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Assessing life cycle related environmental impacts caused by buildings

IEA EBC ANNEX 72

The 2226 Office, in Lustenau, Austria, serves as one of the reference buildings in EBC Annex 72.
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Zusammenfassung

Gebäude und Infrastrukturen dienen der Befriedigung grundlegender Bedürfnisse und sind die Basis für die soziale und wirtschaftliche Entwicklung. Die Herstellung, der Bau, die Instandhaltung und der Betrieb von Bauwerken sind mit erheblichen Energie- und Materialströmen sowie unerwünschten Auswirkungen auf die globale und lokale Umwelt verbunden. Gebäude verursachen einen signifikanten Anteil von etwa 40 % der globalen THG-Emissionen (IEA & UN Environment 2018) und tragen damit zur schnellen Aufzehrung des verbleibenden THG-Emissionsbudgets bei, das dem 1,5°C-Ziel entspricht. Es besteht ein dringender Handlungsbedarf.

Um diese Auswirkungen quantifizieren, bewerten und gezielt reduzieren zu können, werden geeignete Bewertungsmethoden und Gestaltungswerkzeuge benötigt. Solche Methoden und Werkzeuge ermöglichen es den Entscheidungsträgern, die Auswirkungen auf die Umwelt nicht nur zu erkennen, sondern auch zu beeinflussen, und zwar sowohl in der Entwurfsphase als auch während der weiteren Phasen des gesamten Bauprojekts. Die Weiterentwicklung solcher Bewertungsmethoden und Entwurfshilfen für Gebäude war eine der Aufgaben des IEA EBC Annex 72. Die von mehr als 60 Wissenschaftlern aus 25 Ländern Europas, Amerikas und Asiens entwickelten Grundlagen und Handlungsempfehlungen liegen nun vor.

Zur Unterstützung des Hauptziels, den Primärenergiebedarf, die Treibhausgasemissionen und die Umweltauswirkungen entlang des gesamten Lebenszyklus von Gebäuden (Bau, Nutzung und Ende der Lebensdauer) zu reduzieren, bietet der IEA EBC Annex 72 gemeinsame, zielabhängige methodische Leitlinien zur Bewertung dieser Grössen. Es wurden Methoden für die Entwicklung spezifischer Umweltbenchmarks für verschiedene Gebäudetypen festgelegt, um die Planung von Gebäuden mit einem minimalen lebenszyklusbasierten Primärenergiebedarf, Treibhausgasemissionen und Umweltauswirkungen zu unterstützen. Der Annex 72 enthält regional differenzierte Leitlinien und Instrumente (Gebäudeentwurfs- und Planungsinstrumente wie BIM und andere) für Architekten und Planer. Es wird eine Reihe von Gebäudefallstudien zur Verfügung gestellt, die sich auf die Veranschaulichung einiger der Forschungsfragen und auf die Ableitung empirischer Benchmarks konzentrieren. Schließlich wurden Leitlinien für die Einrichtung nationaler/regionaler Datenbanken mit regional differenzierten, auf den Bausektor zugeschnittenen Ökobilanzdaten entwickelt, die die Materialproduktion, die Herstellung von Gebäudetechnik, die Energieversorgung, die Verkehrsdienste und die Abfallentsorgung abdecken.

Résumé

Les bâtiments et les infrastructures répondent à des besoins fondamentaux et constituent la base du développement social et économique. La production, la construction, l'entretien et l'exploitation des ouvrages de construction sont associés à des flux d'énergie et de matières considérables ainsi qu'à des effets indésirables sur l'environnement mondial et local. Les bâtiments sont à l'origine d'une part importante des émissions mondiales de gaz à effet de serre, soit environ 40 % (IEA & UN Environment 2018), et contribuent ainsi au déploiement rapide du budget d'émissions de gaz à effet de serre restant, qui correspond à l'objectif de 1,5°C. Il est urgent d'agir. Il est urgent d'agir.

Afin de pouvoir quantifier, évaluer et réduire spécifiquement ces impacts, des méthodes d'évaluation et des outils de conception appropriés sont nécessaires. Ces méthodes et outils permettent aux décideurs non seulement de reconnaître mais aussi d'influencer les impacts sur l'environnement dès la phase de conception et tout au long du projet. La poursuite du développement de telles méthodes d'évaluation et d'aides à la conception pour les bâtiments était l'une des tâches de l'annexe 72 de l'IEA EBC. Les principes de base et les recommandations d'action élaborés par plus de 60 scientifiques de 25 pays d'Europe, d'Amérique et d'Asie sont désormais disponibles.

Afin de soutenir l'objectif principal de réduction de la demande d'énergie primaire, des émissions de gaz à effet de serre et des impacts environnementaux tout au long du cycle de vie des bâtiments (construction, utilisation et fin de vie), l'annexe 72 de l'AIE EBC propose des lignes directrices méthodologiques communes, dépendantes des objectifs, pour évaluer la demande d'énergie primaire, les émissions de gaz à effet de serre et les impacts environnementaux liés au cycle de vie des bâtiments. Elle établit des méthodes pour le développement de repères environnementaux spécifiques pour différents types de bâtiments afin d'aider à concevoir des bâtiments ayant une demande d'énergie primaire, des émissions de gaz à effet de serre et des impacts environnementaux minimaux sur le cycle de vie. L'annexe fournit des lignes directrices et des outils différenciés selon les régions (outils de conception et de planification des bâtiments tels que BIM et autres) pour les architectes et les planificateurs. Un certain nombre d'études de cas de bâtiments sont fournies, axées sur l'illustration de certaines des questions de recherche et sur l'obtention de repères empiriques. Enfin, des lignes directrices ont été élaborées sur la manière de créer des bases de données nationales/régionales contenant des données d'évaluation du cycle de vie différenciées selon les régions et adaptées au secteur de la construction, couvrant la production de matériaux, la fabrication de technologies de construction, l'approvisionnement en énergie, les services de transport et les services de gestion des déchets.

Summary

Buildings and infrastructures serve basic needs and are the basis for social and economic development. The production, construction, maintenance and operation of construction works are associated with considerable energy and material flows as well as undesirable effects on the global and local environment. Buildings cause a significant share of about 40 % of global GHG emissions (IEA & UN Environment 2018), and with that contribute to the fast deployment of the remaining GHG emission budget which corresponds to the 1.5°C target. There is an urgent need for action.

In order to be able to quantify, evaluate and specifically reduce these impacts, suitable assessment methods and design tools are needed. Such methods and tools enable decision-makers not only to recognise but also to influence the impacts on the environment as early as the design stage as well as throughout the project. The further development of such assessment methods and design aids for buildings was one of the tasks of the IEA EBC Annex 72. The basic principles and recommendations for action developed by more than 60 scientists from 25 countries in Europe, the Americas and Asia are now available.

In support of the principal aim of reducing the primary energy demand, greenhouse gas emissions and environmental impacts along the entire life cycle of buildings (construction, use and end of life), the IEA EBC Annex 72 offers common, goal dependent methodology guidelines to assess the life cycle based primary energy demand, greenhouse gas emissions and environmental impacts caused by buildings. It established methods for the development of specific environmental benchmarks for different types of buildings to help designing buildings with a minimum life cycle based primary energy demand, greenhouse gas emissions and environmental impacts. The Annex provides regionally differentiated guidelines and tools (building design and planning tools such as BIM and others) for architects and planners. A number of building case studies is provided, focused to illustrate some of the research issues and for deriving empirical benchmarks. Finally, guidelines were developed on how to set up national/regional databases with regionally differentiated life cycle assessment data tailored to the construction sector, covering material production, building technology manufacture, energy supply, transport services and waste management services.

Main findings

- When assessing environmental performance of buildings, the complete building in its entire life cycle must be considered, including all upstream and downstream processes. For the planning and assessment, suitable building and life cycle models with a high degree of transparency are needed to make model and data uncertainties visible and able to reduce.
- LCA databases for the building sector should cover construction materials (both generic and company specific), building technologies (such as ventilation and photovoltaic systems), energy supply, transport and waste management services. It should address life cycle related GHG emissions as well as other main environmental challenges such as fine particles, resource depletion and biodiversity losses. Extensive documentation, independent review and full data transparency are considered main features, which help ensure appropriate data quality.
- Currently, benchmarks based on technical and/or economic feasibility are increasingly complemented by target values derived from planetary boundaries, taking into account the GHG emissions budget still available to meet defined global warming limits. With "(net) zero GHG emission", the first universal benchmark exists that is suitable for all types of buildings and uses in all climate zones.
- The environmental impacts of the building should be followed and reduced throughout the design process. Guidelines and recommendations help integrating the LCA into the design process and design tools and to visualize and communicate the LCA results to support the stakeholders involved in the building design process.

Contents

Abbreviations

EBC	Energy in Buildings and Communities Programme
GHG	Greenhouse gas
IEA	International Energy Agency
LCA	Life Cycle Assessment
PED	Primary Energy Demand
TCP	Technology Collaboration Programme

1 Introduction

1.1 Background information and current situation

In response to concerns about climate change, energy security and social equity, countries around the world are either planning to substantially reduce energy demand and greenhouse gas (GHG) emissions or in the case of emerging economies to develop in less energy intensive ways. The construction as well as heating and cooling of buildings is one major cause of primary energy demand (PED), GHG emissions and environmental impacts of developed and emerging economies. Buildings have a long service life of between some decades to more than 100 years. Thus, investment decisions on buildings today determine by and large the environmental impacts during several future decades. Furthermore, the upfront GHG emissions caused by the construction of buildings immediately reduce the remaining emission budget to keep global temperature rise below 1.5°C. Furthermore, such decisions involve a trade-off between additional investments today and potential savings during use and end of life (both in terms of economic costs and PED, natural resources like primary mineral materials, GHG emissions and further environmental impacts). Solutions are needed that minimise and/or balance both the operational and the embodied part of life cycle related environmental impacts of buildings.

Today, natural resources such as clean air, clean water, biodiversity or primary resources are free and their use is hardly charged. The current price system does not (systematically) account for such external environmental effects (market failure) which leads to an inefficient (over)use of environmental resources. That is why, environmental life cycle assessments of human activities are necessary to highlight the inefficient use of natural resources and to take measures and action to increase the resource efficiency of buildings and construction. Environmental life cycle assessments provide a basis for integrating external effects in the form of external costs into economic considerations.

1.2 Purpose of the project

The purpose of the IEA EBC Annex 72 is to increase the knowledge basis and capacities and to exchange experiences in environmental life cycle assessment of buildings, to foster its application and finally to contribute to buildings with lower environmental footprints applying a life cycle perspective.

1.3 Objectives

In support of the principal aim of reducing the Primary Energy Demand (PED), GHG emissions and other environmental impacts along the life cycle of buildings (construction, use/operation and end of life), the work of Annex 72 was organised towards achieving the following objectives:

1. establish a common methodology guideline to assess the life cycle based PED, GHG emissions and environmental impacts caused by buildings
2. establish methods for the development of specific environmental benchmarks for different types of buildings to help designing buildings with a minimum life cycle based PED, GHG emissions and environmental impacts
3. derive regionally differentiated guidelines and tools (building design and planning tools such as BIM and others) for architects and planners
4. establish a number of case studies, focused to allow for answering some of the research issues, including optimisation strategies and how related design processes and decisions happen in practice, and for deriving empirical benchmarks

5. develop national/regional databases with regionally differentiated LCA data tailored to the construction sector, covering material production, building technology manufacture, energy supply, transport services and waste management services; share experiences with the setup and update of such databases

The scope of the Annex is intended to support design processes and decision making related to new buildings and retrofit/redevelopment/repurposing of existing buildings. It covers dwellings (single and multiple family housings), office buildings, school buildings, hospitals and others. The life cycle covers the stages production (production of construction materials including resource extraction), construction process (erection of the building), use (operational energy and water use, maintenance, repair and replanned placement of building components), as well as end of life (de-construction, waste processing and disposal, see Figure 1). The indicators addressed comprise PED (non-renewable and renewable), GHG emissions as well as environmental impacts such as fine particles emissions, resource depletion and biodiversity losses caused by buildings.

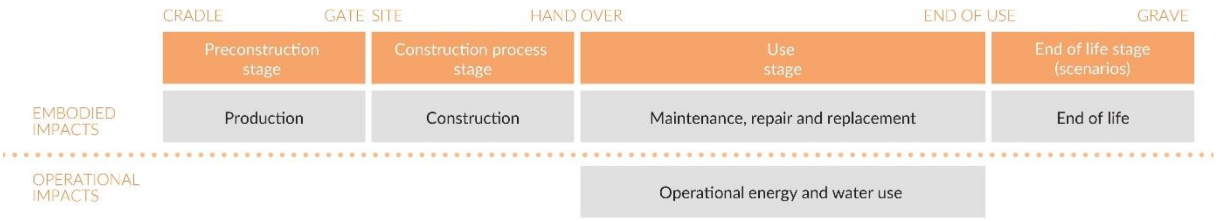

Figure 1 Building life cycle stages and environmental impacts. Embodied impacts occur all along the life cycle whereas operational impacts occur during the use stage only.

2 Findings

The main findings are grouped according to methodology (Deliverable B[1]), data and databases (Deliverables D and G), environmental benchmarks (Deliverable F) and design process and tools (Deliverable C). The main findings can be summarised as follows:

2.1 Methodology

When assessing environmental performance of buildings, the complete building in its entire life cycle must be considered, including all upstream and downstream processes. For the planning and assessment, suitable building and life cycle models with a high degree of transparency are needed to make model and data uncertainties visible and able to reduce.

The main indicator for quantifying potential effects on the climate are the GHG emissions, measured in kg CO_2 equivalents. GHG emissions should be determined using LCA and preferably divided into a fossil and a biogenic share. The resulting carbon footprint of a building should be supplemented by information on the biogenic carbon content as well as other indicators to record the environmental performance.

Some life cycle modelling is methodologically demanding, and clear rules are necessary here. Examples are the handling of biomass (modelling carbon uptake and release), plants for the

[1] See Table 1 which contains the full list of final Deliverables and weblinks to the PDF files.

generation of renewable energy and permissible approaches to offset for GHG emissions in the balance. IEA EBC Annex 72 provides recommendations for these modelling rules.

2.2 Data and databases

Countries lacking a LCA database for the construction sector are encouraged to get started as soon as possible.
The LCA database should cover construction materials (both generic and company specific), building technologies (such as ventilation and photovoltaic systems), energy supply, transport and waste management services. It should address life cycle related GHG emissions as well as other main environmental challenges such as fine particles, resource depletion and biodiversity losses.
Extensive documentation, independent review and full data transparency are considered main features, which help ensure appropriate data quality.

2.3 Environmental benchmarks

Suitable assessment standards in the form of benchmarks and target values are required for the assessment of the environmental performance of buildings, and in particular the GHG emissions in the life cycle of buildings. These benchmarks and target values form an inseparable unit with the respective method and data basis.
Currently, benchmarks based on technical and/or economic feasibility are increasingly complemented by target values derived from planetary boundaries, taking into account the GHG emissions budget still available to meet defined global warming limits.
The benchmarks and target values relating to the complete life cycle can be sub-divided, for example into embodied and operational parts, for orientation and communication purposes.
With "(net) zero GHG emission", the first universal benchmark exists that is suitable for all types of buildings and uses in all climate zones.

2.4 Design process and tools

The environmental impacts of the building should be followed and reduced throughout the design process. A set of guidelines is developed to provide outlook and recommendations related to the integration of the LCA into design process and design tools to support the stakeholders involved in the building design process and transfer to them science-based findings.
The set of guidelines is systematically answering questions such as when and for what purpose will the LCA be conducted, how to prepare the information about the building to be integrated in the tools or workflow, which work-flows and tools should be used, which visualization and communication of the results in LCA should be used, for whom and for what is the LCA needed for each step of the design process.
To improve the understanding and to enable a practical use of the contents of this document to all the stakeholders involved, a summary of these guidelines and recommendations to reduce environmental impacts along the design process have been included in a special practice-oriented document: the **Design Decision Table**.

3 Recommendations

The IEA EBC Annex 72 experts agreed on the following recommendations[2], grouped according to various stakeholders related to buildings and construction.

3.1 Government and administration

1. Introduce legally binding maximum target values for GHG-emissions of new constructions and of refurbishments by 2025 latest with a roadmap to net zero GHG emissions in the life cycle by 2035.
2. Consider introducing a legally binding minimum benchmark for biogenic carbon stored in buildings (biogenic carbon content) taking local availability, building tradition and suitability into consideration. Define the benchmark in a way that it helps to maintain, preferably increase the amount of biogenic carbon stored in the national building stock and in the built environment in general.
3. Facilitate the development, introduction and operation of a national and regional LCA database for the construction sector, covering construction materials, building technology, energy supply, transport and waste management services.
4. Specify the contents of international and national standards to ensure consistency among the life cycle assessments of construction materials, building technologies and buildings in your country.
5. Facilitate the development of bill of materials, material passports, digital logbooks, digital twins and digital permits to document the material and environmental characteristics and to enable the future use of material resources embodied in buildings.
6. Consider launching research programs on sustainable construction and on construction materials and building technology (e.g. HVAC) with low environmental, resource and GHG footprints.
7. Launch a research program on negative emission technologies, either in a joint effort involving several countries or co-ordinated with other countries' research activities.
8. Enhance the education in environmental sustainability and feasible solutions to address environmental challenges in the general population.

3.2 Investors, banks and financial institutions

9. Consider sufficiency ("build less") and to refurbish existing buildings and urban areas as a relevant alternative to new construction following deconstruction.
10. Reconsider the construction and real estate sectors including upgrade and adaptation strategies as an economically attractive sector for financial investments.
11. Demand the quantification of GHG emissions, environmental impacts and resource consumption as a basis for risk assessment and economic valuation which is a precondition to invest in building projects.
12. Invest in building projects with low GHG emissions, environmental impacts and resource consumption and promote and support measures to reduce GHG emissions, environmental impacts and resource consumption of building projects.

[2] The recommendations were previously published in the Monte Verità Declaration on a built environment within planetary boundaries.

13. Demand the integration of an assessment of GHG emissions, environmental impacts and resource consumption in the building design stages as relevant decision criteria and demand their improvements and reduction, respectively.
14. Keep yourself informed about existing and new targets, regulations and target values for buildings with regard to GHG emissions, environmental impacts and resource consumption, including the EU taxonomy for sustainable activities.

3.3 Research organisations (universities, research institutes)

15. Establish a knowledge/information centre on sustainable construction.
16. Foster research on the assessment and reduction of life cycle based environmental impacts of buildings and of construction materials manufacture, on budget based environmental benchmarks for buildings and on negative emission technologies by establishing chairs on sustainable construction, sustainable manufacturing and climate mitigation.
17. Offer mandatory/obligatory courses on environmental LCA and its application in the construction sector and its suppliers within the curricula of designers and architects and of civil and process engineers, business administration and facility management. The courses should also address the awareness and the environmental concern of employees in the building and construction sector.
18. Train engineers and architect to design with low carbon building materials and to design buildings with low GHG emissions, environmental impacts and resource consumption.
19. Offer courses on negative emission technologies in process engineering and forest management.
20. Embed courses on environmental sustainability in all curricula of the university.

3.4 Designers, Architects and Engineers

21. Discuss the overall design targets and actively address the sufficiency question: Challenge the clients brief in view of size and level of comfort of the building project and support the client in target setting.
22. Identify options to reduce the environmental impacts of the building project by changing the design, the static and/or materialisation of the building.
23. Consider the refurbishment of an existing building as a relevant alternative of demolition following new construction.
24. Assess the different design options with environmental LCA and discuss the results with the client.
25. Identify and realise solutions to increase the adaptability and the longevity of the building.
26. Apply circularity principles using locally sourced materials, recycled materials and materials with low environmental impacts, and design building elements for easy disassembly and easy reuse. Use LCA to ensure lower life cycle based environmental impacts of such solutions.
27. Strive for lowering operational energy demand and cover the remaining demand with energy from renewable sources.
28. Introduce GHG emissions, environmental impacts and resource consumption of construction materials, building technology and energy supply during use as an important decision criterion when selecting (construction material and building technology) suppliers and energy systems.

29. Use advanced and reliable tools to quantify the GHG emissions, environmental impacts and resource consumption of the building project from early design stage to hand over and ensure continuity along the design process.
30. In the early design stage, consider to apply safety factors on the environmental impacts of building elements to cope with the uncertainties and to avoid unwelcome surprises later-on.
31. Structure the LCA model of the building and its life cycle according to well accepted schemes.
32. Consider to systematically document the characteristics and materialisation of your buildings and to use digital options such as bill of materials, material passports, digital logbooks/building passports, and digital permits to document the material and environmental characteristics and facilitate the future use of material resources of buildings.
33. Periodically attend further education courses on sustainable construction.

3.5 Operators of Environmental Product Declaration (EPD) programs, sector specific LCA database, certification schemes and labels

34. Follow international standards on environmental LCA to the extent possible.
35. Close the room for manoeuvre offered by international and national standards to ensure consistency among the life cycle assessments of construction materials and building technologies in your country.
36. Ensure to include product, use and end of life stages and consider to also include transport to construction site and construction.
37. Assign and require one single life cycle inventory database to be used to establish the LCA of all products and systems embedded in a construction work and of buildings. Allow to use life cycle inventory data from other databases in exceptional cases.
38. Be cautious in dealing with environmental credits attributed to the building, in particular if borrowed from future generations and other third parties. Check for and eliminate any possible double counting of these environmental credits.
39. Apply the core list of environmental and resource indicators requested by international standards and complement those by indicators that are used or required in your national context to quantify the life cycle based environmental impacts and resource consumption of buildings.
40. Consider method, data, tools and environmental benchmarks and targets as interdependent elements needed for a consistent, reliable and relevant assessment and evaluation of environmental impacts and resource consumption of buildings.
41. Consider keeping benchmarks and target values for environmental impacts of the building and for potential benefits beyond the building's perimeter separate.
42. Introduce a binding and demanding target value for life cycle based GHG emissions of buildings (carbon footprint) including a road map to net zero by 2035. Introduce a second, other than GHG-related footprint target value for life cycle based environmental impacts and resource consumption of buildings to avoid burden shifting.
43. Prefer absolute target values to relative ones (defined against a virtual reference building)
44. Consider introducing a minimum benchmark for biogenic carbon stored in buildings (biogenic carbon content) taking local availability, building tradition and suitability into consideration. It may help to maintain or even increase the amount of biogenic carbon stored in the built environment.

3.6 Construction product and building technology manufacturers

45. Establish a roadmap to net zero GHG emissions of construction material and building technology manufacture and their end of life treatment to be reached by 2035.
46. Establish and publish environmental life cycle assessments of your products and your organisation. Use Environmental Product Declarations (EPD) or other suitable and established ways to document and supply the information and data.
47. Optimise your manufacturing process incl. your supply chains by introducing take back systems, increase the share of recycled raw materials, increase the material and energy efficiency, and generally foster circularity, and further reduce the environmental, resource and GHG footprints of your organisation and your products.
48. Purchase electricity products based on renewable energy, for which production and quality (guarantee of origin, GO or renewable energy certificate, RECS) of the electricity stem from the same power plants or ask the electricity provider for such an electricity product.
49. Invest in negative emission technologies rather than purchasing CO_2 emission certificates to neutralise remaining fossil CO_2 emissions.
50. Engage with suppliers and ask them to reduce their GHG emissions to net zero or change to suppliers with lower GHG emissions and more ambitious reduction targets. Give preference to suppliers, which additionally cause low environmental impacts and low resource consumption.
51. Adhere to international standards, use an acknowledged and transparent LCA database when performing the LCA and report according to a “true and fair view”.

3.7 Construction companies

52. Reduce GHG emissions, environmental impacts and resource consumption caused by construction processes for construction and deconstruction.
53. Choose or recommend suppliers of construction materials with low GHG emissions, low environmental impacts and low resource consumption.
54. Rely on supply transport logistics with low GHG emissions, low environmental Impacts and low resource consumption.
55. Reduce the amount of waste, and sort and recycle material wasted during construction, replacement, refurbishment and deconstruction.

3.8 Real estate agents

56. Encourage the owners of buildings for sale to inform about the buildings’ life cycle based GHG emissions, environmental impacts and resource consumption.
57. Encourage potential buyers and tenants to ask for life cycle based GHG emissions, environmental impacts and resource consumption caused by the buildings under examination.
58. Report on life cycle based GHG emissions, environmental impacts and resource consumption caused by the buildings you are offering.

3.9 Users and tenants

59. Question your demand for a rental object in terms of size, level of comfort and equipment.
60. Use life cycle based GHG emissions, environmental impacts and resource consumption as key criteria when selecting your rental object.

61. Use energy and water economically and use the rental object and its equipment mindfully by e.g. following cleaning and maintenance instructions.
62. Choose energy carriers and products with low GHG emissions, low environmental impacts and low resource consumption.

4 Outlook and next steps

The official deliverables were revised based on the comments received from the Executive Committee reviewers, submitted for final approval and approved. They were published on 15 May 2023. The background reports are ready except for administrative matters (ISBN- and DOI numbers).
In parallel to the finalisation of the Annex 72 work, first ideas, topics and research questions were collected in view of a follow up Annex. The project concept was presented by the designated new Operating Agent, Prof. Alexander Passer and unanimously approved by the Executive Committee as Annex 89 ("Ways to implementation of whole life cycle based net zero greenhouse gas emissions buildings - Implementing net zero emission buildings"). The new Annex 89 held its preparatory meetings and will submit the Annex 89 text to the Executive Committee by 30 May 2023 latest.

5 National and international cooperation

On a national level cooperation took place between the Swiss organizations participating in Annex 72. We were coordinating the national surveys for the architects and planners and the buildings LCA experts with three Swiss member organisations (University of Applied Sciences of Western Switzerland (HES-SO), ETH Zurich and Paul Scherrer Institute). These were mainly conducted until the end of 2019. PSI joined in fall 2019 and focuses its work on Subtask 1 Methodology (uncertainty in construction material LCIs related to the evolution of the electricity mix used in construction material manufacture).

25 different countries (17 from Europe, 5 from Asia/Oceania and 3 from North and South America) are participating in the IEA EBC Annex 72. The IEA EBC Annex 72 fosters international cooperation and functions as a platform to exchange experience and knowledge. We use this to support the application of LCA on buildings in countries with yet little experience. We particularly support the Indian expert in IEA EBC Annex 72 in the development of guidelines to establish an easy-to-use LCA database for the construction sector profiting from the long-term experience with the KBOB recommendation 2009/1 (KBOB et al. 2022).

6 Communication

A final event (special session) was held in September 2022 during the Sustainable Built Environment 2022 Conference in Berlin (SBE'22). A second event (special session) is planned to be held during the WSBE conference in Montréal, Quebec, Canada (Spring 2024).

7 Publications

Eight official deliverables and the project summary report were established within IEA EBC Annex 72 (see Table 1). They are published on the official Annex website.

A number of background reports are being prepared which allow the interested reader to get more information and find further thoughts and discussions about selected topics. They will be made available on the official Annex website too after the administrative issues (ISBN and DOI numbers) are resolved.

A	IEA EBC Annex 72 Website (https://annex72.iea-ebc.org/)
B	Context-specific assessment methods for life cycle-related environmental impacts caused by buildings
C	Guidelines for design decision-makers
D	World Building life-cycle based Databases and Repositories for Building and Construction Sector
E	Assessing life cycle related environmental impacts caused by buildings –Case Study Collection
F	Benchmarking and target-setting for life cycle-related environmental performance of buildings
G	Guidelines for establishing an easy to use National LCA Database for the Construction Sector
I	Life-cycle optimization of building performance: a collection of case studies
J	Understanding the impact of individual, industry & political decisions on transitions towards environmental sustainability
	IEA EBC Annex 72 Project Summary report

Table 1 List of official deliverables developed in IEA EBC Annex 72

Finally, a number of scientific publications resulted from the work and discussions of IEA EBC Annex 72. A selection of them is listed below. Scientific publications, prepared by IEA EBC Annex 72 experts within the Annex work:

- Buildings LCA and digitalization: Designers' toolbox based on a survey
  Di Bari R., Horn R., Bruhn S., Alaux N., Ruschi Mendes Saade M., Soust-Verdaguer B., Potrč Obrecht T., Hollberg A., Birgisdottír H., Passer A. and Frischknecht R. (2022) Buildings LCA and digitalization: Designers' toolbox based on a survey. In: IOP Conference Series: Earth and Environmental Science, 1078(1), pp. 012092, 10.1088/1755-1315/1078/1/012092, retrieved from: https://dx.doi.org/10.1088/1755-1315/1078/1/012092.
- Attitude Towards LCA in Hungary and Czechia – Results of a Survey among Building Design Professionals
  Szalay, Z., Lupisek A. (2022) Attitude Towards LCA in Hungary and Czechia – Results of a Survey among Building Design Professionals. Central Europe towards Sustainable Building International Scientific Conference, Prague
- Demands, default options and definitions: How artefacts mediate sustainability in public housing projects in Sweden and Cyprus

Francart, N., Polycarpou, K., Malmqvist, T., & Moncaster, A. (2021). Demands, default options and definitions: How artefacts mediate sustainability in public housing projects in Sweden and Cyprus. Energy Research & Social Science, 92: 102765 https://doi.org/10.1016/j.erss.2022.102765

- Environmental and Economic Optimisation of Buildings in Portugal and Hungary
  Kiss, B., Silvestre, J. D., Andrade Santos, R., Szalay, Z. (2021) Environmental and Economic Optimisation of Buildings in Portugal and Hungary, SUSTAINABILITY 13 : 24 Paper: 13531, https://doi.org/10.3390/su132413531
- Environmental modelling of building stocks – An integrated review of life cycle-based assessment models to support EU policy making
  Röck M., Baldereschi E., Verellen E., Passer A., Sala S., Allacker K. (2021) Environmental modelling of building stocks – An integrated review of life cycle-based assessment models to support EU policy making. In: Renew Sustain Energy Rev, 2021;151, https://doi.org/10.1016/j.rser.2021.111550.
- Multicriteria-Oriented Optimization of Building Energy Performances: The Annex 72 IEA-EBC Experience
  Montana F., Longo S., Birgisdottir H., Cellura M., Frischknecht R., Guarino F., Kiss B., Peuportier B., Recht T., Riva Sanseverino E., Szalay Zs. (2021) Multicriteria-Oriented Optimization of Building Energy Performances: The Annex 72 IEA-EBC Experience. In: Energy systems evaluation (volume 2) (pp. 239-260). Springer, Cham.
- Dataset of service life data for 100 building elements and technical systems including their descriptive statistics and fitting to lognormal distribution
  Goulouti K., Favre D., Giorgi M., Padey P., Galimshina A., Habert G., & Lasvaux S. (2021) Dataset of service life data for 100 building elements and technical systems including their descriptive statistics and fitting to lognormal distribution. In: Data in Brief, 36, 107062.
- How to define (net) zero greenhouse gas emissions buildings: The results of an international survey as part of IEA EBC annex 72
  Satola D., Balouktsi M., Lützkendorf T., Houlihan Wiberg A. H. and Gustavsen A. (2021) How to define (net) zero greenhouse gas emissions buildings: The results of an international survey as part of IEA EBC annex 72. In: Building and Environment, 192, pp. 107619. DOI: https://doi.org/10.1016/j.buildenv.2021.107619.
- Review of visualising LCA results in the design process of buildings
  Hollberg A., Kiss B., Röck M., Soust-Verdaguer B., Wiberg A. H., Lasvaux S., Galimshina A. and Habert G. (2021) Review of visualising LCA results in the design process of buildings. In: Building and Environment, 190, pp. 107530, https://doi.org/10.1016/j.buildenv.2020.107530, retrieved from: https://www.sciencedirect.com/science/article/pii/S0360132320308970.
- Carbon budgets for buildings: Harmonizing temporal, spatial and sectoral dimensions
  Habert G., Röck M., Steininger K., Lupisek A., Birgisdottir H., Desing H., et al. (2020) Carbon budgets for buildings: Harmonizing temporal, spatial and sectoral dimensions. In: Build Cities 2020:1–24. https://doi.org/10.5334/bc.47.
- Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation
  Röck M., Saade M. R. M., Balouktsi M., Rasmussen F. N., Birgisdottir H., Frischknecht R., Habert G., Lützkendorf T. and Passer A. (2020) Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. In: Applied Energy, 258(114107). DOI: https://doi.org/10.1016/j.apenergy.2019.114107.

- (Net-) zero-emission buildings: a typology of terms and definitions
  Lützkendorf, T. and Frischknecht, R., 2020. (Net-) zero-emission buildings: a typology of terms and definitions. Buildings and Cities, 1(1), pp.662–675. DOI: http://doi.org/10.5334/bc.66.
- Reducing embodied impacts of buildings–insights from a social power analysis of the UK and Sweden
  Moncaster, A. M., & Malmqvist, T. (2020). Reducing embodied impacts of buildings–insights from a social power analysis of the UK and Sweden. InIOP Conference Series: Earth and Environmental Science(Vol. 588, No. 3, p. 032047). IOP Publishing.
- BIM and LCA Integration: A Systematic Literature Review
  Potrč Obrecht T., Röck M., Hoxha E. and Passer A. (2020) BIM and LCA Integration: A Systematic Literature Review. In: Sustainability, 12(14), pp. 5534. DOI: https://doi.org/10.3390/su12145534.
- Environmental Benchmarks for buildings: Needs, challenges and solutions; 71st LCA forum, Swiss Federal Institute of Technology, Zürich, 18 June 2019
  Frischknecht R., Balouktsi M., Lützkendorf T., Aumann A., Birgisdottir H., Grosse Ruse E., Hollberg A., Kuittinen M., Lavagna M., Lupišek A., Passer A., Peuportier B., Ramseier L., Röck M., Trigaux D. and Vancso D. (2019) Environmental Benchmarks for buildings: Needs, challenges and solutions; 71st LCA forum, Swiss Federal Institute of Technology, Zürich, 18 June 2019. In: International Journal of Life Cycle Assessment, 24, pp. 2272–2280. DOI: https://doi.org/10.1007/s11367-019-01690-y.
- A cross-platform modular framework for building Life Cycle Assessment
  Kiss, B ; Röck, M ; Passer, A ; Szalay, Z. (2019) A cross-platform modular framework for building Life Cycle Assessment. In: Passer A., Lützkendorf T., Habert G., Kromp-Kolb H., Monsberger M. (editors) IOP Conference Series: Earth and Environmental Science. Graz, Austria : IOP Publishing, pp. 1-10. Paper: 012103
- The buried giant: construction materials shape the environmental footprint of buildings
  Frischknecht R. (2022) The buried giant: construction materials shape the environmental footprint of buildings. Keynote. Accepted. CESB 2022, Prague, Czech Republic
- NEW MITIGATION SOLUTIONS IN CONSTRUCTION - use case for assessment methods
  Lützkendorf, T.; Frischknecht R., Balouktsi M., Röck M., Houlihan Wiberg A., Satola D., Passer A., Birgisdottir H., Nygaard Rasmussen F., Chae C., Palaniappan S. (2021) NEW MITIGATION SOLUTIONS IN CONSTRUCTION - use case for assessment methods. online
- Implications of using systematic decomposition structures to organize building LCA information: A comparative analysis of national standards and guidelines- IEA EBC ANNEX 72
  Soust-Verdaguer B., García Martínez A., Llatas C., Gómez de Cózar J. C., Allacker K., Trigaux D., Alsema E., Berg B., Dowdell D., Debacker W., Frischknecht R., Ramseier L., Veselka J., Volf M., Hajek P., Lupíšek A., Malik Z., Habert G., Hollberg A., Lasvaux S., Peuportier B., Pomponi F., Wastiel L., Gomes V., Zara O., Gomes M., Gusson Baiocchi A., Pulgrossi L., Ouellet-Plamondon C., Moncaster A., Di Bari R., Horn R., Lenz K., Balouktsi M., Lützkendorf T., Röck M., Hoxha E. and Passer A. (2020) Implications of using systematic decomposition structures to organize building LCA information: A comparative analysis of national standards and guidelines- IEA EBC ANNEX 72. In: IOP Conference Series: Earth and Environmental Science, 588, pp. 022008, 10.1088/1755-1315/588/2/022008, retrieved from: http://dx.doi.org/10.1088/1755-1315/588/2/022008.
- Comparison of the greenhouse gas emissions of a high-rise residential building assessed with different national LCA approaches – IEA EBC Annex 72 Frischknecht R., Ramseier L., Yang W., Birgisdottir H., Chae C. U., Lützkendorf T., Passer A., Balouktsi M., Berg B., Bragança L., Butler J., Cellura M., Dixit M., Dowdell D., Francart N., García Martínez A., Gomes V., Gomes Da Silva M.,

Guimaraes G., Hoxha E., Wiik M. K., König H., Llatas C., Longo S., Lupíšek A., Martel J., Mateus R., Rasmussen F. N., Ouellet-Plamondon C., Peuportier B., Pomponi F., Pulgrossi L., Röck M., Satola D., Verdaguer B. S., Szalay Z., Nhu A. T., Veselka J., Volf M. and Zara O. (2020) Comparison of the greenhouse gas emissions of a high-rise residential building assessed with different national LCA approaches – IEA EBC Annex 72. In: IOP Conference Series: Earth and Environmental Science, 588, pp. 022029, 10.1088/1755-1315/588/2/022029, retrieved from: http://dx.doi.org/10.1088/1755-1315/588/2/022029.

- Survey results on acceptance and use of life cycle assessment among designers in world regions: IEA EBC Annex 72 Balouktsi M., Lützkendorf T., Röck M., Passer A., Reisinger T. and Frischknecht R. (2020) Survey results on acceptance and use of life cycle assessment among designers in world regions: IEA EBC Annex 72. In: IOP Conference Series: Earth and Environmental Science, 588, pp. 032023, 10.1088/1755-1315/588/3/032023, retrieved from: http://dx.doi.org/10.1088/1755-1315/588/3/032023.
- Investigation of maintenance and replacement of materials in building LCA
  Francart N. and Malmqvist T. (2020) Investigation of maintenance and replacement of materials in building LCA. In: IOP Conference Series: Earth and Environmental Science, 588, pp. 032027, 10.1088/1755-1315/588/3/032027, retrieved from: https://doi.org/10.1088/1755-1315/588/3/032027.
- Comparison of the environmental assessment of an identical office building with national methods Frischknecht R., Birgisdottir H., Chae C. U., Lützkendorf T., Passer A., Alsema E., Balouktsi M., Berg B., Dowdell D., García Martínez A., Habert G., Hollberg A., König H., Lasvaux S., Llatas C., Nygaard Rasmussen F., Peuportier B., Ramseier L., Röck M., Soust Verdaguer B., Szalay Z., Bohne R. A., Bragança L., Cellura M., Chau C. K., Dixit M., Francart N., Gomes V., Huang L., Longo S., Lupíšek A., Martel J., Mateus R., Ouellet-Plamondon C., Pomponi F., Ryklová P., Trigaux D. and Yang W. (2019) Comparison of the environmental assessment of an identical office building with national methods. In: IOP Conference Series: Earth and Environmental Science, 323, pp. 012037, 10.1088/1755-1315/323/1/012037, retrieved from: http://dx.doi.org/10.1088/1755-1315/323/1/012037.
- IEA EBC Annex 72 - Assessing life cycle related environmental impacts caused by buildings – targets and tasks Frischknecht R., Birgisdottir H., Chae C. U., Lützkendorf T. and Passer A. (2019) IEA EBC Annex 72 - Assessing life cycle related environmental impacts caused by buildings – targets and tasks. In: IOP Conference Series: Earth and Environmental Science, 323, pp. 012042, 10.1088/1755-1315/323/1/012042, retrieved from: http://dx.doi.org/10.1088/1755-1315/323/1/012042.

8 References

IEA and UN Environment (2018) 2018 Global Status Report: towards a zero-emission, efficient and resilient buildings and construction sector. Global Alliance for Buildings and Construction, Paris.

KBOB, ecobau and IPB (2022) KBOB-Recommendation 2009/1:2022: Life Cycle Assessment Data in Constructon, Status as at February 2022. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: https://www.kbob.admin.ch/kbob/it/home/publikationen/nachhaltiges-bauen/oekobilanzdaten_baubereich.html.