products (e.g. see an example from Switzerland in Figure 4.30), especially the ones for which data gaps are most often seen. For example, CIBSE (2021) in its method for embodied carbon calculation for technical systems provides such values (Table 4.38).

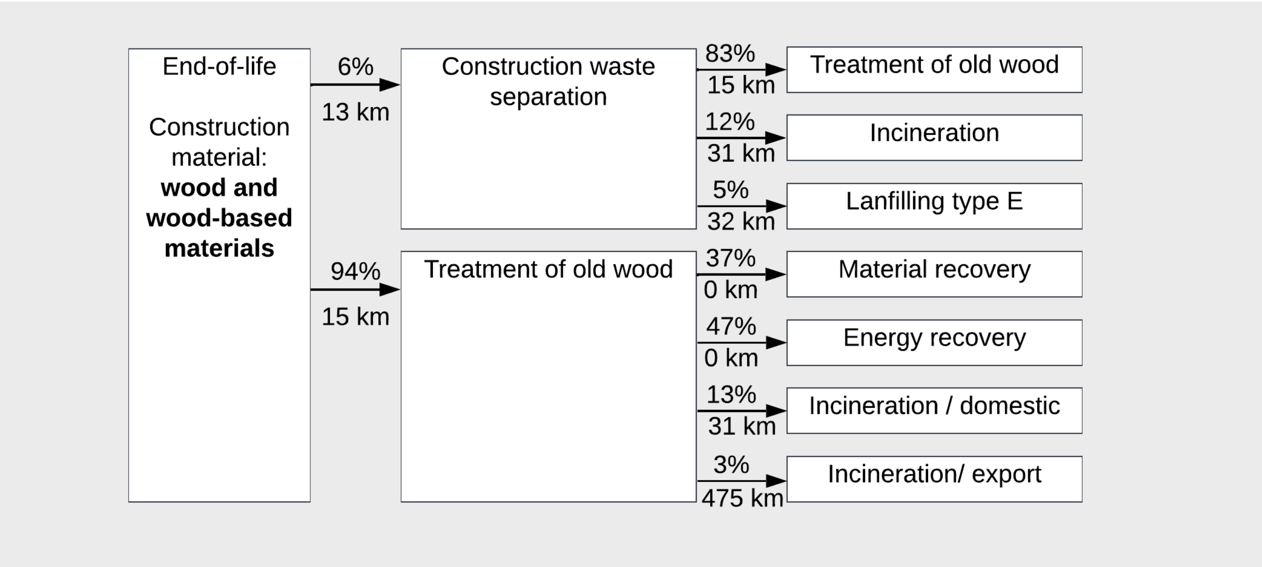

Figure 4.30: EoL pathway for wood products for the Swiss context (Source: Klingler and Savi (2021)).

Table 4.38: Scenarios and values provided by CIBSE (2021) for the EoL of technical building systems in case manufacturer data is not available (C3: waste processing; C4: disposal).

Product type	Recycle/ reuse	Landfill	Source
Heat generation equipment	70%	30%	Blend from Ökobau.dat and EPDs
Pipe	90%	10%	Ökobau.dat
Light	45%	55%	EPD
Ventilation system	40%	60%	EPD
Radiator	80%	20%	EPD
Wire cable	50%	50%	EPD
Landfill emissions	**Value** (kgCO_{2e}/kg waste)	**Source**	
All MEP products	0.0089	UK Government GHG conversion factors for electrical waste, plastic waste and metal waster	

It should be noted that modern landfill sites often employ techniques to capture the gases arising from organic matter decomposition – methane (CH_4) and carbon dioxide (CO_2). This will have an impact on the corresponding landfill emissions that should be adjusted based on the efficiency of landfill gas capture. Potential energy recovery from organic waste incineration and/or captured landfill gas burning should be reported within module D1. Organic items carry inherent feedstock energy and their decomposition also gives rise to CH_4 alongside CO_2 with sizeable associated EoL emissions. It is therefore crucial that any EoL emissions are examined in conjunction with potential benefits from energy substitution when incinerated to ensure the most beneficial and environmentally friendly trade-off.

As mentioned in Section 4.3.13 part of C3-4 scenarios is also the process of carbonation to be assumed at the EoL if the carbonation effect is included in an assessment. This parameter is determinant of the level of overall importance of this effect.

4.3.33 Modules C3-4: Conclusions and guidance

Each type of construction material has a different route at the EoL. it is important for methods to provide such scenarios for different types of products. Rules (Table 4.39) and recommendations are provided below.

Table 4.39: Rules on how to model waste treatment and disposal processes (modules C3-4).

ISSUE(S)	RULE(S)
How to handle C3-4 impacts?	1. C3-4 shall be included in the minimum documentation scope. If not, it shall be justified. The scenarios used for their modelling shall be described in a comprehensive and detailed manner.
	2. Individual 100% scenarios shall be provided in the background so that can be mixed up proportionally.

4.3.34 How deal with impacts beyond the system boundary related to recycling, reuse and energy recovery (module D1)

At the end of a building's useful life, it is deconstructed or demolished. Different types of waste materials occur which can either be landfilled, or recycled, or incinerated for energy generation (energy recovery). Among other things, there are options for material or thermal recycling (incinerated for energy generation). In special cases, dismantled building components can be reused elsewhere. This also applies to building constructions, components or systems that are exchanged in connection with replacement measures (B4) at the end of their service life or useful life. In this case, too, dismantled building components can be reused, materially or thermally recycled or disposed of.

In the interest of reducing buildings' life cycle-based environmental impacts and resource use, minimizing the proportion of deconstructed building materials, products, components and/or technology systems to be landfilled directly (it causes costs and takes up landfill volume) is one strategy. Keeping materials and components as long and sensible as possible in a 'circle' is also a contribution to a circular economy. The reuse and recycling are influenced by:

a. features and properties of the building products themselves (recyclability),
b. type of planning of the building (here influence on the dismantling and recycling friendliness) including the concrete installation situation of components,
c. the type of dismantling planning and the dismantling of components and/or buildings (e.g. selective dismantling with the removal of pollutants) and
d. the type of waste processing.
e. The current and future demand for used products and/or recycled materials.

It has been discussed for decades whether and to what extent the effects of recycling, reuse or recovery can be determined and assessed during the design of buildings. Examples of such work are given by Thormark (2001) and Dorsthorst and Kowalczyk (2002), which show that the idea of determining recycling potential was developed early on. It expresses the potential possibilities for saving resources and relieving the burden on the environment after the end of the life/useful life of the building or components. Such effects are therefore in the future and only occur with a certain probability. One way to increase the probability is for manufacturers to agree on take-back and recycling guarantees.

Transparency on the potential benefits and loads outside the system boundaries of an assessed building of such processes is necessary. In the international and European standards for environmental performance assessment of buildings (i.e. ISO 21931-1:2010, EN 15978:2011, both currently under revision) such information can be reported under Module D "Benefits and loads beyond system boundaries" (see also Figure 4.3). In the latest draft version of European and international standards, Module D is now divided into two submodules:

– D1: represents the potential environmental benefits and/or loads resulting from reuse, recycling and energy recovery resulting from the net flows of materials exiting the system boundary.
– D2: represents the potential environmental benefits and/or loads resulting from exported utilities (e.g. electric energy produced by photovoltaic panels on the roof, thermal energy and potable water) exiting the system boundary (see Section 4.3.26).

In principle, all impacts and benefits related to the energy and mass flows utilized beyond the system boundary can be reported under this module D1. Essentially, Module D1 (in combination with module C3) is the relevant one for 'circular economy' and can be used as a metric to quantify the potential effects of circularity as a characteristic of buildings and/or building components.

Given the speculative nature of these scenarios and the long lifespan of a building module D1 shall be reported separately as supplementary information acc. to the standards. Not only energy mixes and production processes are very likely to evolve (as discussed in previous Sections), but also the market demand for recycled construction products or secondary fuels at the time of demolition is uncertain. On the other hand, a building project may start with the demolition of an existing building, and in this case end-of-life processes occur in the beginning of the study period (unless these EoL processes have already been allocated to the existing building). This is also the case for a renovation project if some elements are decommissioned. Furthermore, the reporting of module D1 has so far been voluntary on building level. Module D is however mandatory on product level according to the A2 amendment of EN 15804 (CEN, 2019) and therefore in the future this information will be available in the selection process of construction products and for assessments on building level.

For example, module D1 can be used to calculate what the GHG emission reduction potential of primary metals is, that are being recycled. The potential depends on how much primary material the EoL recycling is assumed to replace as well as on what manufacturing process is likely to be replaced. Similarly, environmental benefits of energy recovery from waste incineration can be calculated, depending on what fuel it is assumed to be replacing. According to the standards, all information on disposal or recycling/reuse/recovery shall be based on scenarios of today's processes and technologies (acc. to the standards), so the information can be reliable, but must also be interpreted for an assessment of the future cycle options for products.

When discussing D1, a distinction must be made as to whether an assessment handles recycling potential for building products/components/systems or recycling potential of an entire building. A distinguish between a product-related D1 and a building-related D1 is necessary. The use of building products with a high recycling potential is a prerequisite for making buildings recyclable.

In relation to the GHG emissions in the life cycle of buildings, case studies show that the D1 value is comparatively low, i.e. below 5 % (Frischknecht et al., 2019; Frischknecht et al., 2020) (but for other indicators D1 can be significant as later shown). However, this potential can only be tapped if the components are installed in a disassembly- and recycling-friendly manner and corresponding scenarios are selected. Only through such a scenario in C1 at building level can the recycling and reuse potential of products be used and taken into account in D1 of the building. Acknowledging the importance of this issue, the recently published standard ISO 20887:2020 provides the basis for describing the disassembly variants in the form of scenarios. It is also important to stress that D1 of the building is made up of possible effects that arise not only at the EoL of the entire building but also at the EoL of building components at their replacement (B4). Therefore, D1 net benefits occur already after the first 15-20 years of the building operation when the first systems are replaced with new ones. In relation to the treatment of module D1 the following questions arise:

f. Is a building-related module D1 significant relative to the building life cycle impact A-C?
g. What are the different methods suggested for modelling recycling and reuse in LCA for products and/or buildings by important standards and guidelines and how the result changes? What is the current status of national methods?
h. What are the methodological issues related to the practical implementation of a product related module D1 according to the latest EN 15804+A2 standard?
i. How big are national differences in product-related module D1?

Key topic-specific definitions

Recycling rate: it is the rate of waste prepared for recycling into useful material and sent back into the economy by the total amount of waste. For example, a recycling rate of 60% for a material type means that in 100kg of waste material of this type 60kg will be recycled into new materials of this type and 40kg will be sent to landfill.

Secondary material: it is the material recovered from a previous use or from waste which substitutes primary materials. Secondary material is measured at the point where the secondary material enters the system from another system. Examples of secondary materials (to be measured at the system boundary) are recycled metal, crushed concrete, glass cullet, recycled wood chips, recycled plastic.

Closed loop recycling: it is when the discarded material or product is recycled back into the same product without degradation of properties. For example, the recycling of steel scrap to make new reinforcement bars is an example of a closed-loop recycling system. Theoretically, this can happen indefinitely with no loss of value (therefore the loop is closed). This type of recycling is more straightforward to calculate as the environmental impacts are directly offset by the new product that would have been required to be made from scratch.

Open loop recycling: it is when the discarded material or product is recycled back into a different one altering its physical properties, usually being downgraded to a product of lower quality and/or value. In general, open loop recycling needs special treatment to differentiate where impacts and benefits will be allocated. Usually, economic allocation is used to understand the impacts that are being offset. Typical examples of open loop systems include: (1) Brick waste or concrete waste that is crushed and used in road base; (2) Plastics that are down cycled into less pure products; (3) Glass that is crushed and used as aggregate. Although these materials do offset the use of primary materials and hence can have net benefits on the environment, the materials they are replacing often have very low primary impacts anyway (e.g. road base). Therefore, the benefits can be marginal and may depend largely on transportation distances.

Energy recovery (from waste): It is the conversion of non-recyclable waste building materials into usable heat, electricity, or fuel through a variety of processes, such as combustion.

End-of-waste state: The end-of-waste state for waste is considered to be reached when the material conforms to the following criteria (EN 15804):

- the recovered material, product or component is commonly used for specific purposes;
- there is a market, characterized by a positive economic value, for, or a demand for, the recovered material, product or component;
- the recovered material, product or component meets the technical requirements for the specific purposes and complies with existing legislation and standards for products;
- the use of the recovered material, product or component does not lead to any overall harmful environmental or human health consequences.

Relative significance of Module D on the building level: Until 2020 the declaration of module D has been optional both at product and building level and therefore most LCA studies exclude it. This has resulted in little experience regarding its calculation. The question of the relevance of module D for building LCAs was recently addressed by Delem and Wasties (2019a) based on a Belgian case study. This study showed that module D (here in the meaning of D1) can be significant for some indicators (Table 4.40). It also showed that the contribution of module D varies less according to the building variants than to the impact categories considered. From a material perspective, module D is particularly significant for metals both because of their high recycling rates and the high impact of their primary production which is potentially avoided by recycling (Figure 4.31). The significance of module D, however, highly depends on the choice of several assumptions (e.g. recycling rates and recycled content, transport scenarios for primary and secondary materials, potentially avoided primary production, definition of point of functional equivalence, efficiency of incineration) which are later discussed. Therefore, care should be taken for its interpretation.

Table 4.40: The relative importance of module D (based on net output flows) compared to the total life cycle impact (modules A to C set to 100%) excluding operational energy (B6) of five building variants of a multi-residential building (with the same lay-out but different material compositions), shown across different impact categories as assessed in the Belgian assessment methodology (Source: Delem and Wasties 2019a). Note: green represents the highest benefit and red the lowest.

Impact category	building variant of a multi-residential building				
	Sand-lime brick	Hollow concrete block	Concrete skeleton	Wooden skeleton	CLT
GWP	-21%	-23%	-21%	-20%	-24%
ODP	-21%	-22%	-21%	-20%	-27%
AP	-15%	-15%	-12%	-6%	-6%
EP	-42%	-42%	-39%	-30%	-25%
POCP	-27%	-27%	-24%	-14%	-12%
ADPelements	-52%	-52%	-52%	-47%	-45%
ADPfossil	-25%	-26%	-24%	-23%	-28%
HTcancer	17%	18%	16%	9%	8%
HTnoncancer	44%	45%	41%	24%	16%
PM	-18%	-19%	-17%	-13%	-9%
IR	-17%	-17%	-16%	-20%	-36%
Ecotox	-4%	-3%	-4%	-4%	-4%
Water	-14%	-12%	-14%	-34%	-26%
SOM	-13%	-14%	-13%	-11%	-4%
Biodiversity	-23%	-24%	-22%	-12%	-3%
Monetised score	-8%	-8%	-7%	-9%	-10%

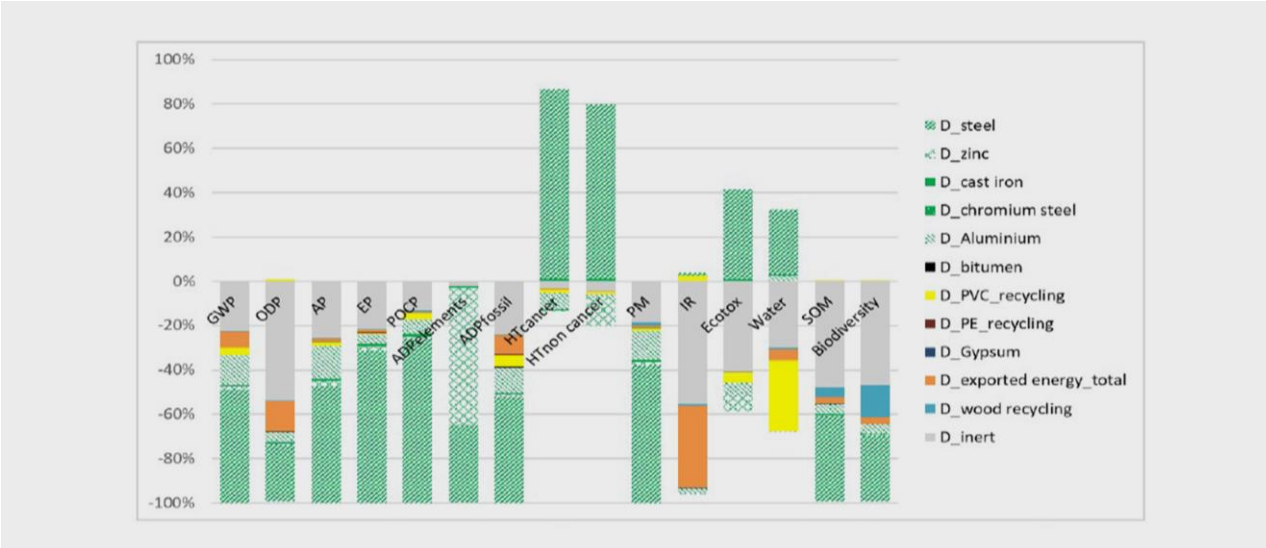

Figure 4.31: An overview of the contribution of each type of material to module D for the sand-lime brick framed building as an example. (Source: Delem and Wasties 2019a). Note: Even though no metal structure was considered among the building variants, and technical installations were excluded from this case study, metals and especially steel represented a major contributor to module D.

Different approaches to recycling modelling: Different methods are proposed to account for recycling and/or reuse of products. The case study below uses a simple example regarding recycling of 1 kg steel used in a building to clarify these methods[70]. In the case of steel, these five methods are proposed by official organisations: cut-off, PEF (Product Environmental Footprint, versions 1 and 2), Worldsteel and EN 15804+A2. It is important to highlight that the cut-off method leads to the same results as EN 15804+A2 without module D1 (as additional information). These two methods are the most applied by national assessment methods. Only the official French method E+C- deviates from current standards by considering one third of module D results and deducing it from A-C results (A+C+D/3). According to the authors of this method, the objective is to encourage design for recycling, but the benefit is divided by 3 accounting for uncertainty. The recycling process may occur at the fabrication stage or at EoL and thus four sub-cases have been defined (Table 4.41). It is assumed that the other stages (construction, use) are the same for new and recycled steel, therefore only impacts for A1-A3, C1-C4 and D are evaluated.

Table 4.41: Presentation of four subcases depending on whether steel is recycled at fabrication, at EoL or not at all.

1kg steel used in a building, 4 subcases:	% recycling at fabrication	% recycling at end of life
1) No recycling: new steel used at fabrication stage, steel is landfilled at end of life	0%	0%
2) End of life recycling: new steel used at fabrication stage, steel is recycled at end of life	0%	100%
3) Fabrication recycling: recycled steel at fabrication stage, steel is landfilled at end of life	100%	0%
4) Both recycling: recycled steel at fabrication stage, steel is recycled at end of life	100%	100%

[70] using LCIA data from ecoinvent v3.4 for “steel production, converter, low alloyed, RER”, “steel production, electricity, low alloyed, RER”, “treatment of scrap steel, inert material landfill, Europe without Switzerland”.

The graphs hereunder show the results regarding GHG emissions and separating modules A, C and D (Figure 4.32). All methods avoid double counting, and the highest impacts correspond to subcase 1 (0% recycling case): fabrication of new steel + landfill of steel waste. The cut-off method accounts for the recycled steel impacts in sub-cases 3 and 4 at the fabrication stage but the avoided impacts corresponding to EoL recycling are not considered part of the studied building's life cycle. On the contrary the worldsteel method considers that recycling steel at EoL and is equivalent to a closed loop recycling, i.e. subcase 2 leads to similar impacts as sub-case 4. The PEF version 1 method "50/50" is intermediate because the avoided impacts (fabrication of new steel + landfill – recycling) are shared 50% at fabrication and 50% at end of life. In the PEF version 2, avoided impacts may be shared differently for each material, depending on the demand and offer: for steel, there is not enough offer of recycled steel compared to the demand, so that EoL recycling is encouraged by a higher share of avoided impacts (80%). But adapting the allocation of avoided impact in terms of the demand and offer may lead to oscillations, whereas a 50/50 allocation could foster an equilibrium on the long term.

The results indicate that that one needs to be aware about how the used allocation method handles module D1. Some allocation methods value potential benefits of tomorrow as important as impacts of today (also considering the same production impact of future steel), while for other methods this is argued to be wrong. A key question is whether the choice of method would steer a building designer to take different decisions.

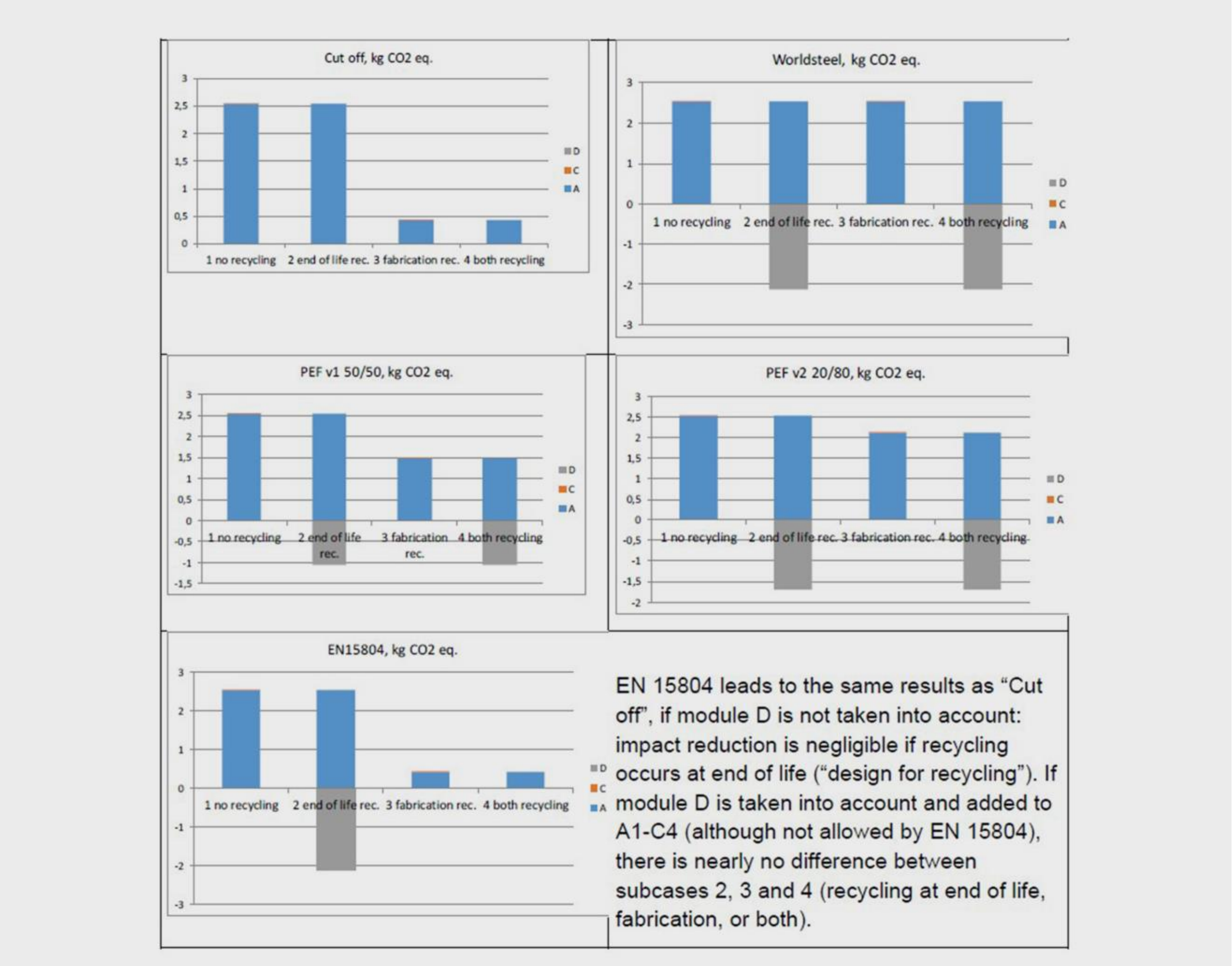

Figure 4.32: Presentation of four subcases depending on whether steel is recycled at fabrication, at EoL or not at all (Source: Annex 72 case study on modeling recycling).

Methodological issues for module D: When it comes to the practical implementation of product-related module D (here in the sense of D1) as described in the EN 15804+A2 standard, several methodological issues arise (see Delem and Wasties (2019b) for a more detailed analysis) which have a significant impact on the results on building level and therefore cause high uncertainty. These are:

a. **Calculation of net output flows**: According to EN 15804+A2 for module D (currently renamed to D1 for the building level), benefits and loads are calculated for the resulting net output flows of secondary materials or fuels to avoid double-counting. Therefore, in the case of recycling, previously recycled material inputted in the system is deducted from the amount of material going to recycling after the end-of life to hinder considering in module D recycling benefits already considered in module A (recycled content of materials). Delem and Wasties (2019b) illustrate the basic principles of calculating net output flows, distinguishing between four cases (depending on whether a closed loop or an open loop or no recycling takes place, as well as whether the input secondary flows are larger than the output flows) and discuss the inconsistencies of EN15804+A2 for some of these cases.

b. **Point of functional equivalence:** According to the standards, potential loads and benefits reported in module D are calculated from end-of-waste up to the point of reaching functional equivalence of the substituted primary material or fuel. Delem and Wasties (2019b) showed that the determination of the point of the functional equivalence can have a major impact on the loads and benefits reported in module D using the example of 1 kg of concrete and setting its functional equivalence at different levels, as well as the example of 1 kg alloyed steel (e.g. see Figure 4.33).

c. **Avoided "primary" production:** The primary production potentially substituted using secondary materials, fuels or exported energy determines which potential benefits are reported in module D1. However, this primary production cannot always be determined unambiguously. It may be unclear what product is actually potentially substituted when the secondary material becomes part of common (usual) practice. For example, secondary concrete aggregates, instead of substituting primary aggregates as infill for road constructions which is the most common assumption, could substitute stabilized sand in road construction. In that case the potentially avoided impact (potential benefit) reported in module D1 would no longer be crushed limestone, but a mix of 90% sand and 10% cement. This hypothesis would result in significantly higher net potential benefits in module D1 as shown in Figure 4.33.

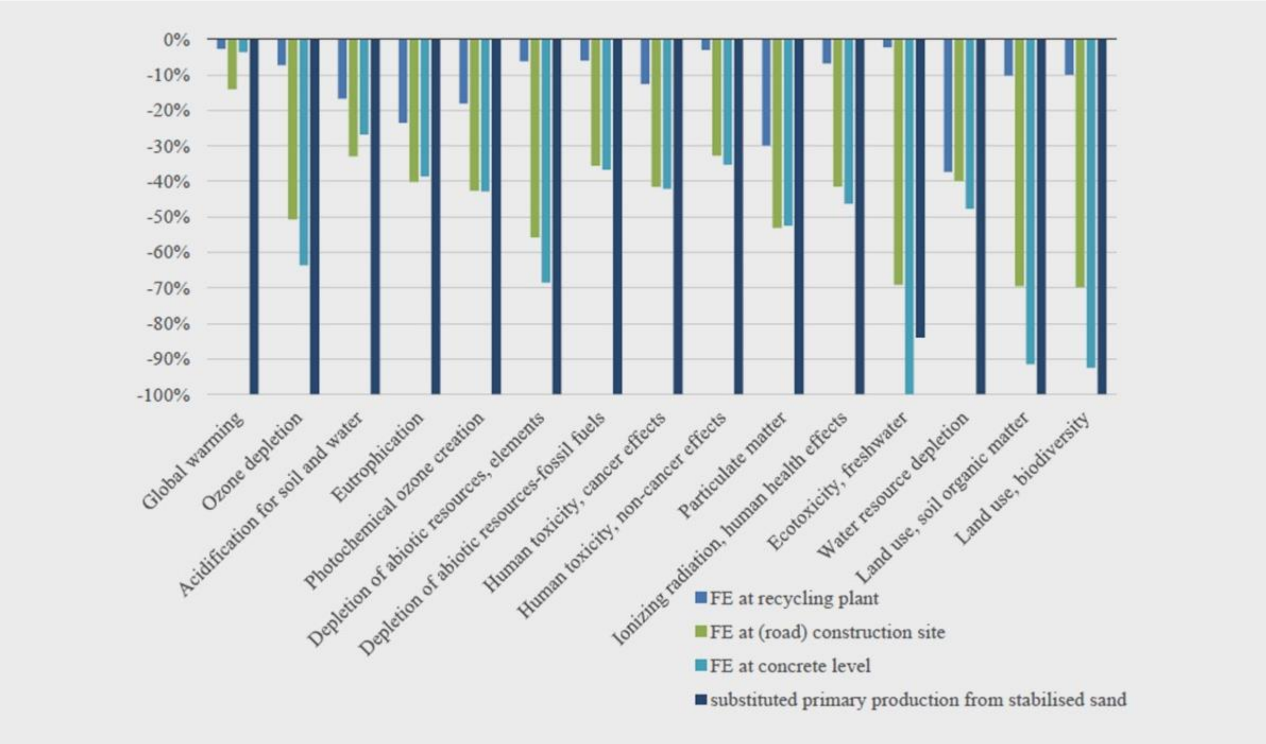

Figure 4.33: Net benefits reported in module D of concrete when recycled aggregates substitute crushed limestone and the point of functional equivalence (FE) is set at different levels, or when recycled aggregates substitute stabilised sand (Source: Delem and Wasties (2019b))

4.3.35 Modules D1: Conclusions and guidance

Module D1 does not only occur at the EoL of the entire building but also during replacements and refurbishment. While it may have the potential of an important module for designers who desire to determine the recycling and/or reuse potential of a building's components, its assessment still remains unclear. In this context, rules (Table 4.42) and recommendations are provided below.

Table 4.42: Rules on how to handle impacts and benefits related to recycling, reuse and/or energy recovery as part of module D1

ISSUE(S)	RULE(S)	
How to handle impacts and benefits related to recycling, reuse and/or energy recovery as part of module D1?	1.	If for any products used in the building module D data are available, these shall be considered at the building level in accordance with the project-specific end of life scenarios developed. In other words, if the assumptions made to estimate module D values in specific data sources differ from the project-specific scenarios, module D values shall be adjusted to fit the latter. The exclusion of module D despite the availability of data shall be justified (e.g. low confidence in data, unclear assumptions, etc.).
	2.	If recycling, reuse and recovery potentials are considered in a method, the applied allocation approaches of impacts and benefits shall be clearly described.
	3.	Users shall be requested to always report the underlying scenarios when reporting results from module D.

Recommendations for action

Recommendations for policy, regulation and law makers, as well as national standardisation bodies (application / use case: C, see Table 1.2) (application / use case: C, see Table 1.2)

a. Specify the 'selective deconstruction' scenario for the EoL of the building in C1. EoL recycling rates shall reflect today's practice rather than future predictions. This is the prerequisite for the determination and assessment a building-related D1 using information on product-related D1.
b. If addressed, request the reporting of module D1 separately from A-C results to be in line with the current international and European standards or justify.

Developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

c. Same as recommendation (a)

Data providers (application / use case: F, see Table 1.2)

d. Determine module D1 for your product for each possible treatment/recycling path, assuming current conditions in the region and/or in line with your national method. Determine a weighted average for the product-related module D1. The time of collection and the period of validity of the information should be declared.

Designers and engineers (application / use case: D, see Table 1.2)

e. Calculate module D1 on the building level, if product-level data are available for any kind of installed product and if national method requires module D1 reporting. D1 can give guidance about the recycling friendliness of a building design and show the potential benefits of design for deconstruction and reusability[71]. Investigate if there are options for a separate assessment of the building-related module D1 using benchmarks.

Researchers (application / use case: B, see Table 1.2)

f. Perform sensitivity analyses for different assumptions in relation to module D1.

[71] There is also a related ISO standard dealing with this topic, i.e. ISO 20887:2020 *Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance*

4.3.36 How to deal with exported utilities (module D2): Conclusions and guidance

D2 is a new module added to the recently updated standards of CEN TC 350 to cover exported utilities exiting the system boundary. This also includes exported energy as earlier mentioned. The question arises on how to calculate the net potential benefits associated with potentially substituted impacts and aspects from the most likely corresponding energy supply. Specific emission factors are needed to be provided by the method for this (reflected in the rule in Table 4.43). For rules on how to treat renewable energy generated on-site, incl. the exported part one may refer to Section 4.3.27.

Table 4.43: Rules on how to handle exported utilities as part of module D2

ISSUE(S)	RULE(S)
How to handle exported utilities as part of module D2?	Sources for emission factors shall be specified for potentially avoided emissions from exported utilities.

4.4 Environmental Indicators

4.4.1 General

To be able to quantify the use of resources and the undesired impacts on the local and global environment caused by a building during its whole life cycle, indicators are required. When benchmarks are set to each indicator, the life cycle-related environmental performance of a building can be assessed (see A72 report by Lützkendorf et al. (2023)). Another option is a full aggregated approach with one single benchmark.

In Paris agreement the focus is on GHG emissions but the standards oblige a set of indicators. A single focus on GHG emissions can be dangerous since problem shifting can occur in the future, where improvements are seen in reducing GHG emissions but an increase is seen regarding other environmental impacts such as fine particle emissions, increased biodiversity losses or generation of nuclear waste. Against this background, this section discusses issues surrounding indicators that can be assigned to the environmental performance assessment and safeguard both alignment with the current standards and avoidance of burden-shifting. It intends to support selected target groups in the development, selection, application and interpretation of individual indicators, as well as closed systems or open sets of indicators. Although this Section and this report as a whole focus on environmental aspects, it should be noted that consequences for a social and economic performance assessment may be considered in an overall sustainability approach, using additional related indicators.

4.4.2 Derivation, selection and description: General

In accordance with ISO 15392 (2019), assessment criteria and indicators shall generally be derived from the issues of concern (areas of protection) of sustainable development. These are (1) natural resources/ecosystem services (2) ecosystem quality and (3) human health and correspond to the endpoints of a life cycle assessment Figure 4.34).

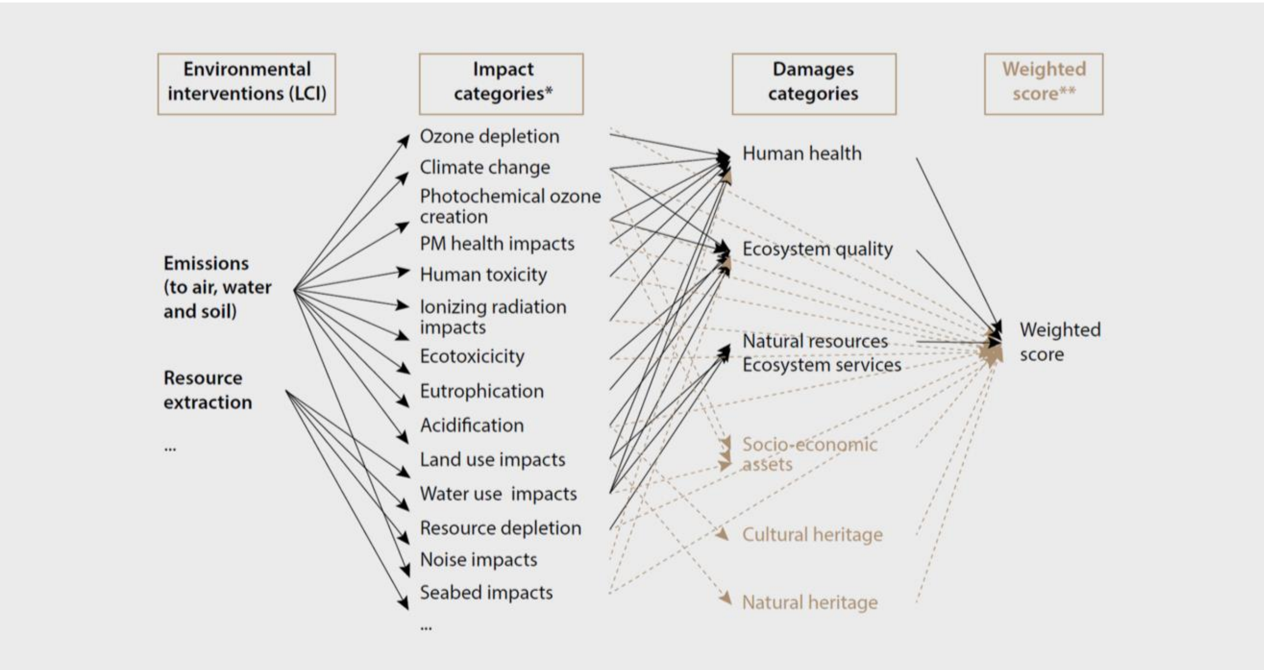

Figure 4.34: Updated structure of LCIA Framework (Source: Frischknecht and Jolliet 2016).

In an age of international recognition of the need to limit global warming by drastically reducing GHG emissions, the importance of the GHG emissions indicator is growing. In the construction and real estate sector, carbon footprint of buildings becomes a central design and verification parameter. However, it is necessary to use additional indicators to ensure that (a) there is no environmental burden-shifting to other impacts and (b) all relevant impacts on the global and local environment are taken into account. A wide variety of environmental and health-related topics can be described, calculated and assessed in the form of LCA indicators, partially also complemented with non-LCA indicators. Both ISO 21931-1:2022 and EN 15978 (2011) – which is now under revision – recommend lists of environmental related assessment criteria and specific indicators for the building level, which can and usually do form a basis for the selection of indicators by third parties.

Developments in standards: The recommended core environmental indicators by EN 15978 are shown in Table 4.44. The indicators highlighted in blue are the ones included in the product related standard (EN15804 +A2:2019[72]) and will likely be also included in the new version of EN 15978. It is important to note that the last three indicators in the list (Abiotic Depletion Potential (ADP)-minerals&metals, ADP-fossil and Water Depletion Potential (WDP)) are considered as needing special care when used according to the standard, as they may be subject to high uncertainties due to the limited experience with them.

The most important observation from the latest developments regarding the core indicators in the standards is that, although GWP 100 is an established and generally recognised indicator, the shares to be included (or excluded) have only been recently specified. There are now special prescriptions regarding the consideration of biogenic carbon, as well as the inclusion of impacts from land use and land-use change (LULUC). Furthermore, recent product-related standards (EN 15804+A2:2019 and ISO 14067:2018) require and recommend, respectively, the reporting of the **biogenic carbon content** (kg C) as additional information, which development will also be adopted by EN 15978 (see A72 background report by Saade et al. (2023)). A European standard (EN 16449:2014) already exists setting out the basic principles for its calculation[73].

The majority of the experts involved in IEA EBC Annex 72 believe that the biogenic carbon content specified by the standard should be supplemented by the fossil carbon content of products that are based on the material use of fossil fuels - e.g. plastics. In this respect, buildings can also be regarded as potential source for fossil CO_2 emissions.

Soil carbon storage may also be included as additional environmental information when proof is provided (EN 15804+A2:2019). However, the maturity of assessment method for soil carbon accumulation is poor. It should be also noted that the characterization factors for determining GWP can differ. Thus, information on the GWP for individual construction products, and therefore also for buildings, is not always comparable.

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[72] This European Standard is observed and applied worldwide.

[73] EN 16449:2014 Wood and wood-based products—Calculation of the biogenic carbon content of wood and conversion to carbon dioxide.

Table 4.44: Core environmental impact indicators according to 15804+A2 which will be followed by the new EN 15978 (currently under revision). Note: the updates to be included in the new EN15978 (compared to the version of 2011) are shown in blue.

Impact category	Indicator	Unit	Comment on EN 15978 updates
Climate change - total[a]	Global Warming Potential total (GWP total)	kg CO_2eq.	The new version will require to also report the different shares of GWP separately.
Climate change - fossil	Global Warming Potential fossil fuels (GWP fossil)	kg CO_2eq.	
Climate change - biogenic	Global Warming Potential biogenic (GWP-biogenic)	kg CO_2eq.	
Climate change - land use and land use change[b]	Global Warming Potential land use and land use change (GWP luluc)	kg CO_2eq.	
Ozone Depletion	Depletion potential of the stratospheric ozone layer (ODP)	kg CFC 11 eq.	same
Acidification	Acidification potential, Accumulated Exceedance (AP)	mol H^+ eq.	unit in the 2011 version: kg SO_2 -eq.
Eutrophication aquatic freshwater	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP freshwater)	kg PO_4 eq.	same
Eutrophication aquatic marine	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP marine)	kg N eq.	The topic of Eutrophication is more detailly handled than in 2011 version
Eutrophication terrestrial	Eutrophication potential, Accumulated Exceedance (EP terrestrial)	mol N eq.	
Photochemical ozone formation	Formation potential of tropospheric ozone (POCP);	kg NMVOC eq.	unit in the 2011 version: kg Ethene eq.
Depletion of abiotic resources - minerals and metals[c, d]	Abiotic depletion potential (ADP-minerals&metals) for non-fossil resources	kg Sb eq.	called ADPelements in the 2011 version
Depletion of abiotic resources - fossil fuels[c]	Abiotic depletion potential (ADP fossil) for fossil resources	MJ, net calorific value	same
Water use	Water (user) deprivation potential, deprivation-weighted water consumption (WDP)	m^3 world eq. deprived	new indicator

Notes:

a. The total global warming potential (GWP) is the sum of
   - GWP-fossil
   - GWP-biogenic
   - GWP-luluc

b. It is permitted to omit GWP-luluc as separate information if its contribution is < 5 % of GWP-total over the declared modules excluding Module D.

c. The abiotic depletion potential is calculated and declared in two different indicators:
   - ADP-minerals&metals include all non-renewable, abiotic material resources (i.e. excepting fossil resources);
   - ADP-fossil include all fossil resources and includes uranium.

d. ultimate reserve model of the ADP-minerals&metals model

Current standards also provide the following additional impact indicators which may be included in assessment only where appropriate data is available (see Table 4.45). Apart from the indicator describing the ionizing radiation, all these indicators are also considered as needing special care due to high uncertainties and limited application up to now.

Table 4.45: Additional environmental impact categories and related indicators according to EN15804+A2 (to be also included in the new version of EN 15978, but not part of the current version). Note: They should be specified if there is enough good data.

Impact category	Indicator	Unit
Particulate Matter emissions	Potential incidence of disease due to PM emissions	Disease incidence
Ionizing radiation, human health	Potential Human exposure efficiency relative to U235	kBq U235 eq.
Eco-toxicity (freshwater)	Potential Comparative Toxic Unit for ecosystems	CTUe
Human toxicity, cancer effects	Potential Comparative Toxic Unit for humans	CTUh
Human toxicity, non-cancer effects	Potential Comparative Toxic Unit for humans	CTUh
Land use related impacts/ Soil quality	Potential soil quality index	dimensionless

Indicators describing resource use (Table 4.46), waste categories (including radioactive waste), output flows leaving the system are also included in the EN 15978 (no changes expected from the old to the new version). To support resource management, mass-based information on the use of metal ores, non-metallic minerals and biomass might be more helpful. This can be additional information, not to be considered a replacement of the ADP indicators or the indicator “Use of renewable primary energy resources used as raw materials”. For example, in Europe there is the basic works requirement “sustainable use of natural resources” part of Construction Product Regulation. The resource types should be presented less in the sense of an indicator but more in the sense of additional information. For example, such information can be used to address the criticality surrounding the depletion e.g. of gravel or sand resources (Mayer et al. 2019). There are also corresponding statistics (e.g. Eurostat).

Table 4.46: Resource use indicators according to EN15804+A2 (to be also included in the new version of EN 15978).

Indicator	Unit
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ, net calorific value
Use of renewable primary energy resources used as raw materials	MJ, net calorific value
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	MJ, net calorific value
Use of non-renewable primary energy resources used as raw materials	MJ, net calorific value

Finally, an upcoming development in the new EN 15978 is the likely inclusion of indicators describing environmental aspects relating to the local environment. Some examples are the “contribution to local biodiversity” and “Local emissions to soil, outdoor air, and water” (the latter measured according to the assessment methods of standards developed by CEN TC 351).

The currently ongoing modification and supplementation of indicators for construction products in European standardization opens new possibilities for assessing the environmental performance of buildings. However, it is not yet certain whether all indicators from the product level can be immediately adopted for the building level; at least a transition phase is required. However, the transition phase also creates problems. First and second-generation environmental product information is available at the same time but should not be mixed.

This must be taken into account when making calculations as well as when developing or updating benchmarks. For example, EPDs published before 2020 in Europe are dominantly based on the EN 15804+A1 standard, and these EPDs will be valid up until 2025. Hence, stable conditions are expected in approximately 3 years.

Furthermore, the great enlargement of the list of indicators presented in the standards raises the question as to whether it is sufficient to focus on a few important topics or cover a broader list of indicators in assessments and for which purposes.

Current status of methods: Despite the minimum list of indicators recommended by the current standards (EN15978:2011 and ISO 21929-1:2010) already since a decade, according to a survey by A72 (see A72 background report by Balouktsi and Lützkendorf (2023b)) most methods focus on GWP, POCP, AC and ODP from the core indicators describing environmental impacts as well as primary energy non-renewable (PEnr) from the indicators describing resource use. Particularly, the lowest level of acceptance/inclusion can be observed for the core indicators ADP_{fossil} and $ADP_{elements}$. Often, the decision of excluding an indicator from an assessment method is not based on its level of significance for the LCA results, but its inclusion or not in most LCA databases (see A72 report by Chae and Kim (2022)).
The two extreme deviations of what is currently prescribed in the standards are the following:

a. Only GHG emissions: recognising the need to act with urgency on climate change, some government and industry-driven methods focus exclusively on GHG emissions, such as the Swedish Act on climate declarations for buildings (Boverket, 2020) the British RICS method (RICS, 2017) and the Norwegian standard NS 3720 (Norsk standard, 2018).
b. Broad list of additional indicators exceeding standards' core expectations: some methods also include indicators such as human toxicity and eco-toxicity as well as land use. These methods usually choose to present their final results in a partially or even fully aggregated form (see also next section). Examples are the Belgian method "Environmental profile of buildings" (Lam & Trigaux, 2021), the Dutch method GWW (SBK 2014), French methods RE2020 (2021) and Pleiades ACV EQUER (Wurtz et al., 2021), the British method BRE EN Ecopoints (BRE Group, 2013), as well as the Swiss Eco-points 2021 according to the ecological scarcity method (Frischknecht et al., 2021).

Regarding GHG emissions, since the shares to be included (or excluded) have only been recently specified in the standards, it is no surprise that there are variations among the different methods. The detailed representation into GWP biogenic, GWP fossil and GWP luluc is not yet common in most countries (Ouellet-Plamondon et al., 2022).

Reporting several indicators is one side of the coin, assessing them is another. In some countries while adherence to the full list of mandatory indicators in standards is requested in reporting the LCA results for building permit, the assessment focuses only on GHG emissions. Therefore, results are in place for different indicators, but specific requirements are in place only for GHG emissions. This is the case in Denmark and France.

There is a need for solutions to the question of how a middle ground can be found between the extreme positions of (a) and (b). This will depend on the conditions (construction traditions, choice of energy carriers, regulatory context) of each country as different environmental aspects may be considered as critical. A distinction can be made between the following starting positions:

a. Countries and/or organizations already have a list of mandatory (and possibly voluntary additional) indicators after coordination processes or are based 1:1 on the status of standardization. This is interpreted as a system of indicators. In this case, the data collection and the assessment of the environmental performance of buildings must be based on these indicators.
b. Countries and/or organizations have a defined list, but desire to review, adapt or extend it.

c. Countries and/or organizations do not yet have an exhaustive list of indicators and may have been working with an open set from which context- and actor-specific indicators are selected. For reasons of comparability, they have an interest in stipulating a minimum list of indicators in standards, laws and/or sustainability assessment systems.

In the context of this report, the following checklist is suggested for the last two cases. The starting point is that for countries only considering GHG emissions indicator in laws, regulations and standards, PEnr needs to be used as an additional core indicator (and vice versa) to cover both of the issues of concern/areas of protection 'ecosystem' (incl. climate) and 'resources' (fossil energy carriers and uranium here). For countries already including these two indicators in their methods, they can first orient themselves to the new minimum list of indicators presented in EN 15804+A2 and use the indicators (from this list) for which data already exists, and second ask questions such as the ones in Table 4.47.

Table 4.47: Questions to ask to identify the need for additional environmental indicators.

Question	Option
Can it be ensured that the use of energy with low emission factors does not lead to problems elsewhere - e.g. radioactive waste or particulate matter emissions due to wood burning for heating?	If a country's nuclear share of electricity generation is large or a higher share of nuclear power plays a role in the purchasing of energy, the inclusion of an **indicator for nuclear waste** in a core list is necessary to avoid burden-shifting. If the energy supply of a project is characterized by broader use of biomass for heating the inclusion of **an indicator for particulate matter** as an effect on the local environment is indispensable to avoid burden-shifting.
Can it be ensured that saving energy/ fossil fuels does not lead to an increased use of other primary raw materials?	If particular resources are critical for a country, the **documentation of the use of different types of natural resources** (biomass, ores, other mineral raw materials) is necessary[74].
Can it be ensured that the use of land for building construction and/or other processes does not cause biodiversity loss?	If a country/region is exposed to or imports construction materials from countries with biodiversity decline, a **biodiversity loss indicator** shall be used.
Can it be ensured that measures to reduce LCA impact indicators will not cause negative impacts to local environment?	Non LCA-indicators are necessary for impacts on local environment (emissions to air, water, soil, glare, sound, ….)
Can it be ensured that measures to reduce core LCA indicators do not cause human toxicity?	Damage indicators regarding human health and biodiversity complement core LCA indicators by aggregating various midpoints in a limited but comprehensive list of indicators, as an alternative to weighting.

4.4.3 Derivation, selection and description: Conclusions and guidance

International and European standards already provide a rather comprehensive list of indicators quantifying environmental impacts and resource use, and related product-data are expected to be available for at least the core list of these indicators. This makes it possible to add environmental indicators other than the GHG

[74] This can be additional information, not to be considered a replacement of ADP indicators. For example, in Europe there is the requirement "sustainable use of natural resources". The resource types should be presented less in the sense of an indicator but more in the sense of additional information. There are also corresponding statistics.

emissions and use of PE,nr. The GHG emissions are an important but not sufficient indicator for assessing the environmental performance of buildings. Rules (Table 4.48) and recommendations (gray box) are provided below on how to select and describe indicators among others, with the intention to avoid burden-shifting.

Table 4.48: Rules on how to develop, select, describe and classify environmental indicators

ISSUE(S)	RULE(S)	
How to develop and select indicators?	1.	Indicators for an environmental performance assessment shall be derived from areas of protection of sustainable development/ endpoints of a life cycle assessment (human health, ecosystems and natural resource). Starting point for the selection of indicators shall be the latest versions of ISO 21929-1[75] (core set of indicators) and ISO 21931-1[76] (environmental performance assessment). Interested parties are advised to also consider EN 15978 in its current and future version.
	2.	At the minimum, the assessment method shall make use of those indicators that are relevant in terms of legislation and environmental policy of the respective country, if this is already in place. Since the available international and European standards provide a comprehensive list of indicators quantifying environmental impacts and resource use, the reasons for excluding some or many of them shall be clearly stated (e.g. not yet available product-related data in national databases, not relevant for national policy, limited experience, etc.).
How to describe indicators?	3.	The description of environmental indicators shall be publicly available and shall contain at least the following information: – Name – Definition with information on the object to be considered – Unit of measurement – Reference unit(s) – System boundaries – Method of calculation or measurement – Rules for documentation and presentation of the result – Linkage of the indicator with existing international, regional and/or national standards – Linkage of the indicator with existing national benchmarks or targets
How to deal with multiple effects in indicator systems?	4.	ISO 21931-1 declares that double-counting shall be avoided. While taking multiple effects into account (e.g. the effects of emissions causing both ozone depletion and global warming) shall not be considered double-counting, it has to be indicated by the method so that they are kept in mind when evaluating the results.
How to classify indicators?	5.	A distinction shall be made between indicators that (1) are LCA-based or non-LCA-based; (2) have an impact on the global or local environment; (3) relate to direct effects on the environment or to processes with effects on environment relevant aspects (e.g. environmental management systems). Note: Technical features (e.g. U values or airtightness of building envelope) shall be rather declared as technical characteristics and not as environmental indicators. Management process quality related information (e.g. waste management or logistics) shall be used as additional information only.

[75] ISO 21929-1:2011: Sustainability in building construction — Sustainability indicators — Part 1: Framework for the development of indicators and a core set of indicators for buildings
[76] ISO 21931-1:2010. Sustainability in building construction — Framework for methods of assessment of the environmental performance of construction works — Part 1: Buildings – under redevelopment

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Include at the minimum level both indicators describing the impacts on the global environment (at minimum GHG emissions) and indicators describing resource use (at minimum PEnr). In environmental performance assessment systems with a broad list of indicators, these two may be used as knock-out criteria.
b. Concentrate on a limited set of core indicators. At a minimum, it should be ensured that environmental loads cannot be shifted. To that end, consider addressing the following topics in the form of additional indicators or additional requirements to GHG emissions and PEne, as well as the minimum list presented in the standards: (1) radioactive waste; (2) particulate matter; (3) biodiversity loss; (4) use of biomass, non-mineral ores and minerals.
c. Align indicators with the reporting of the complete life cycle, and subdivide them into partial results that support an analysis of influences on the assessment result (e.g. embodied versus operational).
d. Check whether the indicators are independent of one another or influence each other and develop an approach to identify conflicting goals.

4.4.4 Aggregation: General

Often, drawing the correct conclusions based on a broad variety of environmental impact and/or aspect-related indicators can be challenging. Sometimes, assessment methods choose to select a single LCA indicator perceived as the most important to focus on. Indeed, optimization towards one variable is much more straightforward than doing the same for more than a dozen indicators, and this partly explains the popularity of single-issue approaches like carbon footprint. However, some assessment methods support their users in interpreting disparate LCA results by applying aggregation methodologies to:

a. combine the assessment results of numerous indicators using weighting factors to form an overall result (or several partial results/scores) which is dimensionless. Benchmarking happens at a mid-point level, i.e., a score is assigned to each indicator based on whether given benchmarks were fulfilled (assessment for individual indicators) and then the scores are weighted and combined to produce an overall score. This type of aggregation is typical for environmental performance assessment as part of sustainability assessments; and
b. derive a fully aggregated indicator with a unit of measurement (e.g., eco-points) and check the fulfilment of benchmarks set at this aggregated level.

A difference between cases (a) and (b) is that in the former all individual indicators are determined and assessed first and then aggregated, while in the latter only the aggregated indicator is used for the assessment. In that case, all initial information is already transformed into these individual aggregated indicators[77]. Special cases combine aggregated indicators with a few other essential indicators (see Switzerland with its KBOB recommendation 2009/1 on Eco-points, Primary Energy and Greenhouse gas emissions).

Aggregating indicator results into single indexes involves the optional LCIA steps of normalization and weighting (ISO, 2006). In general, and simple terms, each indicator result is normalised, i.e. divided by normalisation factors connected to reference information which expresses the total impact of a certain region in a reference year. Then, the normalised values can be multiplied by a weighting factor assigned to each indicator. Once they are all expressed on the same basis, they can be added up into a single value. The weighting applied may be equal for each indicator.

Various options are available for both normalisation and weighting. The purpose of weighting is to ensure that the focus is on aspects considered or perceived most relevant. However, while normalisation can be science-based, this is often not the case for weighting schemes, which inherently involve value choices that

[77] In some assessment schemes, such as the KBOB recommendation 2009/1, the initial information, the life cycle inventories, as well as the life cycle inventory results remain accessible.

depend on policy, value systems, and cultural and other preferences (Sala et al. 2018). This may cloud its application for many multi-criteria approaches, including LCA. Additional controversy arises when the partial results are usually no longer visible at the first look, and whether insufficiently robust indicators should be included in external communications or in a weighted result until their robustness is improved (Sala et al. 2018).

Several concepts are applied to weighting across impact categories, but the following are most often used, also within the building sector:

– **Distance-to-target (DTT)**: an example of such an approach is the ecological scarcity method where critical flows are derived from statistics and policy targets. Weights stem from how far society's activities are from achieving the desired targets. The underlying assumption is that a correlation exists between the seriousness of an effect and the distance between the current and target levels. So, if for achieving a sustainable society impact A must be reduced by a factor of 2, and impact B must be reduced by a factor of 6, then impact B is regarded as three times as serious.
– **Monetisation**: or also called 'monetary valuation' of impacts (Pizzol et al. 2016). Monetisation is most often based on 'prevention' (aka. 'control or abatement') or 'damage' cost methods (see also Isacs et al. (2016) for a review on this topic). Prevention cost methods value an impact based on marginal cost to securing the relevant policy target for an impact. Doing so requires policy objectives clearly expressed quantitatively (e.g., pollutants' concentration in the air), and cost-effectiveness analyses of all potential prevention measures to enable ranking in monetary terms per prevention (control or abatement) unit, like €/kg emission. The costs of the least cost-efficient measure to meet a given target indicates the value that society is willing to pay or impose on citizens or firms to control that environmental problem (De Nocker and Debacker, 2018). As quantitative policy objectives are not always available, and at times defined more on political than on scientific grounds (Castellani et al. 2016), damage cost methods are sometimes preferred (Allacker et al. 2020). Damage cost methods calculate how emissions or use of resources damage human health and ecosystems, in terms of additional costs, loss of ecosystem services, reduced income or loss of well-being for current and future generations. Individual environmental indicators are hence aggregated by multiplying their respective characterization values (e.g., X kg CO2eq) by a monetisation factor (e.g., Y €/kg CO2eq) that indicates the extent of the damage to the environment and/or humans. Such extent is expressed as the financial amount corresponding to the external environmental costs.
– **Social and expert panel-based methods**: in this approach, a number of experts express their perceived severity of a given impact relatively to others in the local/regional/national/global context. In LCIA, a panel approach has been used, for instance, in damage-oriented (endpoint) methods like eco-indicator 99 (Goedkoop and Spriensma 1999) and ReCiPe (Goedkoop et al. 2008), which combine a series of individual midpoint indicators into three standardized endpoints - human health, ecosystems quality, and resource scarcity - based on scientific factors. As such, value judgment is applied close to the end of the cause-effect chain. In the context of building LCA, the panel-based approach has been used in the UK (Abbe and Hamilton 2017) to convey single-scores of normalised values of indicators mostly based on EN15804+A1.

Each approach has advantages and drawbacks, and the fit-test approach is defined by the application conditions and by preferences of individuals or organisations. Table 4.49 provides summarised information of aggregation approaches adopted by selected methods used in the building sector. More information on the several types of weighting approaches, as well as the background of selected methods presented in the Table below are provided in Gomes et al. (2022a,b).

Table 4.49: Aggregation approaches adopted by selected methods used in the building sector (Gomes et al. 2022b).

Approach	Method			
	UBP'21 (CH)	**MMG (BE)**	**Determination Method (NL)**	**BRE EN Ecopoints (UK)**
Application				*BREEAM**
Weighting				
Partial/total aggregation	environmental areas and total	"CEN", "CEN+" and total	total	total
Normalization	yes	yes (Flanders, Western Europe, RoW)	no	yes (Western Europe)
Characterization	yes	yes	yes	yes

distance to target — monetisation — expert/stakeholder panel

product level — element level — whole building level

Note: "CEN" and "CEN+" indicators refer to the terminology used by the MMG method. See Gomes et al.(2022a) for more information.

It is important to highlight that monetisation approaches may involve discounting after conversion of impacts into financial units, a practice which is common in economics. Costs and future benefits differ in their distribution over time and must be brought to a common point in time to become comparable. A centrepiece to do so is discounting, which uses discount rates to put a present value on costs and benefits that will occur at a later date. According to ISO 14008:2019 (ISO, 2019), the discount rate is defined as:

$$r = d + g \cdot \mu$$

where

d is the pure rate of time preference

g is the growth rate of per capita consumption

μ is the elasticity of social marginal utility of consumption.

At an analytic level, the discount rate is a major determinant of the valuation outcomes (i.e. present value of costs and benefits). Its choice greatly influences valuation outcomes when impacts and mitigation measures spread over very long time periods, as for climate change. GHGs long lifespan in the atmosphere requires that the damages expected of their emissions today are valued centuries into the future. Discounting using positive discount rates gives a lower numerical value to damages or benefits in the future than to those happening in the present. When using a low discount rate, more importance is given to future generations' wellbeing in cost–benefit analyses compared to using higher discount rates, which supports the view to act now to protect future generations. This is called "social discount rate".

In an inter- generational framework, the 'pure time preference rate' characterizes the ethical attitude towards future generations. There is a strong case for factoring in the ethical issues of (intergenerational and income) equity- and age-weighting via the social discount rate. The IPCC AR2 notes recommended, as early as 1996, a discount rate of 2-4%, by considering fair to account for a pure time preference rate equal to zero (ISO 14008:2019 also suggests that for such considerations, the pure rate of time preference should be set to zero), and a growth rate of GDP per capita of 1-2% per year for developed countries and a higher rate for developing countries that anticipate larger growth rates (IPCC, 2007, p.136). IPCC's AR5 (Kolstad et al., 2014) reinforced the case for a zero or near-zero pure rate of time preference to, holding consumption constant, give all generations equal weight in calculating social welfare.

Based on these considerations, many authors and governments propose a small discount rate (near 0%) when monetising environmental impacts, especially for long time horizons. For example, the Federal Environment Agency (UBA) in Germany proposes a discount rate of 3% for short-term periods (up to around 20 years), while for claims that extend further into the future, proposes the use of a 1.5% discount rate as a default (Schwermer et al., 2014, p.37). Furthermore, it requests to carry out a sensitivity calculation with a discount rate of 0% for cross-generational considerations.

From the monetisation approaches currently used in the context of life cycle assessments in the building and real estate sector, only the Belgian method MMG explicitly declares adoption of a social discount rate of 3% p.a., on average in line with declining rates over time used by several governments, and of purchasing power parity (PPP) to counterbalance/eliminate GDP/capita variations. The Dutch DM uses a shorter list of individual LCIA indicators, whose monetary values mainly refer to a study on shadow prices commissioned by the Dutch Ministry of Infrastructure and Environment to TNO in 2006. Shadow prices have been updated since then, until a thorough conceptual update commissioned by the same Ministry resulted in the 'Environmental prices Handbook 2017' (CE Delft, 2018). From its 2020 supporting documentation, the Determination Method has not adopted the updated environmental prices concept so far. It only provides the shadow price-based weighting set used, without explicitly declaring key monetization decisions it relies upon. The discount rate is herein inferred to be a 3% p.a. rate, as advised by the Discount Rate Working Group (van Ewijk et al., 2015), but no reference to purchase power parity/equity weighting was found.

What can be expected in the background report by Gomes et al. (2023b)?

1. An overview of approaches used to aggregate LCA-based indicator values into single-scores for buildings
2. Recommendations for communication and overall calculation rules.

4.4.5 Aggregation: Conclusions and guidance

The weighing of environmental impact scores into one or a few scores is often requested by the target audience. Using a single-score indicator to express the environmental performance makes it easier to compare the environmental performance of different buildings with each other, and to communicate it. It also provides a comprehensive picture, which allows to identify the important environmental impacts and the most relevant building elements or construction materials. That is why some countries like Switzerland have a long-term tradition in applying single score methods in LCA which are endorsed and authorised by the Swiss Federal Administration.

Examples exist demonstrating the use of weighting factors derived from panel exercises, DTT or monetisation estimates, but comparable information is not ubiquitously available. As impact assessment methods are becoming increasingly regionalized, the monetary valuation of associated impacts should also be region-specific, to deliver meaningful results. Monetisation is most often based on "prevention cost methods" or "damage cost methods". Both approaches are used.

There is no best method for aggregating impact results, though, and each one has strengths and limitations. Moreover, not all countries and regions have equally developed science, targets, and data. That said, general rules (Table 4.50) and recommendations (gray box) when pursuing to express the environmental performance of a building as a single-score are provided.

Expressing policy targets in quantitative terms is not always straightforward and factors for relevant categories indicators still lack. Value choice-based damage estimations often embeds personal attitude and perspectives of the decision-maker. And monetisation costs are established within a virtual market, whose results can involve considerable uncertainty.

Bottom line is: LCA practitioners carrying out studies in regions or countries with data and methods that allow weighting are encouraged to report an aggregated index in addition to the detailed environmental profile, for communication's sake. Target audiences not familiar with the implications of weighting should be made aware of the controversy and objections to do so, of the uncertainties embedded, and of the fact that despite the acknowledged limitations, attempts to evolve are in course to help to fulfil their practical relevance.

Table 4.50: Rules on how to ensure transparency, robustness and interpretability in the case of semi- or fully-aggregated indicators when applied in a method.

ISSUE(S)		RULE(S)	
Where fully- or semi-aggregated indicators are used for the assessment results, how to ensure transparency, robustness and results interpretability?	Transparency	1.	Use a method that explicitly declares all conversion/weighting factors and assumptions made (e.g. geographical scope, discount rates, equity weighing). Aggregation procedures shall be transparently described in easily accessible documents.
	Robustness	2.	Aggregation methodologies shall, where appropriate, use conversion factors that comply with scientific or engineering principles first. These normative principles apply to any level of aggregation (see also ISO 21931-1).
		3.	Preference to weighting schemes endorsed by authoritative bodies like national environmental agencies or ministries shall be given. Among others, this is expected to ensure that the sets of prices/costs/weights are updated every few years to reflect the latest policies.
		4.	If monetisation methods are used, a discount rate shall be chosen that takes into account the perspective/interest of future generations, in line with IPCC's recommendations. Sensitivity analyses shall be performed for different discount rate options.
	Interpretability	5.	Partially disaggregated information shall always be provided (including the carbon footprint), the life cycle inventory result or, even better, the unit process data shall be provided in addition to the aggregated score.
		6.	In monetisation, purchase power parity shall be applied, i.e. uniform value of life for all worlds citizens.
		7.	If impact category indicators embed high uncertainty (e.g., ecotoxicity), the aggregated result shall be presented with and without those individual indicators

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Inform target audiences not familiar with the implications of weighting of the controversy and objections as well as the advantages and benefits to do so, of the uncertainties embedded, and of the fact that despite the acknowledged limitations, attempts to evolve are in course to help to fulfil their practical relevance.

b. In selected cases, partial aggregation is an alternative to full aggregation. It is recommended to use the endpoint categories in the case of a partial aggregation of the results of an assessment of the environmental performance.

Researchers (application / use case: B, see Table 1.2)

c. Carry out sensitivity analyses for understanding the weighting's influence on the single score result and on the ranking of different product/design alternatives. This can be done by applying several different single score methods.

d. Caution is advised whenever performing direct comparisons. Refrain from interpreting comparisons across indices obtained through different aggregation methods beyond sensitivity analyses purposes, for which they are in fact very useful and encouraged.

4.4.6 Reference units: General

The results of an environmental performance assessment of buildings must be interpreted and analyzed – a task that is particularly important during the design stage when still many possibilities exist to influence the environmental impacts of buildings by improving the design. The question arises as to what the suitable forms of presentation of results are and consequently reference units that can support a meaningful interpretation and analysis of the assessment results. These may differ depending on the use case, which may be:

- Presentation of benchmarks and performance values in the context of a sustainability certification
- Provision of information in the context of object documentation/ a building pass for third parties (e.g. valuation professionals)
- To support the design process by analyzing and comparing different design solutions
- Statistical analysis to gain empirical values or benchmarks

There are different possible variations of reference units based on which information can be presented.

a) Most common building-specific reference units

- m^2 gross floor area (GFA)
- m^2 net floor area (NFA)
- m^2 heated floor area (HFA) (alternative terms: living area / lettable surface area / main usable area/ energy reference area)
- m^3 (volume net or gross)

Note 1: The selection of reference areas has grown historically. While the GFA was often used for expressing the structural effort, the NFA or HFA is used for information on building operation. It can make sense - similar to cost parameters - to use several reference areas in parallel. On the one hand, this ensures continuity, and on the other hand, it allows plausibility checks and reduce the risk of confusion[78].

Note 2: 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 (see: Background report by Balouktsi and Lützkendorf (2023b)). Although there are some international and regional standards

[78] The choice of type of floor area also depends on the focus of each method. For example, in the Swedish regulation it was decided to use GFA due to the focus on modules A1-A5. If HFA had been used instead for the assessment, buildings with basements and underlying garages were discredited. GFA seemed as a unit that works well for the limited scope, no matter underlying basement and garages or not. The reasoning was also that it should be a reference unit easily available for the developers.

aiming at harmonization of terms and definitions, 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.

b) Possible variations for use-/user-specific reference units

- capita
- hours 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)

Note 3: Such reference values can usefully supplement surface area and volume-related values. They include aspects of the intensity of use of the building and thus represent a transition between a pure efficiency assessment and an additional sufficiency assessment. Therefore, they are useful for investigating densification strategies. Several of these user-oriented reference units can also be combined into novel functional units like the one introduced by Hoxha et al. (2020), i.e. “eq-nominal people per effective presence”[79]. This unit was found as most suitable to evaluate environmental performance according to real building usage, as a complement to square meter function units.

The question of annualisation or not: Following the tradition of operational energy performance assessments which are in place in most countries since many years now, most methods prefer to express life cycle-based results on a per-year-basis and therefore establish this reference unit for expressing the results of indicators. Annualisation of results is typically achieved by dividing by an 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 finally another spike with the end-of-life treatment in the final year. Consequently, a solution can be to also present embodied part (A1-5) with an additional ‘non-annualised’ result in addition to the annualised one for the RSP.

Current status of methods. Most methods use a single reference unit for the presentation of the assessment results, which reference unit is usually impacts/m²/year (the type of surface area considered by each method differs). However, solely measuring annualised impacts per square metre of floor area often tends to favour larger houses (Stephan & Crawford, 2016). Thus, a comparison on the basis of the former would offer incorrect design guidance from an environmental point of view. On the other hand, basing decisions only on the normalized impact per occupant buildings with high occupational density would always be favoured at the expense of spatial comfort and other social and health-related concerns. More importantly, occupant’s behaviour can only be based on predictions, it cannot be influenced by the building and can also change during building’s lifetime (i.e. occupational density or hours of use among others are highly uncertain parameters). Therefore, in general, an end-use perspective is more discussed in research literature rather than being followed by actual methods. However, methods can propose the use of additional reference unit(s) for exploratory purposes on the side of one core surface-based reference unit.

4.4.7 Reference units: 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 LCA 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

[79] However, it should be noted that the same flat occupied by workers (60% present) or e.g. retired persons (90% present) will get different results. Therefore, it is more appropriate for research/exploratory purposes.

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 require ments are possible and sensible and should be checked in each case. The following rules (Table 4.51) and recommendations (gray box) are applicable to both new and refurbished buildings.

Table 4.51: Rules on how to define the reference unit to be applied in a method

ISSUE(S)	RULE(S)
How to define the reference unit of assessment?	1. A core reference unit shall be named and defined in detail to be used for binding assessments. The choice of the core reference unit shall be based on an analysis with regard to the advantages and disadvantages of several reference units.
	2. Methods may provide guide values (partial benchmarks) for non-binding assessments: in this case, several reference units can and shall be used in parallel to simultaneously cover different perspectives.
	3. Special care shall be taken in selecting, describing and interpreting the time parameter in reference units. Note: In the case of partial benchmarks as guide values, a combination: non-annualised values for EMBODIED + annualized values for OPERATIONAL impacts is possible. Note 2: embodied values can be non-annualised EMBODIED upfront + non-annualised EMBODIED in the year(s) of replacement + non annualised end of life treatments

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. Describe the applied reference units in adequate detail. Especially in the case of area-based reference units (such as NFA and HFA), the type of floor area applied must be specified in detail, preferably with reference to a standard or other definition.

b. Present the LCA results on the basis of several reference units in parallel to cover different perspectives (efficient building, sufficiency with regard to the user, etc.). This can result in a vertical and horizontal system of reference units that would provide the possibility, on the one hand, to present the results on the basis of different reference areas (potentially providing factors for the change in the measurement from one type of floor area to the other) and on the other hand, include a parallel representation also with alternative reference units (e.g. per building user).

4.5 Handling of Uncertainties

4.5.1 General

Often, life cycle-based environmental performance calculation and assessment results flow in the proof of compliance with environmental performance requirements formulated in laws or voluntary performance assessment and certification systems, in the economic valuation, in financing and purchase decisions as well as in sustainability reports. This places a high demand on the reliability, traceability and quality-proofness of the LCA results. This building LCA transition from a scientific interest toward having real-world influence on decision-making, necessitates the clear articulation of the confidence in the results and the recognition of key driving forces of the uncertainty and variability.

Buildings are complex entities with long and unpredictable lifespans/service lives, as well as they are designed and built by a fragmented industry and geographically scattered supply chains. Therefore, their LCA includes inherent uncertainties. These uncertainties broadly arise from:

- methodological choices and simplifications in modelling like all the ones presented in the previous sections (here called: method-related uncertainties).
- reliability, representativeness as well as spatial, temporal and technological variability inherent in third party data, such as emission factors for the different types of products; all kinds of data, either collected or generated, are potentially affected by various kinds of quality and variability issues on which the quality checks of LCA data are frequently based (here called: data-related uncertainties).
- design variability due to the fact that many details of design, such as exact layout and geometry as well as types and quantities of products to be installed in the building are not known in early design stages (here called: design-related uncertainties).

In this report, the term 'uncertainty' encompasses both uncertainty and variability, i.e., the overall sources of uncertainty in LCA are understood to include those related to lack of knowledge and inherent fluctuations in the real world. Key topic-specific definitions are provided below (grey box).

Key topic-specific definitions

Uncertainty: Strictly speaking, uncertainty arises due to lack of knowledge about the true value of a quantity. Uncertainty is distinguished from **variability**, which is attributable to the natural heterogeneity of values which arise from the inherent variability of the real world. Uncertainty can be reduced by more accurate and precise measurements. Variability cannot be reduced by further measurement, although better sampling can improve knowledge about variability.

Uncertainty analysis/propagation: It is the process of propagating input uncertainties to calculate the overall uncertainty in the final LCA result. Uncertainty analysis can be performed with an analytical method (such as Taylor series expansions) or a sampling method (such as Monte Carlo). The latter is more common and is available in some LCA software tools like SimaPro. Uncertainty analysis should not be confused with **sensitivity analysis**; the latter is aimed at understanding the influence that input parameters have on the final results whereas the former is aimed at understanding the overall uncertainty of the final results.

Uncertainties may have a great impact on the LCA result. Although it has been more than 25 years ago that the role and impact of uncertainty and variability in LCA modelling was brought to researchers' and practitioners' attention[80], there is still a great lack of uncertainty analysis in the LCAs of buildings and building products. In this sense, there is a need for developing basic principles and methods for considering and communicating uncertainties. It is nowadays essential that every environmental performance assessment is accompanied by an uncertainty assessment/analysis or a related statement. The way of treating uncertainties

[80] SETAC Guidelines for Life-Cycle Assessment, A Code of Practice. Proceedings from the SETAC workshop held in Sesimbra, Portugal (31 March–3 April 1993)

in LCA is influenced by the respective application. In simple words, checking the adherence to binding benchmarks requires the reporting of deterministic results (single point value results) and therefore the handling of uncertainty is focused on clearly articulating the assumptions and quality of data used. On the other hand, to be able to report the quality of data and the related uncertainty, this should be quantified by the data provider.

At large, uncertainties can be distinguished into (1) the ones that cannot be influenced by designers and are primarily related to LCA (method and data), and (2) the ones that can be influenced by designers and are primarily related to design process – i.e. exogenous uncertainties (see Figure 4.35). This section focuses on the former: how method developers and providers should treat **method-related uncertainties** and approach **data-related uncertainties.** How design-related uncertainties should be handled by the designers – such as uncertainties due to simplifications and use of generic data necessary to compensate for the lack of details about the designed building as well as uncertainty due to different ways of structuring the data from elements to materials, among others – is the topic of the related A72 report by Passer et al. (2023). However, not all design practitioners are self-motivated to do so, therefore method providers can include rules that encourage designers to deal with uncertainties along design process so that to increase the chances of fulfilling the benchmarks in late design stages.

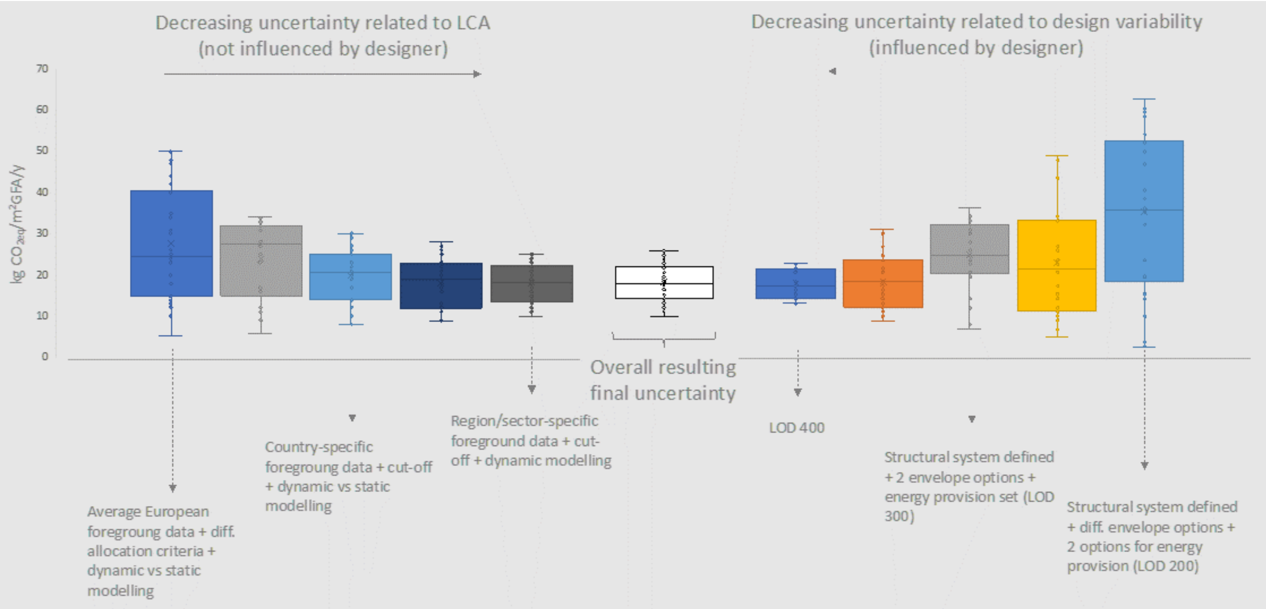

Figure 4.35: Uncertainty sources in building LCA, divided according to the designer's influence (Source: Passer et al. (2023)).

Method-related uncertainties: Methods involve normative choices made in constructing scenarios about future conditions and events occurring during the building lifespan. Examples with a large influence on the final output are the uncertainties in service life of building elements (Section 4.3.17), uncertainty in user behaviour during building operation (Section 4.3.24), as well as in climate change (Section 4.3.23) or future energy mixes (Section 4.3.2). They also involve choices related to the framing of the assessment; aspects such as selecting the reference unit (Section 4.4.6), the reference study period (Section 4.1.4) and system boundaries (Section 4.1.6-9). Different choices may generate different LCA results. This type of uncertainty cannot be eliminated – at least up to building handover – but it can only be quantified. These aspects are usually determined/fixed by the building certification program operator and/or the regulator so that LCAs can be compared to benchmarks. Sometimes, despite the existence of national standardised methods, a broad range of methodological choices remains possible; this leads to the need for method developers to specify the choices in as much detail as possible. On the other hand, as LCA become more common in the building industry, there is a growing need for simpler methods to make accurate assessments attainable with fewer resources. There is a need for method developers to understand the choices with the most important effects on the finals results as well as realise how different kinds of simplifications affect accuracy and precision.

Data-related uncertainties: In wanting to work with approaches that provide as more accurate and precise results as possible, it is necessary to pay attention to the quality of the data to be used and, consequently, in their uncertainty. Therefore, on how to deal with the uncertainty, the question of how to describe, assess and communicate the quality of input data and of calculation and assessment results arises. This is currently the subject of standardization within the framework of CEN TC 350 (particularly standard EN 15941) as well as treated under the LEVEL(s) framework. Dealing with data-related uncertainties is also shaped by the tasks of the respective actors. A distinction can be made between the following cases, among others see also Figure 4.36:

a. The creators of environmental data on construction products, e.g. in the form of EPDs, are confronted with the uncertainty of data from the upstream chains
b. The users of environmental data on construction products, which are taken from databases and/or manufacturer information, are confronted with uncertainties. This situation can be improved by data providers when (1) assessing and communicating their quality and (2) specifying ranges and distributions
c. When comparing design variants, designers are confronted with uncertainties and ranges of calculation and assessment results. The question arises as to whether and to what extent design variants can be classified in a clear ranking and sequence or this is not certain due to the uncertainty ranges of the results. This raises the question of how results with overlapping uncertainty ranges can be compared.
d. Assessment results are used by decision-makers to support their decisions. They are interested in knowing how "safe" the results are – whether and to what extent they can trust these results. They are not able to trace back all data sources and assumptions. They have an interest in a statement for which an actor takes responsibility - also in a legal sense. There is a "chain of responsibility" back to the input variables, which could be mapped using a block chain, for example.

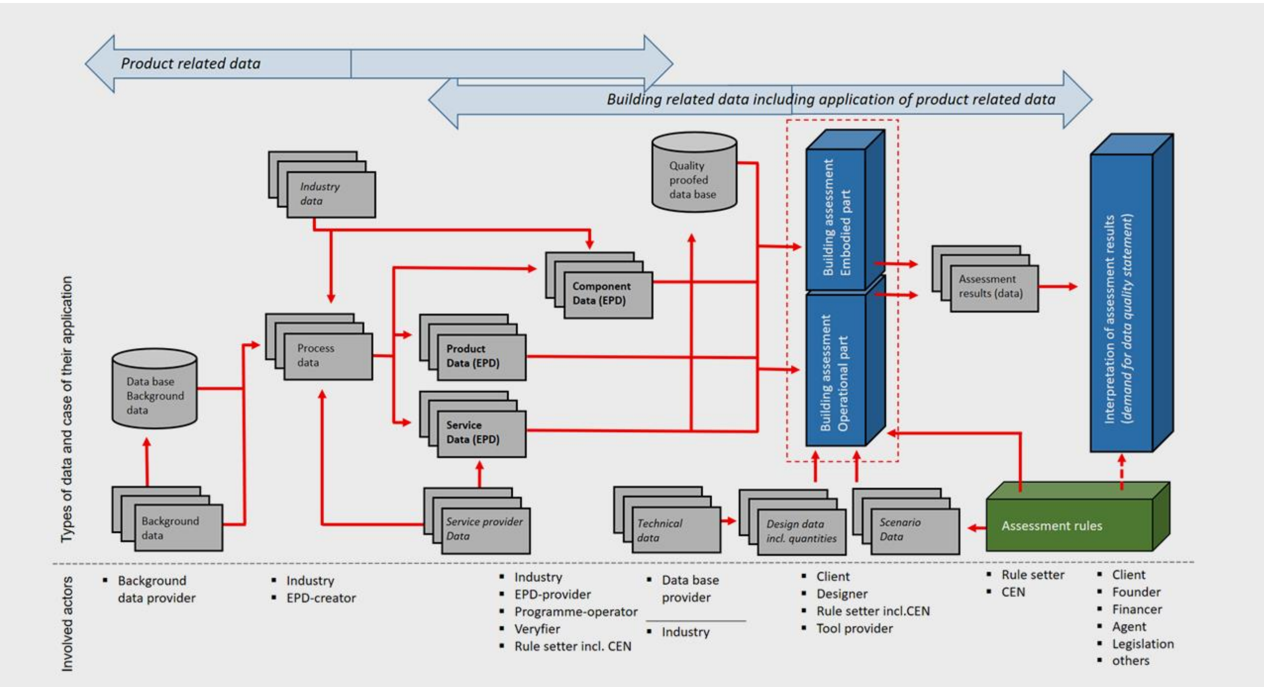

Figure 4.36: Influence of data quality along the data provision flow (Source: T. Lützkendorf 2021, unpublished).

Overview of method- and data-related uncertainties: The uncertainty sources listed in Table 4.52 fit broadly into the two categories dealt with in this report – method-related uncertainties and data-related uncertainties – and are mapped based on which stage of environmental performance assessment process need to be handled, which stage of the building life cycle affect, and which building industry actors play a role in their handling. The sources presented in the table are they are not necessarily exhaustive. The purpose is to suggest a need for greater recognition of the challenges involved in providing detailed specifications in methods.

Table 4.52: Typology of uncertainties for this report (MP: Environ. assessment method provider/building level; D: Designer; DP: Environ. data provider/product level; TP: Tool Provider)

Environ. performance assessment process[81]	Type of uncertainty	Source of uncertainty (non-exhaustive list)	Affected life cycle module	Reduced along design process?	Actor responsible for the handling	Section of this report or other A72 report
Specification of the object of assessment	METHOD	Reference unit	n/a	No	MP	Section 4.4.6-7
		Reference study period[82]	B1-B7	No	MP	Section 4.1.4-5 Lasvaux et al. (2023)
		Building components included[61]	n/a	No	MP	Section 4.1.6-7
		Life cycle modules included[83]	n/a	No	MP	Section 4.1.8-9
		Expected service life	B1-7	No	MP	Section 4.1.2-3
		Occupancy Scenario (i.e. pattern of use)	B6-7	No	MP	
Scenarios for the building life cycle		Thermal comfort scenario (i.e. heating/cooling setpoint)	B6	No	MP	Section 4.3.23
		Climate scenario		No	MP	Section 4.3.22 Guarino et al. (2023)
		Electricity mix scenario	B6, B2-5, C1-4, D	No	MP	Section 4.3.2-4 Peuportier et al. (2023)
		Maintenance and repair cycles	B2-3	No	MP	Section 4.3.16
		The replacement cycles based on components' service life	B4	No[84]	MP, DP	Section 4.3.17 Lasvaux et al. (2023)
		Deconstruction/ Demolition scenario	C1	No	MP	Section 4.3.3 Section 4.3.12
		EoL Transport scenario	C2	No	MP	
		Waste scenario (disposal, recycling, recovery, reuse)	C3-4, D	No[4]	MP, DP	Section 4.3.32-34
		Climate model		No	MP	Section 4.3.22 Guarino et al. (2023)
Selection of environmental data and other information	DATA	If structured under-specified databases are used (from average to manufacturer-specific data)	A1-A3, A4-A5, B1-B4, C1, C3-C4, D	Yes	D, DP	Passer et al. (2022) Palaniappan et al. (2023)
		Quality of data (e.g. pedigree)		No	MP, DP	Palaniappan et al. (2023)
	METHOD	Generic vs marginal data (attributional vs consequential)	n/a	No	DP, TP	Palaniappan et al. (2023)
		Choice of characterization method[85]	n/a	No	MP, DP	Section 4.4
		Choice of static vs dynamic characterization factor	n/a	No	MP	Section 4.3.5-7
		Choice of time horizon	n/a	No	MP	Section 4.3.7

[81] Acc to EN 15978
[82] In some countries, it is called reference service life.
[83] as part of system boundaries choices
[84] this uncertainty is reduced slightly from early to late design stages because this information will be product-specific at late design stage.
[85] The EPD must contain a core set of predetermined environmental impact indicators. The EPD may also contain additional environmental impact indicators.

Current status of methods and research: Deterministic approaches are the norm in national environmental performance assessment methods for confirmatory purposes. Following a probabilistic approach could impede clear statements and communication of the fulfillment (or not) of benchmarks. The interpretation of an assessment would be even more complex when both the calculated results and the benchmarks were represented as ranges or distributions resulting in overlapping areas (e.g. see Figure 4.37). This would require sophisticated interpretation methods (Mendoza Beltran et al., 2018), which go beyond the perceptual ability of non-experts. Methods, however, may use probabilistic approaches for exploratory purposes when developing benchmarks and/or default values. The intention of these explorations is to derive conservative assumptions and safety factors (also known as uncertainty factors).

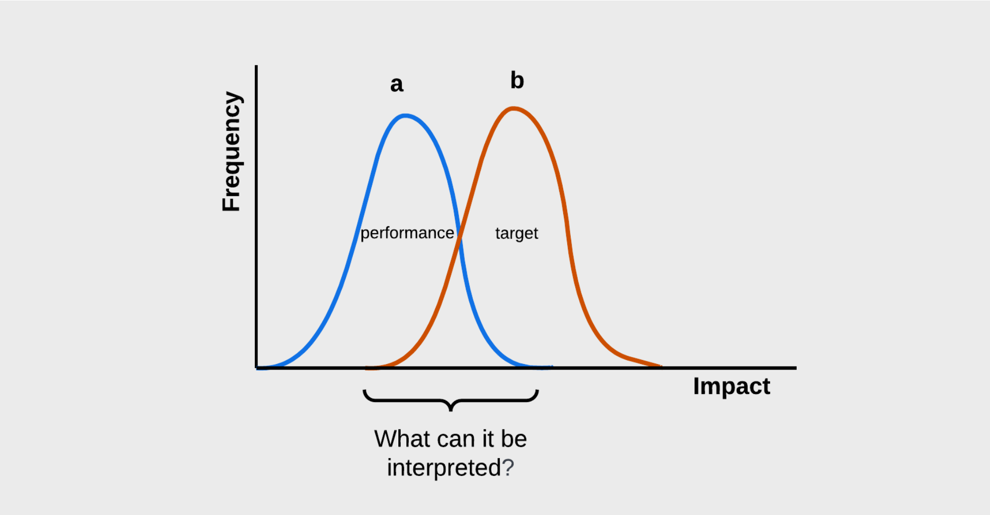

Figure 4.37: Overlapping probability density functions of the (a) design environmental performance result and of the (b) targeted environmental performance (target value).

On the other hand, when it comes to research, an accelerating, but still early-stage application of uncertainty analysis in building environmental performance calculations can be observed in recent years. Overall, most studies focus on two sources of uncertainty: (a) uncertainty in accurately quantifying materials used in construction in early design steps and (b) uncertainty in material choices and the variation in environmental impact intensity of those construction materials. These sources of uncertainty have been examined for different types of buildings (Hoxha et al., 2014; Häfliger et al., 2017, Hoxha et al., 2017, Pomponi & Moncaster 2018; Hester et al., 2018, Tecchio et al., 2018; Hollberg & Ruth 2016, Cavalliere et al., 2019). However, there is a lack of studies dealing with method-related uncertainties, either in isolation or in combination with data- and design-related uncertainties.

Uncertainty and sensitivity analyses are very powerful tools to characterize and specify the uncertainty in the LCA models used, particularly because they allow efforts to be focused on the most important parameters of the model. In most studies, the most prevalent practice is a mixture of sensitivity analysis and Monte Carlo Simulation to target uncertainties in design features and background LCI data, while scenario analysis is used to treat uncertainty due to methodological choices. A large panel of sensitivity analyses methods was compared by Pannier et al. (2018) on the basis of a building case study, in terms of their precision, computational cost and set of influential factors identified. However, there are also 'non-mainstream' methods identified in some studies, which provide alternative solutions to tackle uncertainties of LCA (e.g. Hoxha et al., 2017).

Nevertheless, sometimes research findings are not easily applied to practice and vice versa. Often, solutions identified in literature may not be easily implemented by 'new' practitioners in the LCA field especially when the exact process followed is not provided in sufficient detail. Tools are needed to bridge this gap, which are also attractive to users who prefer less complex analysis and user-friendly interfaces (For a discussion on available tools and their capabilities see Passer et al. (2023)).

4.5.2 Conclusions and guidance

The question of dealing with uncertainties that do not result from the design process has several dimensions. On the one hand, methods can be developed in such a way that they deal appropriately with systematic uncertainties. This includes the provision of default values and safety factors (among others) which are intended to ensure that the assessment result is on the safe side. They are used in particular in the early design steps. Uncertainties in relation to data can be reduced on the one hand by assessing and communicating their quality and their temporal and spatial applicability and on the other hand by specifying ranges that result from technical reasons. The following example illustrates the options for action by individual actors in the area of reducing uncertainties/ranges through requirements/conventions in deterministic models.

Example "Uncertainty on occupancy density of residential buildings"

a. **Policy, regulation and law maker, national standardization body, developer and provider of sustainability assessment systems**: factor out the influence of uncertainty by prescribing occupancy densities to be considered when determining the energy and water requirements in the use stage.
b. **Designer and engineer**: Use the prescribed occupancy densities, no uncertainty calculations required.
c. **Client**: if the planned occupancy densities are much different than the ones prescribed by a regulation, standard or assessment system, ask the designer and/or engineer to check the robustness of the design also against these additional occupational densities.
d. **Provider of LCA databases**: n/a (occupancy density does not matter in the life cycle inventory of building materials, building elements, etc.)
e. **Provider of design and assessment tools**: Integrate the required occupancy densities in the calculation routines for determining the operational and water energy consumption.
f. **Researcher**: run sensitivity analysis with different occupancy densities to support benchmarking

Against this background, rules and recommendations are provided below (Table 4.53 and gray box).

Table 4.53: Rules on how to treat uncertainties from the perspective of method providers.

ISSUE(S)		RULE(S)
How to reduce the complexity associated with uncertainties?	2.	uncertainties shall be distinguished into **thematic groups**, as well as **the most important sources of uncertainty** under each group, **which uncertainties can be reduced as the design progresses** and which not (processes lying in the distant future will remain uncertain), and what uncertainties can be influenced by whom (**responsibility**) shall be identified (see Table 4.42 as an example).
How to reduce room for interpretation caused by method-related uncertainties?	3.	It is the task of method provider to **reduce room for individual interpretation**. Hence, to treat method-related choice uncertainties, the methodological choices, assumptions and databases that shall be applied by the users shall be specified in as much detail as possible, as well as their adaptation to the specific steps in the design progress when necessary. Particularly, the following shall be provided: – specification of fundamental methodological choices (RSP, system boundaries, reference unit, indicators) – specification of methodological choices related to scenarios. Particularly, to treat unknowns and uncertainties post-construction 'fixed' realistic and based on latest research assumptions shall be provided[86].

[86] The client/building owner is responsible for the description of the pattern/intensity of the expected use. He/she can be supported by specialized consultants and designers. During building operation, the actual type and intensity of use must be checked regularly. When assessing the environmental performance in the use phase (real performance), it should be noted that the actual use may have changed compared to the assumptions made in the design, particularly with regard to the energy consumption of heating, electricity, water, etc. In this case, the TARGET values/setpoints for facility management shall be adjusted. This is particularly relevant for sustainability assessment systems that contain variants for assessing the "in use" performance of buildings

		– specification of the applied databases for construction products, transport and energy services (if possible, also background databases), including version number. Since datasets can define and map changes over time, it shall also be declared how the time factor is dealt with. For dynamic considerations, the source for such assumptions shall be given. – specifications of default values or other types of simplifications or cut-off rules for life cycle stages or building components (see also next rule).
How to treat uncertainty due to incompleteness related to the selected system boundaries?	4.	Often, for reasons of simplification, selected parts of the building and/or selected life cycle stages are excluded in a method, or the method allows that these are taken into account across design as **default values or safety margins**. If this is the case, this shall be stated and justified. Ideally, default values, safety margins and/or proxies shall be provided by the method itself so that exclusions are avoided. In the case of neglected life cycle stages and or components without compensation in the form of default values or safety margins, it shall be ensured that the benchmarks also match those conditions. Exclusions shall only be assigned to less influential factors for the purpose of simplifying the building and life cycle model description.
How to encourage designers to deal with design-related uncertainties, i.e. handle the increase in level of detail during design process?	5.	Concerning the LCA data to be used for construction products, building components and technical systems, there is the peculiarity in early design stages that usually neither the specific material composition of the components nor the manufacturer is known, let alone the specific product. Generic components or "macro elements" (such as an "average" outer wall or a variant of an already known construction) are often used, the environmental impacts of which have been determined using industry EPDs, average LCA data or generic data. Therefore, **method users shall be requested to work with ranges in early design stages and use the upper limit of the range to represent the calculated value** to be on the safe side when comparing to the benchmark provided from the start. This has consequences for the preparation of corresponding data and databases. To help in this direction safety margins for material quantities can be recommended by the method (e.g. see recomm. c under Section 4.2), while safety margins with respect to environmental values of specific types of products can be recommended by the database provider.
	6.	**Users shall be requested to present the calculated result and its assessment (adherence to the benchmark) at different stages of the design process**, declaring how the details of individual components regarding the specific layer structure/ content of product components as well as a description of the types of materials have been further specified from one design stage to the next.
	7.	Two starting points for quantifying the building in early design stages exist**:** generic LCA data for types of construction products (e.g. average concrete) or generic LCA data for macro-elements (e.g. average external wall). **Regardless of the starting point, method users shall be requested to use manufacturer- and product-specific information under specified databases by the method during the detailed design steps[87].** With this data, which is now more specific, especially after the receipt of tenders, there are additional options for evaluating partial aspects of environmental performance - including effects and risks for the local environment due to outgassing and leaching, consideration of return guarantees for shorter-lived products or types of disposal by manufacturers when assessing the recycling potential.

[87] From the designers' point of view, these questions are treated in the A72 report by Passer et al. (2022).

Who is/should be responsible for treating environmental data-related uncertainties? **How this type of uncertainty shall be approached by the method?**	8.	The respective provider is responsible for the correctness of the content of data and databases as well as the appropriate presentation of the uncertainties associated with them, both in relation to variability and quality of data. The user of the data is responsible for checking the quality and suitability. The user is also responsible for passing on information on uncertainties, quality and suitability of the data and databases used to third parties together with the calculation and assessment results. In the case of complex design and assessment tools with permanently linked databases, this responsibility falls to the provider of the tools. **Transparency and traceability of data flows shall be ensured**.
	9.	**This type of uncertainty shall be considered when determining benchmarks to be integrated in the method with the precondition that such information is given by the data or database providers**. Either the exceeding of benchmarks can be permitted (only at early design stages), or the benchmark sees itself as a defined limit that already takes such uncertainties into account in the calculation (i.e. conservative approach).
	10.	**The method shall request the users to report the quality of the environmental data used as background information**, with the precondition that this information is provided by the data provider.
How to communicate uncertainties?	11.	An index of the quality and adequacy of the data underlying the result shall be developed to accompany each result - as well as a statement of uncertainty.

Recommendations for action

Policy, regulation and law makers, national standardization bodies, developers and providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. provide specific requirements to the method users regarding the transparency and traceability of all types of data used (bill of quantities, environmental data, climate data, etc.) and publish this information together with the assessment result regardless of the design stage the assessment was conducted. Provide a specific template to method users for this purpose.
b. Recommend or allow the use of quality-proved design and assessment tools
c. Based on latest scientific studies, develop and regularly review default values and/or safety margins for environmental impacts of building components, life cycle stages as well as other parameters to be used at the early design stage. The default values and/or safety margins should follow a conservative approach as fall back option. Show a preference of using default values first to fill in any type of gaps; safety margins depend on what is 100% and are more building specific.
d. make all information on the calculation and assessment bases accessible. It is possible to charge a fee.
e. Request users to convey the degree of confidence when presenting LCA results, i.e. the uncertainties/ ranges shall be indicated in an understandable presentation format by third parties, accompanied with suitable information on assumptions and unknowns in background report.
f. if you are interested in designers providing probabilistic results as background information (therefore on top of a deterministic result to be compared to a benchmark), make sure that you provide the following conditions:
g. identify the uncertainties sources not influenced by the designer to be considered in these investigations (at the minimum, the most influential uncertain input parameters as identified by current literature sources);
h. provide particular values, ranges or PDFs for each of the uncertain parameters to be considered in a probabilistic way covering the “worst case scenario” (even if this means to use large ranges) and citing particular literature sources or databases. In case a user uses other ranges or distributions

than the ones recommended, it should be justified. Information on ranges and distributions shall be updated frequently (e.g. every 5 years)

i. provide or propose tools/ways to propagate uncertainty (e.g. Monte Carlo simulation) and produce sensitivity indices

Designers and engineers (application / use case: D, see Table 1.2)

j. When comparing design variants, check whether the differences between the variants are sufficient for the ranking and order or are still within the uncertainty range. Dependent uncertainties must be excluded. (Example: The uncertainty in the environmental impact of the production of cement (or the supply of 1 kWh of electricity) is the same for all variants and should be excluded). This is achieved by a Monte Carlo simulation of the DIFFERENCE of two variants.

Clients, owners, investors (application / use case: H, see Table 1.2)

k. It is the client's responsibility to describe the type and details of the use of the building. In the use phase, the assumptions about the type and details of the use should be checked. The result of this review should be used for the adjustment of parameters and reference values for the description and assessment of the environmental performance.

l. It is the client's responsibility to check whether and to what extent the RSP generally used for the particular type of building and type of use makes sense for the life cycle of his/her building project with respect to the planned technical lifespan or economic useful life - if not the case, additional analyses can be performed, along with analyses using the RSP (e.g. to fulfil legal requirements).

Researchers (application / use case: B, see Table 1.2)

m. When analysing case studies always run sensitivity analysis to identify the most influential uncertain parameters with respect to the final result. These analyses can support benchmarking.

n. Through scientific analyses, define the safety margins that should be considered by designers for different parameters in early design stages.

4.6 Specific Aspects of Refurbishment and their Consequences

4.6.1 General

As discussed in Sections 4.3.15 and 4.3.16, maintaining the technical and/or functional characteristics/features of a building in use by undertaking maintenance, repair work, as well as replacement of components whose service life is shorter than the service life of the building (modules B2, B3 and B4 in an LCA) is important and necessary. However, over a comparatively long building service life or period of use, changes arise that must be responded to. Specifically, changes may occur in social, legal, climatic and/or economic boundary conditions, changes in user and usage requirements, changes in space requirements and/or technical progress. In addition to maintaining the technical and/or functional features, there is a need to check whether the current usability, rentability or marketability of a building will be valid in the future. The need may arise to go beyond building maintenance at some point in a building's life cycle and apply improvements in the technical and/or functional performance to adapt to technical progress (better products are entering the market), and/or to new requirements or changes in the real estate market. Such improvements can be realized by refurbishment measures. Apart from special occasions or a change of ownership, major building refurbishments are usually planned in the life cycle of buildings in a cycle of 20-30 years and are combined with maintenance, repair and/or replacement measures or other activities to adopt the building to new needs or new technologies.

Refurbishment helps in extending the service life of buildings and often present a more environmentally friendly option compared to demolish a building and replace it with a new one. Of particular importance is the preservation and further use (i.e. retainment) of the load-bearing structure. A longer service life or use of buildings or main building components can slow down the material cycles, reduce the energy and mass flows as well as impacts on environment.

While many new buildings will have to be constructed in parts of the world in the coming years, in Europe adapting and further developing the existing building stock is a major priority. The use of the environmental performance assessment of refurbishment options is an important tool to support design and decision-making processes in this context. This application of the environmental performance assessment is therefore becoming more important on the one hand, but has not yet been sufficiently methodologically penetrated, on the other. In contrast to new design/new buildings, not only studies but also methods on the use of LCA approach to refurbishment are lacking.

It should be here noted that within the professional and scientific literature, varied terminologies can be observed: refurbishment, renovation, (deep) retrofit, conversion, modernisation, re-purposing, amongst others. Here the term refurbishment is used as an umbrella term to be in line with the standards (e.g. EN 15978). In literature, sometimes a more detailed distinction is made between:

a. **Retrofit:** implies the process of upgrading the technical characteristics of a building, by substituting products and systems in use with better ones, and/or including new types of products not being present when the building was constructed. Synonyms: Upgrade
b. **Refurbishment**: implies a process of improvement the quality of a building by keeping intact some part of the building structure, while many components are being replaced and/or added. It may include elements of retrofitting, re-purposing and/or extension (up to a certain extent). It implies a large-scale building modification. Seen as synonyms: renovation, modernization, deep retrofit.
c. **Re-purposing:** implies a process of changing the function (and therefore also type of use) of an existing building, e.g. transforming an office building to an apartment block. In this report, re-purposing is treated as a special case of refurbishment, as it involves the same type of system boundaries, but with a changed function. Seen as synonyms: conversion
d. **Extension:** implies a process of adding horizontal or vertical (addition of stocks or basement) building extensions

Table 4.54 shows the typical assessment parts applied in each project type case. In the case of complex measures on existing buildings, these cannot always be clearly assigned to a category/term. For further treatment of the topic, however, this only plays a subordinate role.

Table 4.54: Example of how to distinguish between the different terms used to denote improvement measures applied to existing buildings.

Project type		**Building part applying**			
		Fabric & structure	Core services	Local services	Interior design
Refurbish-ment	Major	✓	✓	✓	✓
	Fit-out	-	✓	✓	✓
	Shell and core services	✓	✓	-	-
	Only shell	✓		-	-
Retrofit	Only core services	-	✓	-	-
	Internal re-modelling	-		-	✓
Re-purposing		✓	✓	✓	✓
Extension		✓	✓	✓	✓

Measures on existing buildings are diverse. They differ in terms of occasion, goal, depth of intervention, type and scope. In the following, only measures are discussed which lead to an improvement in the technical and/or functional characteristics of building components or technical and/or functional performance of buildings or to the re-purposing and/or small expansion of buildings. The aim of is to increase understanding of the subtleties of the use of LCA for design options for refurbishment projects (to support the design process) and refurbished buildings (assessment of the building "as refurbished"). One of the main questions in this context is how to deal with the embodied impacts of the initial building structure continued to be used (retained) and the embodied impacts of the parts removed prematurely (before exhausting their service life) when assessing the environmental performance of a refurbished building, depending on the application case (i.e. design, environmental due diligence, certification, portfolio management, research, etc.).

While the cases of planned refurbishment described in Section 4.3.19 form already part of the design a new building and are simply documented via module B5, the case of unforeseen refurbishment, which is the focus here, involves designing a major refurbishment for a second/further use phase after the (initially unforeseen) end of a first/initial use stage.

Typical cases for the application of LCA to major refurbishment are:

a. Guidance for a choice between refurbishment versus maintenance or refurbishment versus demolition/deconstruction and rebuilding in terms of environmental performance as part of an overall decision-making process (e.g. Lützkendorf et al., 2016; Assefa & Ambler, 2017; Palacios-Munoz et al., 2019). Related tools for comparing such scenarios in early decision-making are now being developed, such as the CARE tool by Architecture 2030[88].
b. Support of design optimisation of the environmental performance of the refurbished building (see case studies 5-6-7 and 10-11 in A72 report by Birgisdóttir and Stranddorf (2022))
c. Sustainability assessment of the refurbished building for the purpose of certification (e.g. BREEAM Refurbishment and Fit-Out)

[88] https://architecture2030.org/caretool/

d. Support of research, to generate different types of benchmarks (i.e. limit, reference and target values) for different refurbishment solutions
e. Support of research to improve the modelling of the dynamics of changes in the building stock.

It is important to distinguish between a complete package of refurbishment measures and single/isolated measures; this distinction has an influence on the way the assessment is performed. When assessing individual refurbishment or retrofit measures, for simplification, the LCA implementation can be restricted to the measure than including the entire building. For example, the environmental impacts associated with a specific measure can be put against the benefits that it brings (e.g. energy or environmental savings during use), and a payback period can be determined as part of the assessment (e.g. Ardente et al. 2011; Rasmussen & Birgisdóttir 2016).

Special case: Life cycle-based environmental assessment of existing buildings in use

(Partial) LCA can be applied to existing buildings without a particular view to refurbishment. Reasons for such an application may be:

– Knowledge of environmental impacts and/or the overall environmental performance of an existing property to support purchase or sale (environmental due diligence). For example, the Swiss standard SIA 2032 (SIA 2020) proposes modelling rules for such a case.
– Sustainability assessment “in use” for existing buildings (e.g. BREAAM in use, LEED O+M and DGNB for Buildings in Use)

A calculation and assessment of the performance of existing buildings can be used to either resell the building or prepare a refurbishment plan. The availability of any updated documents of the initial design in the form of a building passport, for example, is an advantage. The building diagnosis serves, among other things, to check the possibility of further use of existing components, to determine their condition and to identify risks to the environment and health.

Reflections in standards: When it comes to unforeseen refurbishment, EN 15978:2011 standard states that “*if a building is refurbished and the refurbishment was not taken into account at the outset, i.e. in any previous assessment, a new assessment should be carried out, particularly where the refurbishment changes the functional equivalent,…In the new assessment of the refurbished building, the environmental impacts and aspects of the refurbishment materials and reconstruction/installation processes are allocated to modules A1 to A5*”.

Although the standards resulting from ISO TC 59 SC17 and CEN TC 350 deal in principle with both new building and refurbishment projects, the peculiarities of the assessment of refurbishments have hardly been discussed in detail so far. The statement above does not provide clarity on how to treat the environmental impacts of the initial building, whose parts are being further used in the next life/RSP, among other peculiarities of applying LCA to refurbishments of existing buildings. Special rules and guidance are needed. Such rules are expected to be added in the new version of EN 15978-1, as well as the results of the work of the CEN TC 350/ WG 8 Sustainable Refurbishment remain to be seen.

Reflections in existing national methods: Up to now only a few countries provide special guidance on how to calculate the life cycle environmental performance of refurbishment projects (see Table 4.55, adapted from Balouktsi and Lützkendorf 2023a), and even less provide benchmarks for their assessment (see A72 background report by Rasmussen et al. (2023)). However, the inclusion of mandatory calculations and legal binding benchmarks also for refurbishments, along the requirements for new buildings, is currently examined in some countries (e.g. Sweden, see Boverket 2020).

Existing buildings after refurbishment start a second life cycle, expressed with the modules A-C like a new construction. What in principle a typical refurbishment involves is:

a. **New components** are installed in the building to replace existing components (with similar ones or technically/functionally better ones) or not
b. **Retained components** constituting part of the initial building structure continue to be used post-refurbishment in a next period of service life (life cycle n+1)
c. **Removed components** constituting part of the initial building are either disposed, or recycled or reused either in another building or in the refurbished building itself (in another location)

Table 4.55: Overview of national methods providing guidelines also for the case of refurbishment[89]. Note: All methods include impacts associated with newly installed components and the post-refurbishment activities of retained components.

COUNTRY	METHOD	YEAR	New components [A-C[3]]	Retained components		Removed components	
				Initial [A-B]	New [A-C[3]]	Initial [A-B]	Current [C[3]]
Belgium	TOTEM tool	2020	✓	-	✓	-	✓
Finland	Method for the whole life carbon assessment of buildings[1]	2019	✓	-	✓	-	✓
Germany	Certification BNB (Offices)	2017	✓	-	✓	-	-
	Quality labelling QNG	2022	✓	-	✓	-	-
UK	Professional guide RICS[1]	2017	✓	-	✓	-	-
Switzerland	SIA 2032[1,4]	2020	✓	-	✓	-	-
New Zealand	Certification Green Star	2019	✓	-	✓	-	-
Netherlands	Addendum to determination method (building code)	2020	✓	✓[2]	✓	✓[2]	✓
France	Certification HQE (Renovation LCA: Practical Guide)	2020	✓	✓[2]	✓	✓[2]	✓

[1]document applicable to both new buildings and refurbishments (generic rules for refurbishment)
[2]proportional to the remaining/residual service life
[3]the same considerations apply to recycling, recovery, reuse potential (i.e. D1), if considered.
[4]SIA 2032 also includes approaches considering residual value and reinvestment value for existing buildings.

Table 4.44 shows the difference of existing methods surrounding the treatment of (b) and (c) particularly. What all methods include are the life cycle impacts of the new components and the life cycle impacts of replacements of retained components occurring during the next life cycle/RSP (post-refurbishment). This already necessitates the determination of an additional parameter compared to a method for new buildings: the residual/ remaining service life of retained components so that to be able to define the next replacement in the next building life. Most methods do not yet provide calculation rules for this (see Section 4.6.2). What makes the methods differ is how to treat the 'past' impacts of all initial building, either retained or removed. This leads to various modelling approaches as defined in Section 4.6.3.

4.6.2 Remaining service life of components

All methods involve the consideration of the impacts associated with the further use of retained building parts, but first one needs to identity, to quantify and to characterise the products and equipment intended to a further use. This is challenging if the initial building is not well-documented.

[89] works on this topic are currently going on in some countries. E.g. in Sweden, Boverket will come with their new report on this matter (and other issues like suggestions on limit values) in May 2023.

For existing buildings, often, incomplete or no information from the initial use is available, and therefore, the repairs and replacements made in the previous use are not well-recorded. Furthermore, pollutants may have entered the construction from previous use (petrol station, dry cleaning). A documentation and assessment of the current situation in the form of a building diagnosis is therefore indispensable. In the case of completely missing documents, even the materials originally used must be determined.

A building diagnosis supported by the analysis of existing design documents of as starting point for a design for refurbishment is always needed to determine the type, quantity and properties of components that are intended for further use. It is important to assess the load-bearing capacity, the presence of pollutants and the assessment of technical features, such as thermal insulation. However, retracing the history of a specific building to determine all or some of these aspects is often a complex task. There are different information sources. Sometimes, information is available in individual countries for selected construction methods and age classes, including information on pollutants that were used in specific construction methods in defined periods of time and / or information on technical features (such as U-values of old components).

It is possible to infer the remaining service life of initial components to be further used (as identified during a building diagnosis) by classifying the condition of existing components and systems in "condition stages" (e.g. Figure 4.38). These assumptions are associated with risks; in the further course of the life cycle these parts should be subjected to more frequent inspections. In case the remaining service life of an element cannot be estimated, there are methods proposing simplified approaches. For example, HQE (2020) recommends considering the remaining service life equal to half of the service life of an equivalent today's product.

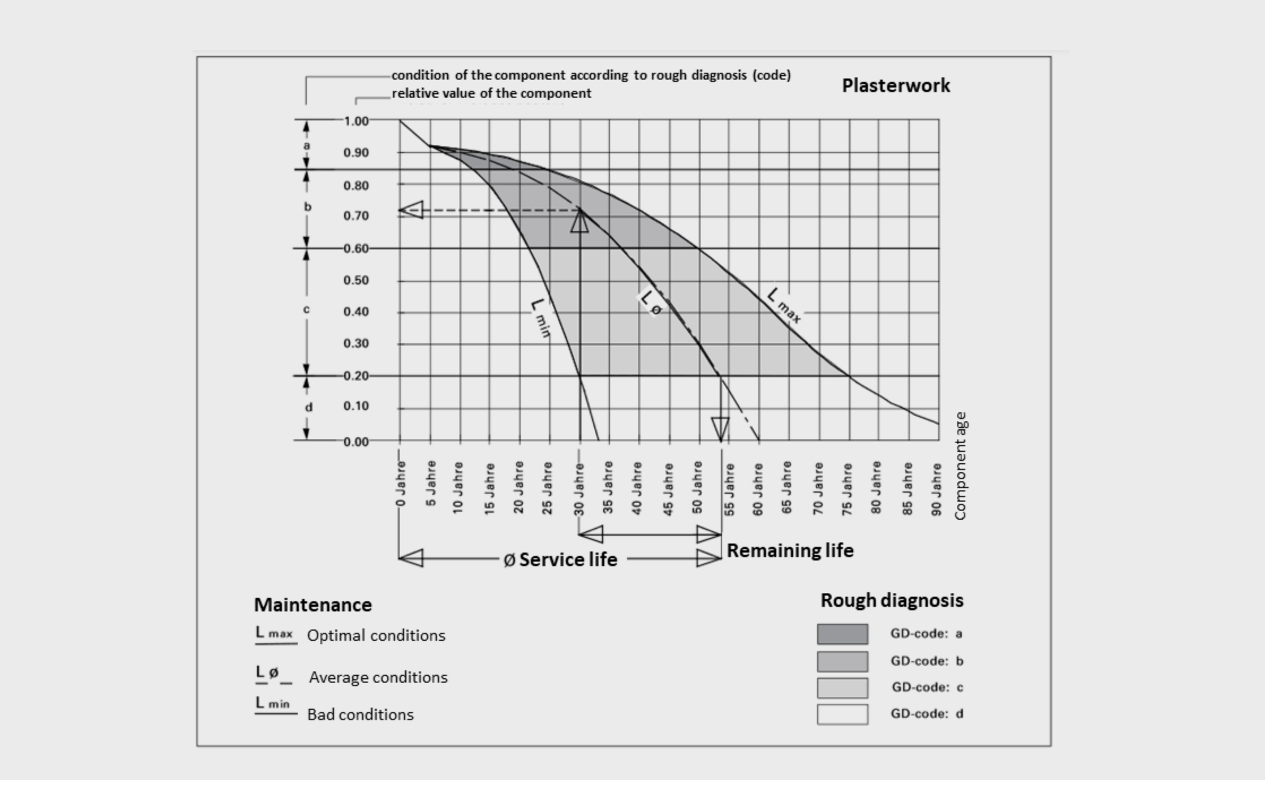

Figure 4.38. Example of an aging diagram of a component to identify the remaining service life value (Source: adapted from Bundesamt für Konjunkturfragen (1994)).

4.6.3 Typology of options in modelling of refurbishment activities

In the case of refurbishment of an existing building as a starting point of a next service life/RSP, different modelling and inclusion/exclusion possibilities exist for the initial (pre-refurbishment) impacts of the parts of the initial building structure that remain for further use as well as of the parts of the initial building structure that are removed and processed (for recycling, reuse, recovery) or disposed. In relation to the treatment of the initial structure further used, there are three main approaches, visualized in Figure 4.39:

- **Approach 'zero'**: impacts occurred in the past are allocated to the past, i.e., embodied impacts of the initial structure that occurred pre-refurbishment are neither calculated nor considered in the LCA of the refurbished building.
- **Approach 'residual load'**: It involves the determination of the 'residual environmental load' at the time of refurbishment, with straight-line depreciation hypothesis, i.e., the environmental impacts of the initial building parts are divided over their planned service life and allocated proportionally to the service life that has already taken place. The remainder corresponds to the residual load at the time of consideration.
- **Approach 'fictive replacement of components'**: It measures the savings that are assumed by continuing to use existing parts of the building, i.e. not entirely constructing a new identical building (same functionality, size, operational energy efficiency, etc.). Structural parts continued to be used can be assessed based on current LCA data. This results in a 'fictive replacement of building components' if existing components continue to be used in the sense of 'as if newly constructed'. For example, if one maintains only the structural system of an existing building for further use post-refurbishment, while the rest is demolished and replaced by new components, then: *fictive replacement of components' = C1-4 impacts of existing structural system 'as if deconstructed' + A1-5 impacts of a comparable structural system 'as if rebuilt' for fulfilling same technical requirements for the next RSP.* This can be seen as additional information/metric to demonstrate the benefit of refurbishment compared to building entirely new (i.e. additional information to an A-C result of a zero approach).[90]

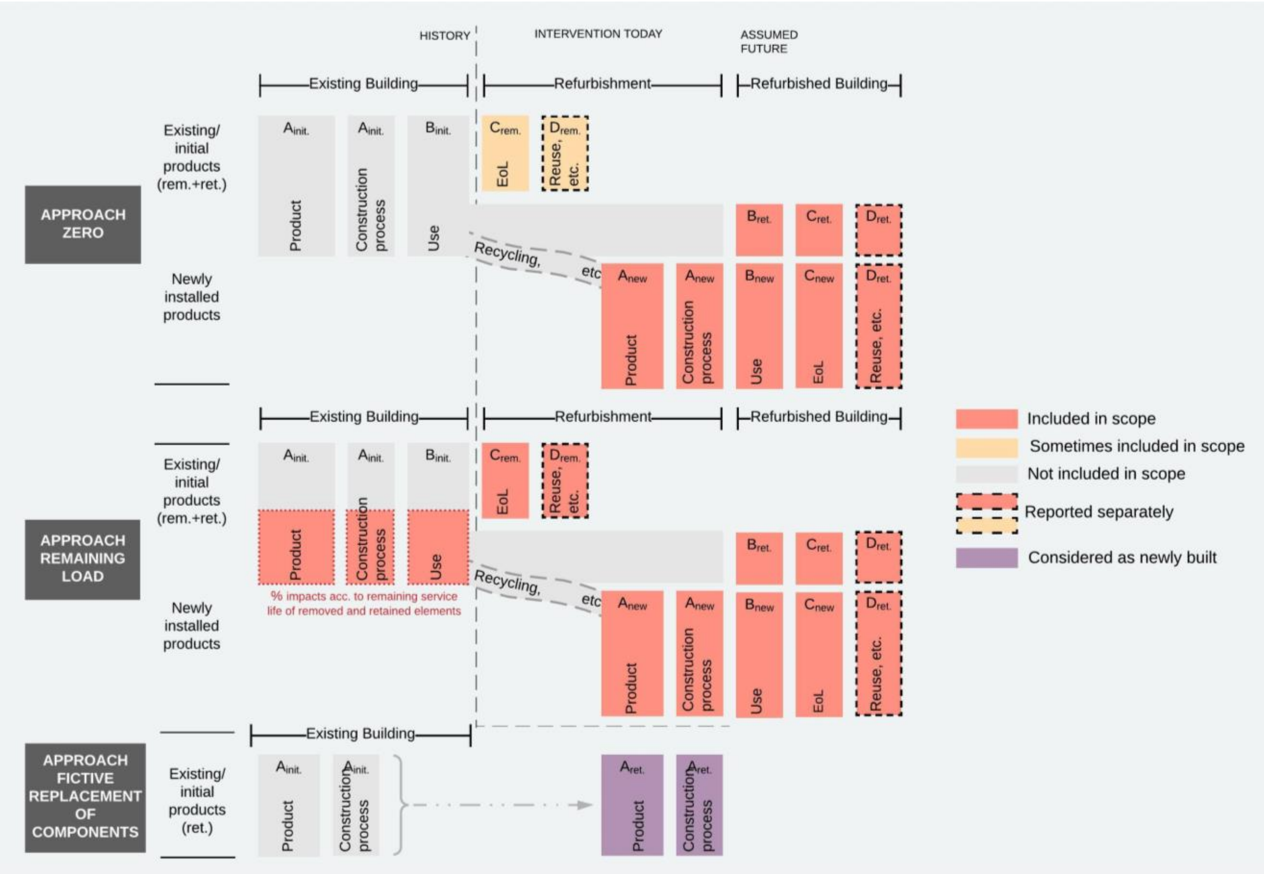

Figure 4.39. Visualisation of the three allocation approaches of the pre-refurbishment impacts associated with initial structure further used in a refurbished building (Source: Balouktsi and Lützkendorf 2022). Note: newly added is denoted as "new", removed is denoted as "rem." and retained as "ret.".

[90] This approach partly resembles the approach 'replacement value' seen in SIA 2032 for the case of existing buildings (not particularly refurbishments). The replacement value of the environmental impact of a building has its economic counterpart in the new value insurance. It corresponds to the environmental impact of an existing building if it were newly constructed. It corresponds to the sum of residual load and value retention over a defined observation period.

The implications are discussed in Table 4.56. Their appropriateness is dependent on the decision-making situation.

Table 4.56: Brief overview of the pros and cons of the three allocation approaches of the pre-refurbishment impacts associated with initial structure further used in a refurbished building (Summarised from Balouktsi and Lützkendorf 2022).

Approach	Pros	Cons
Approach 'zero'	– **Calculation is straightforward**; no need to calculate residual values – **Appropriate for budget approaches**; It makes particular sense in the context of setting a specific allowable budget for environmental impacts (including GHG emissions) for a time period. All building construction and maintenance activities carried out in the past have already been charged to a budget of a past time period. According to budget-approach, assigning effects that occurred in the past to future time periods (here to a current, subsequent life cycle) in the sense of a residual "load" could be a double-counting. – **Focuses on what can be influenced today**; what has already been 'spent' cannot be influenced retrospectively.	**It does not 'directly' guarantee avoidance of premature removals** (but in principle the more components are discarded, the more components will be newly added to replace them, leading to higher environmental impacts)
Approach 'residual load'	**It 'punishes' premature removal of products without possibility or intention of reuse** (in another building or within the building under study); It acknowledges that when observing a building at a specific point of time during its life cycle, some materials are already at (or close to) the end of their service life and some still have a large remaining service life, because either they have a very long service life, or they were recently exchanged. The effect of premature removal can be a significant in the case of long-lived products and undesirable in view of circular economy.	**Calculation is more complex**; it involves the determination of the 'residual environmental load' at the time of refurbishment, which requires the definition of at least two additional parameters/inputs: – materialisation of the components retained (type and quantity of each product/material); – environmental impacts (LCA data) Residual loads are independent of any future actions on a particular building.
Approach 'fictive replacement of components'	– it can be a useful additional piece of information/metric to demonstrate the benefit of refurbishment compared to building entirely new.	**It is a hypothetical representation of the reality**; developers do not often replace an existing structure with a similar one in terms of size and basic design. Therefore, there are several options and perspectives one should consider here.

It should be noted that the 'residual load' approach may have different variants based on the type of LCA data used for the calculation, adding in different ways to the overall uncertainty. These can be:

– **historical data**: the precondition is that the original environmental impact data during the construction and repair/replacement measures of the initial building are still known or can be reconstructed. Usually, it very difficult or unfeasible to retrace the 'environmental' history of long-standing buildings, since in most countries, LCA applications and life cycle-based environmental information of products have not been around for more than 20 years. This would perhaps be less of a problem in the future with increasing digitalization of environmental information and calculations in the construction sector.

- **present-day data**: original components can be calculated as they were built today (i.e. by choosing the environmental values of equivalent products in current databases). However, material efficiency in production and use significantly improve decade after decade.
- **dynamically modelled data**: current LCA datasets can be re-modelled to correspond with the electricity mix used at the time of the production of the products constituting the existing building. For example, this was done by Obrecht et al. (2021) for a typical residential building from 1980, the differences in residual value due to different electricity mixes in material manufacturing were in the range of 10 percent (for a summary, see A72 report by Birgisdottir and Stranddorf (2022), case study 08).

The methods that currently follow the residual load approach exclusively (see Table 4.44) do not clearly specify what type of LCA data shall be used for the original structure. It can be assumed that the data found in their national tools apply (present-day-data).

When it comes to the removed components, there may be cases in which they have not yet reached the end of their useful life or of wear margin (early removal), i.e. they still have a potential for residual life. Like the existing components retained for the second life, the treatment of removed components can follow a zero or a residual load approach. The main difference is that the residual service life of these products is most probably not used in the next building cycle of the specific existing building (unless reused in situ), but potentially in other construction activities. The different courses of life for components that can occur post-removal lead to different allocation possibilities of past impacts within the two main approaches as seen in Table 4.57.

Table 4.57: Different ways of allocating the past impacts (A and B modules) of removed elements with residual service life (Source: Balouktsi and Lützkendorf 2022a).

Variant for removed products with considerable residual life	Zero approach			Residual load approach		
	Initial Building	Refurbished Building	Another Building*	Initial Building	Refurbished Building	Another Building*
1 – removed and finishes its EoL (no intention of reuse)	Full allocation	Zero	n/a	Pro-rata allocation	Pro-rata allocation	n/a
2 – removed, sold & reused in another building	Full allocation	n/a	Zero	Pro-rata allocation	n/a	Pro-rata allocation
3 – reused in the same building (in situ)	Full allocation	Zero	n/a	Pro-rata allocation	Pro-rata allocation	n/a
*outside the system						

Allocation of EoL and D1 impacts of components removed: When an existing building is (partially) deconstructed as part of a refurbishment process, EoL and recycling, recovery or reuse of the removed components do not take place far in the future but (nearly) concurrently with the refurbishment interventions (see Figure 4.41). Therefore, issues arise on how to proceed with all processes concerning modules C1-4 and D1 of initial building parts being removed. Does the demolition or deconstruction of an existing building in the sense of clearing the property form the end of a previous or the beginning of a next life cycle/object of assessment? In reality, the two life cycles overlap; partial demolition, deconstruction, and transport of removed elements to different EoL routes are activities happening during the construction process of the refurbished building and can be influenced (in the cases of reuse in situ only the processes of deconstruction, restoration for reuse[91] and re-installation are relevant). Ignoring these processes, as is the case in some methods (see Table 4.44) produces a gap between the end of the initial building life cycle and the beginning of the new

[91] some retained and in-situ reused elements may need treatment before being reused in the project

one, as in most cases it is unlikely that this information has been part of a previous LCA. Particularly, all the methods currently including C1-4 impacts of removed components in the scope of the refurbishment report them in A4-5 modules of the refurbished building. For the Dutch method (Anink 2020) and the French method HQE (2020) which follow the residual load approach, it is however not clear whether this is also done on a pro-rate basis (i.e. acc. to the residual service life).

Special considerations in the case of non-reuse (Variant 1): As earlier mentioned an advantage of residual load approach over zero approach is the 'punishing' of premature removal of products without possibility or intention of reuse. While this can be a significant effect in the case of long-lived products and undesirable in view of circular economy (Anink 2020), it can be negligible for short-lived products since the moment of refurbishment will often not deviate that far from the regular replacement moment. Not all country methods following the residual load approach have yet set rules of what premature removal means, and therefore for what removed components the impacts can be overlooked; for example, would a component replaced just two years before its EoL be considered early removal? When the residual load approach is chosen clarity should be provided for such issues. For example, HQE (2020) allows overlook the residual load of existing components when the remaining service life ≤ 10% the technical service life.

Special considerations in the case of reuse (Variants 2, 3): The reuse of building components is not yet a mainstream practice. Therefore, it is highly unlikely that this would be the route for most removed components if a refurbishment would happen today. The decision to sell components for reuse will be based on economic criteria (e.g. cost of careful deconstruction compared to demolishing and the revenues from sale either for reuse or recycling) as well as organisational and market limitations (e.g. lack of coordination between the owners of the old building site and the new building, lack of an established market for reused products). When reuse is chosen as a route, there is a need to embed additional qualitative features in the assessment of the reused components (e.g. see De Wolf et al. 2020).

4.6.4 Conclusions and guidance

The refurbishment of the building stock to adapt to new conditions and energy efficiency standards becomes an essential strategy towards the achievement of climate and energy goals around the world. This becomes particularly important in the European context where the large existing old building stock would soon need to be transformed. It is necessary to develop methodological bases for the life cycle-based environmental performance assessment of refurbishment measures that lead to reliable results. Special rules for such cases must also find their way into standardization in the short term. At the moment, there are too many approaches and variants, as well as open methodological questions, but too little guidance on which approach suits which decision-making situation best. This is the case as using LCA for refurbishment projects is still a quite unexplored area and the purpose of it in terms of supporting environmental impact reductions of refurbished buildings.

To this end, Table 4.58 connects the typical application cases of LCA regarding refurbishment projects mentioned in the previous sections to the three main approaches of allocation of impacts earlier described. The first two decision-making situations deal with the question of how to deal with an existing building, where three possible options exist: (a) further maintain it (no major intervention that deviates from the regular replacements and maintenance will be carried out); (b) refurbish it (with the same or changed function); (c) deconstruct it and build a new similar one. The rest decision-making situations are relevant for situations where refurbishment has already been decided.

Table 4.58: Brief overview of the pros and cons of the three allocation approaches of the pre-refurbishment impacts associated with initial structure further used in a refurbished building (Summarised from Balouktsi and Lützkendorf 2022).

Typical cases for the application of LCA to major refurbishment	Approach 'zero'	Approach 'residual load'	Approach 'fictive replacement…'
Guidance for a choice between refurbishment versus maintenance	X	(x)	n/a
Guidance for a choice between refurbishment versus demolition/ deconstruction and rebuilding	X	(x)	n/a
Support of design optimisation of the refurbished building	X	(x)	n/a
Sustainability assessment of the refurbished building for the purpose of certification	X	(x)	X**
Support of research to improve the modelling of the dynamics of changes in the building stock	X	(x)	(x)

* To reduce the risk of manipulation, a minimum retention/ use period of 5 years should be guaranteed.

** useful as additional information or indicator

Practically, both main approaches (zero and residual load) are applicable to the respective decision-making situations. The majority of Annex 72 advocates the "zero" approach; this is reflected in the rules (Table 4.59) and recommendations (grey box) provided below. The reason is that it is essential to focus on impacts that can be influenced and have not yet occurred as well as to map the points in time the energy and material flows occur more precisely so that they be better combined with sectoral considerations[92]. To highlight and communicate the potential environmental advantages of refurbishment, in an environmental performance assessment, it is possible and sensible to additionally (and separately) indicate the savings by continuing to use parts of the existing building fabric. Refurbishment slows down material cycles. In any case, for an assessment approach dedicated to refurbishment projects to play a role in the decision-making of property owners, it ought to focus on:

– choosing environmentally improved solutions of the measures taken
– avoiding removing well-functioning components
– promoting keeping existing building structures
– promoting operational energy savings

[92] It can also be said that if there is no reuse of the removed components of the initial building to another building, residual load value does not differ between maintenance, refurbishment and replacement of an existing building.

Table 4.59: Rules regarding the application of LCA to refurbishments

ISSUE(S)	RULE(S)
How to allocate the pre-refurbishment embodied impacts of the initial building structure with a residual life (continued to be used or removed)?	1. Approach zero shall be used (Figure 4.41), i.e. existing building elements retained for further use shall not bear loads from the past. The same applies to the removed elements with a residual life. Although this approach does not directly guarantee avoidance of early removals, it is likely that the more components are discarded, the more components will be newly added to replace them, which will be reflected in the results.
	2. If the approach 'residual load' (Figure 4.41) is chosen to be applied in any case, the following shall be clearly specified: how the retained components shall be materialised in case historical data is not available (type and quantity of each product/material); what type of LCA data for environmental impacts shall be used in case historical data are not available; cut-off rules in relation to for what removed components the remaining impacts can be overlooked (e.g. are only early discarding/removals considered and how is this defined?).
How to allocate the EoL impacts of removed components?	3. The EoL impacts (C modules) of the removed components from the initial building shall be allocated to the construction process impacts (A4-5 modules) of the refurbished building, unless justified. This also includes considering the release of biogenic CO_2 in case bio-based products are removed but not reused.
How to deal with the post-refurbishment embodied impacts of the initial building structure retained?	4. In addition to the inclusion of the life cycle impacts associated with any new parts, components and ancillary products needed for the refurbishment, also the impacts of replacements of initial building components occurring during the second life cycle as well as their end-of-life of impacts shall be included in an assessment. This presupposes the provision of simplified approaches to consider the residual service life in case its estimation is not possible. 5. The RSP of the refurbished building shall be determined and reasoned carefully. It is limited by the remaining service life of the load bearing structure. In the case of comparison of design option new construction versus refurbishment the RSP shall be the same.
How to deal with single measures?	6. When analysing individual refurbishment measures, a method shall not mandate the calculation of the entire building if the effects on B6 and B7 are known and taken into account.
Special case: how to assess an existing building for purchase purposes after a short time of its construction?	7. In cases where an existing building was only used for a short time after its construction and before an ownership change (purchase) the embodied impacts of the existing building shall be part of its environmental certificate/profile either fully or in a depreciated form (depending on its residual service life and how "short time" is defined). The definition of short time depends on the type of building and the conditions in the national real estate market.

Recommendations for action

Policy, regulation and law makers, developers / providers of sustainability assessment systems (application / use case: C, see Table 1.2)

a. When developing benchmarks for the refurbishment of buildings, formulate identical life cycle-related target values. When developing partial guide values and/or partial requirements as additional side requirement to life cycle-related values, it should be noted that it can be more difficult to achieve ambitious goals for the operational part of a refurbishment project, but easier for the embodied part.
b. Define what constitutes a refurbishment project that would be subject to a legal requirement.
c. Work out principles of how to deal with existing buildings on an area to be developed, consisting of existing buildings to be teared down, existing buildings to be refurbished and new buildings.

National standardisation bodies (application / use case: C, see Table 1.2)

d. Work out basic principles for the estimation of the remaining useful life of components depending on the deterioration condition.
e. Work out basic principles for the estimation of the pollutant content and risks of existing components to the environment and health.
f. Work out basic principles for the assessment of the technical performance of existing components.
g. To assist decision-makers in pre-design stages to decide on refurbish or build new, provide typical construction typologies the new building to which the refurbishment scenario should be compared.

Researchers (application / use case: B, see Table 1.2)

h. Develop more and better data/models for assessing the condition of existing building structure (for further use) and its remaining useful life
i. To investigate the advantages of refurbishment over new construction, compare multiple refurbishment and new construction scenarios for single case studies, also integrating projected future emission intensity data for energy services and future availability (maximum potential) of renewable energy sources.

4.7 Reporting Requirements

Along with describing the system boundaries and calculation procedures per life cycle module and as a whole, methods also need to specify the minimum items (assumptions, results, etc.) that need to be disclosed as well as provide an organised reporting structure for clarity and consistency. There are good examples of methods and guides providing such structures, such as RICS (2017), Carbon Leadership Forum (2019), Kuittinen (2019) and Level(s)[93]. Furthermore, A72 report on benchmarks by Lützkendorf et al. (2022) provides a checklist for the documentation and communication of benchmarks, which checklist can also be used to document the calculation basis of an environmental performance result. This checklist focuses on providing clear statements and explanations on the functional equivalent and the assumptions and scenarios applied for every life cycle module to facilitate the calculations. In the case of a calculation result additional reporting requirements are necessary, such as:

- a clear indication of the point in time within the project process the assessment was conducted (e.g. Table with design steps)
- the degree of coverage of building parts and life cycle processes, including a description of how this was determined
- clear statement on uncertainty of the result and explicit declaration of all sources of data, material quantities and all relevant technical information accompanied with a quality index
- clear statement of life cycle design concepts incorporated in the building solution and how (e.g. net zero emission construction, design for adaptability, design for deconstruction, etc.)

It is recommended that method providers offer a dedicated database where the outputs and background information of all assessments can be entered to aid the collection of robust lifecycle-based data and benchmarking.

[93] the European Commission's assessment and reporting framework for the sustainability performance of buildings

5. Outlook

Appropriate calculation and assessment methods play an important role in achieving environmental goals such as the conservation of primary raw materials as a contribution to the efficient use of resources and the reduction of greenhouse gas emissions as a contribution to protecting the climate. Methods form the basis for relevant actors to be able to integrate the aspects of environmental protection into their processes and decisions. The methods help to enable a problem perception based on scientific methods and consequently create a pressure to act. At the same time, they form a basis for assessing options for action and supporting success measurement. Suitable methods contribute to quantify difficult discussions and allow the selection of targeted measures in the process of continuous improvement.

Policymaking and practice are currently benefiting from decades of preparatory scientific work. An important contribution was made by providing methodological foundations and data for the life cycle assessment of buildings. These now need to be integrated into suitable requirements, robust and reliable assessment processes and practical assessment tools. The possibly necessary simplifications must always be scientifically checked in order to guarantee that the building designs are improved/optimised in the right direction.

The (further) development of methodological principles is a dynamic process. New findings, e.g. in environmental sciences, technical progress, social change including changes in values and other influences must be reflected in the calculation and assessment methods. In particular, the current phase is characterized by high dynamics and challenging issues. This concerns dealing with the already occurring consequences of climate change and the technical progress and the accelerating decarbonisation of energy supply and production, among others. At the same time, the uncertainty of forecasting future developments is increasing, with even more complex issues.

The further development of methodological foundations must therefore do two things at the same time: (a) react to current developments and requirements and advance the basic scientific work - for example for testing dynamic probabilistic approaches and (b) make manageable, robust and directionally reliable methods available to politics and practice, which are suitable for formulating legally binding requirements, among other things. It is still necessary to have a scientific lead for the development and testing of consensus-based solutions for the methodological bases. This is where the "method dispute" can and should be settled. When transitioning to rules of policy and practice, only a consistent solution is likely to provide a suitable basis for decision-making. International standardization also plays an important role here, which must find a solution that can be reached by consensus on selected topics – with science having a right of veto.

The following topics must therefore be dealt with relatively quickly in order to adapt to the needs of policymakers and practitioners: (a) assessment of biomass, (b) benchmarks for upfront emissions which nevertheless take into account the further life cycle, (c) improvement of information flows along the value chains – while other topics need to be dealt with soon enough in order to fill implementation gaps such as the establishment of (d) dynamic emission factors that represent credible decarbonisation strategies as well as (e) quality assurance procedures of LCI data and tools.

It is already clear that selected topics should and must be taken up and worked on in a next IEA EBC Annex.

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