Energy in Buildings and Communities Programme

International Energy Agency

Evaluation of Embodied Energy and CO_{2eq} for Building Construction (Annex 57)

Subtask 1: Basics, Actors and Concepts

September 2016

Participating Countries

Australia
Austria
China
Czech Republic
Denmark
Finland
Germany
Italy
Japan
Korea
Portugal
Norway
Spain
Sweden
Switzerland
The Netherlands
United Kingdom
USA

Observer Country

Brazil

EBC is a programme of the International Energy Agency (IEA)

International Energy Agency

Evaluation of Embodied Energy and CO_{2eq} for Building Construction (Annex 57)

Subtask 1: Basics, Actors and Concepts

September 2016

Edited by

Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
Thomas Lützkendorf (ST1 leader), thomas.luetzkendorf@kit.edu
Maria Balouktsi, maria.balouktsi@kit.edu

Key contributors

Treeze Ltd., Switzerland
Rolf Frischknecht

Published by the Institute for Building Environment and Energy Conservation,
Zenkyoren building, Kojimachikan, 3-5-1, Kojimachi Chiyoda-ku, Tokyo 102-0083 Japan

ISBN 978-4-909107-05-3

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

Additional copies of this report may be obtained from:

EBC Bookshop

C/o AECOM Ltd

Colmore Plaza

Colmore Circus Queensway

Birmingham B4 6AT

United Kingdom

www.iea-ebc.org

essu@iea-ebc.org

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 29 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. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

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 (*):

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 (*)

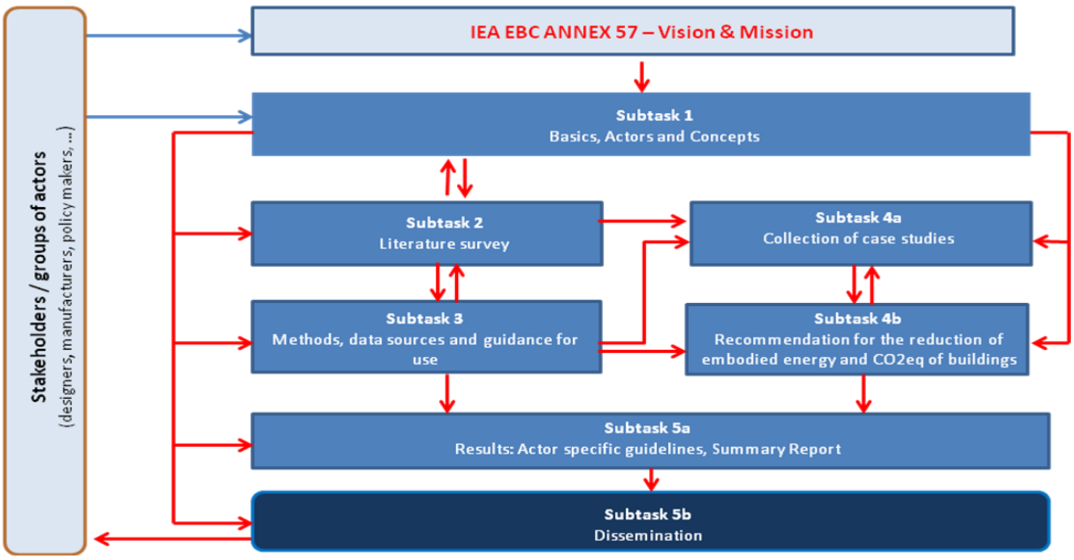
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic 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 & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & 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 Simulation
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational Strategies for High IAQ in Low Energy 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

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 (*)

Foreword

The interest in issues related to the determination, assessment and influencing of embodied energy and embodied greenhouse gas emissions of construction products and buildings has grown significantly during the last years. Although the fundamentals in the form of terms, system boundaries, data bases and calculation rules have already been, to some extent, a subject of scientific discussion and international standardization, they are not yet in a form that facilitates their application and leads to clear and transparent results. This is where the contribution of IEA EBC Annex 57 comes in; it presents the fundamentals in such a way that they can be efficiently included in the decision-making of relevant actors. The overall work is accomplished through the different subtasks (STs):

- **ST2** analyses the status of the scientific discussion on the basis of an evaluation of available literature. The identified misconceptions and gaps form the basis for the Annex 57 work.
- **ST1** picks up on the results of ST2 and develops recommendations for indicators and system boundaries to ensure transparent and accountable results and allow for the classification of existing approaches in a unified system. Additionally, it explains how to describe the building and its life cycle and the data needs for calculations at the building level. Finally, it presents the relevant stakeholder groups and decision-making situations, including recommendations for action.
- **ST3** deals with issues related to the development and provision of data. Specifically, it describes specific methods for developing data for embodied energy and emissions and analyses available databases, while classifying them in an overall system.
- **ST4** deals with the collection, presentation, evaluation and classification of case studies using a typology developed on the basis of partial results of the other STs. As a result, design recommendations for achieving buildings with low embodied energy and GHG emissions are derived from the analysis of the extensive collection of case studies taking into account their interaction with the other design objectives and criteria.
- **ST5** presents the results in a way to appeal to politicians, scientists and practitioners. In this context, actor specific guidelines were developed that can be found available at www.annex57.org/. The interrelationships between STs are illustrated below:



Summary

Objectives of the report

This report is part of a suite of publications of IEA EBC Annex 57, which deals with the *Evaluation of Embodied Energy and Embodied CO_2eq for Building Construction*. In this report both aspects are referred to collectively as "embodied impacts", and the term "embodied CO2eq." has been replaced by "embodied GHG emissions".

This report emerged from the results of Sub-Task 1 that has as a purpose to identify and clarify the methodological issues related to the definitions and fundamental concepts of embodied energy and embodied GHG emissions. At the same time, ST1 aims at presenting a comprehensive framework and transparent reporting format that can be used by design professionals and designers (and other interested parties) for the determination, assessment and reporting of embodied energy and embodied GHG emissions at the building level. The intent is to ensure the appropriate interpretation and application of embodied impacts assessment results.

Another objective of this sub-task is to identify relevant actor/stakeholder groups and decision-making situations. There is a need for discussing and investigating whether and to what extent specific actions are required and how a stronger integration of embodied impacts into the decision-making processes can be achieved. In this sense, this report also analyses the tasks and roles of individual stakeholder groups, works out the peculiarities in connection with the demand for and supply of information related to embodied impacts and encourages the development of specific guidelines/recommendations for selected groups of actors.

Relation between ST1 and other STs

The definition of the fundamental concepts, as well as the development of a framework to select the system boundary determining these concepts is supported by two streams. The first stream comes from the existing literature, where also findings from Subtask 2 – *"A Literature Survey"* are utilized to fit this purpose. ST1 reacts to the wide variations in terms, definitions and system boundaries observed in the literature survey performed by ST2.

The second stream comes from the underlying theory of "embodied energy" and "embodied GHG emissions" and the existing standards and guidelines. In the process of these investigations, ST1 realizes a transition of the existing experiences of dealing with "embodied energy" to the newest concept of "embodied GHG emissions" and makes a clear distinction between the latter and stored carbon. At the end, as a result of the above analysis, ST1 develops and proposes specific definitions, system boundary types and indicators.

Through the definition of key concepts and consequently the formulation of a specific system boundary typology and reporting model, Subtask 1 sets the scene for Subtask 4 which deals with "*Design and construction methods for buildings with low embodied energy and CO_2 emissions"*, and focuses on case studies for achieving its objectives. This means that the developed recommendations and identified reporting requirements in relation to system boundaries selection within Subtask 1 were fulfilled by Subtask 4 and used as a basis for the description of the case studies in a consistent manner. At the same time, the results of ST4 are utilised to analyse the data needs in specific decision-making situations and to develop recommendations for specific groups of actors (especially design professionals and consultants).

While ST1 focuses on the practical application of the concept of an assessment of embodied impacts in the decision-making processes related to the design of buildings, ST3 deals with issues related to the calculation and provision of construction products related data required for the design process. In both ST1 and ST3, the issues of transparency and comparability of data are discussed, but from two different perspectives: in ST1 from the “data user” perspective and in ST3 from the “data supplier” perspective.

In terms of dissemination of the achieved results, ST1 has already initiated a number of scientific papers for journals and conferences.

Table of content

Abbreviations

List of frequently used abbreviations

Abbreviations	Meaning
BIM	Building information modelling
CED	Cumulative energy demand
EC	Embodied carbon
EE	Embodied energy
EEC	Embodied energy and carbon
EEG	Embodied energy and GHG emissions
EG	Embodied GHG emissions
EN	European Norm
EOL	End of life
EPD	Environmental Product Declaration
GHG	Greenhouse gas
GWP	Global warming potential
IEA-EBC	Energy in Buildings and Communities Programme of the International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kWh	Kilowatt hours: 1 kWh = 3.6 MJ
LC	Life cycle
LCA	Life cycle assessment
LCC	Life cycle costing
MJ	Mega joule; 1 kWh = 3.6 MJ
NRE	Non-renewable energy (fossil, nuclear)
ZEB	zero energy building or zero emissions building
PE	Primary energy
RE	Renewable energy
PV	Photovoltaic (cell or panel)
Ref	Reference
RSP	Reference study period
SFB	Single family building
SIA	The Swiss Society of Engineers and Architects
ST1	Annex 57 Subtask 1 (Basics, Actors and Concepts)
ST2	Annex 57 Subtask 2 (Literature review)
ST3	Annex 57 Subtask 3 (Databases)
ST4	Annex 56 Subtask 4 (Case studies)
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VDI	The association of German engineers

Definitions

Term	Definition
Cradle to Gate	This boundary includes only the production stage of the construction products integrated into the building. Processes taken into account are: the extraction of raw materials, transport of these materials to the manufacturing site and the manufacturing process of the construction products itself. Thus, in the case of a building the impacts of this stage are accounted for as the sum total of the "cradle to gate" impacts of its individual components.
Cradle to Site	Cradle to gate boundary plus delivery to the construction site.
Cradle to Handover	Cradle to site boundary plus the processes of construction and assembly on site.
Cradle to End of Construction	See Cradle to Handover
Cradle to End of Use	Cradle to handover boundary plus the processes of maintenance, repair, replacement and refurbishment, which constitute the recurrent energy and emissions. This boundary marks the end of first use of the building.
Cradle to Grave	The cradle to grave system boundary includes the "cradle to end of use" boundary plus the end of life stage with processes such as building deconstruction or demolition, waste treatment and disposal (grave)
(EN 15978) **Product stage**	Includes raw material supply (A1), Transport[1] (A2) and Manufacturing (A3).
(EN 15978) **Construction process stage**	Includes transport[2] (A4) and construction/installation process (A5).
(EN 15978) **Use stage**	In the case of embodied energy and GHGs, it includes the use (B1)[3], maintenance (B2), repair (B3), replacement (B4) and refurbishment (B5). These processes are defined in the design process on the basis of scenarios.
(EN 15978) **End of life stage**	Includes deconstruction and demolition (C1), transport[4] (C2), waste processing (C3) and disposal (C4). These processes are defined in the design process on the basis of scenarios.
Net benefits and impacts beyond the system boundary	Loads and benefits beyond the system boundary related to recycling, reusing or combustion of construction waste after the end of life stage of the building, as well as the effects of carbon sequestration. Sometimes this is expressed as module D. In the case of buildings this can be interpreted as a recycling potential.
Recurrent/ Recurring energy	The recurring energy and is the energy consumption related to material or components maintenance, repair and replacement during a building's life cycle.

[1] Transport to the manufacturing site
[2] Transport to the building construction site
[3] According to the CEN/TC 350 standards B1 includes scenarios determining the release of substances into the environment among others.
[4] Transport to the waste processing site

Term	Definition
Embodied	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[5] (embodied in a virtual sense). It can also be seen as a result of an allocation of energy and material flows to a product or service.
Embodied energy (EE)	*Embodied energy* is a method of accounting for the primary energy resources (regardless of their type) consumed/used in one or more life cycle stages of a given product (of a given functional equivalent), other than the ones related to the operation (this applies only to buildings and products relevant for the energy supply of a building).
Embodied Energy 1 (EE1)	*Embodied energy 1 (EE1)* is the cumulative fossil primary energy demand (CED_f) for one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense, the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product. [MJ/reference unit/year of the RSP]
Embodied Energy 2 (EE2)	*Embodied energy 2 (EE2)* is the cumulative non-renewable primary energy demand (CED_{nr}) for one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product. [MJ/reference unit/year of the RSP]
Embodied Energy 3 (EE3)	*Embodied energy 3 (EE3)* is the cumulative primary energy (renewable and non-renewable) demand (CED_{nr+r}) one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product. [MJ/reference unit/year of the RSP]
product	It refers to construction products, constructed assets and buildings.
Processes and services	Processes or services related to the life cycle of a product can also sometimes be the object of assessment.
(First part adapted from ISO 14040) **Feedstock energy**	Heat of combustion of a raw material input that is not used as an energy source to a product system, expressed in terms of higher heating value or lower heating value. Thus, this represents the **non-energy-related use of energy resources**. This could be non-renewable (fossil) or renewable (biomass).
Use of fossil primary energy carriers	This is the same as the respective impact category in LCIA “abiotic depletion potential for fossil resources (ADP-fossil fuels)”.

[5] In reality operation is not a stage in itself, but refers to the operational processes as part of the use or (in-use) stage of the building and are the ones related to the operational energy use and operational water use (thus, mainly the energy and GHGs associated with the energy used by building-integrated technical systems during the operation of the building). The processes in the use stage associated with embodied energy and GHGs are described under the “use stage” definition.

Term	Definition
Primary Energy fossil (PE_f)	This indicator represents both the energy-related use of fossil fuels and the non-energy related use of fossil fuels (feedstock energy). However, they must always be separately reported as in Part A and B.
Primary Energy non-renewable (PE_{nr})	Fossil + Nuclear primary energy. Feedstock energy must always be separately reported.
Primary Energy total (PE_t)	Renewable + Non-renewable Primary Energy. Feedstock energy must be always separately reported.
(ISO/ TS 14067) **CO_2eq.**	Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide. Mass of a greenhouse gas is converted into CO2 equivalents using global warming potentials.
(first part adapted from IPCC) **Greenhouse gases (GHG)**	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. They are listed in different IPCC reports and dealt with under Kyoto Protocol and Montreal Protocol (specific to substances that deplete ozone). Here, the GHGs listed in the 5th IPCC report are taken into account.
(first part adapted from ISO/ TS 14067) **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-CO_{2eq}]
Process related emissions	non-fuel related CO_2 emissions emitted during the manufacturing processes of some construction products as a result of specific chemical effects (e.g. CO_2 is emitted as a chemical reaction in cement manufacture).
Embodied Carbon (EC)	*Embodied Carbon* is a widely-used term in literature that usually describes a method of accounting for the amount of greenhouse gases (regardless of their type and source) emitted during one or more life cycle stages of a given product (of a given functional equivalent), other than the ones related to the operation (this applies only to buildings and products relevant for the energy supply of a building). To avoid confusion with stored carbon ("check definitions of "biogenic carbon" and "carbon storage") that is embodied in a physical sense in the product, Annex 57 uses the term "embodied GHG emissions" instead.
Embodied GHG Emissions (EG)	*Embodied GHG emissions* is a method of accounting for the amount of greenhouse gases (regardless of their type and source) emitted during one or more life cycle stages of a given product (of a given functional equivalent), other than the ones related to the operation (this applies only to buildings and products relevant for the energy supply of a building).
Embodied GHG Emissions 1 (EG1)	*Embodied GHG Emissions 1* is the cumulative quantity of greenhouse gases (CO_2, methane, nitric oxide, and other global warming gases included in the 5th IPCC report), which are emitted during one or more processes (depending on the scope of each study) related to the creation of the product, its maintenance and end-of-life. This is calculated and expressed as CO_2 equivalent.

Terms	Definitions
Embodied GHG Emissions 2 (EG2)	*Embodied GHG Emissions 2* is the cumulative quantity of CO_2 and F-gasses, which are emitted during one or more processes (depending on the scope of each study) related to the creation of the product, its use (excluding operation), maintenance and end-of-life. This is calculated and expressed as CO_2 equivalent.
Biogenic	Produced by living organisms or biological processes.
Calorific value	The *calorific value* of a fuel is the quantity of heat produced by its combustion – at constant pressure and under "normal" (standard) conditions. It is usually expressed in unit of energy per unit mass (e.g. MJ/kg). It can be measured as lower heating value (LHV) or higher heating value (HHV).
Lower heating value (LHV)	*(or net calorific value (NCV) or lower calorific value (LCV))* means that the products of combustion contains the water vapor and that the heat in the water vapor is not recovered.
Higher heating value (HHV)	*(or gross energy or upper heating value or gross calorific value (GCV) or higher calorific value (HCV))* means that the water of combustion is entirely condensed and that the heat contained in the water vapour is recovered.
(EN 16485) **Biogenic carbon**	carbon derived from/contained in biomass
(EN 16485) **Biomass**	material of biological origin excluding material embedded in geological formations and material transformed to fossilised material
(EN 16485) **Carbon storage**	biogenic carbon stored over a specific period of time
Carbon sequestration	The absorption (capture) of carbon dioxide by trees during their growth
Input and Output Tables	The Input-Output Tables are systematically present and clarify all the economic activities being performed in a single country, showing how goods and services produced by a certain industry in a given year are distributed among the industry itself, other industries, households, etc., and presenting the results in a matrix format.
Input and Output analysis	The use of national economic and energy and CO_2 data in a model to derive national average embodied energy /CO_2 data in a comprehensive framework.
Energy Intensity	The total energy embodied, per unit of a product or per consumer price of a product. [MJ/unit of product or price]
CO_2 Intensity	The total CO_2 emission embodied, per unit of a product or per consumer price of a product. [kg-CO_{2eq} /unit of product or price]
(UNEP SETAC 2011) **Process based life cycle assessment**	subdivides the product/building system into a foreground system, for which primary data are collected and a background system, for which generic data are being used
Hybrid analysis	Integrates the useful features of process based LCA and IO analysis into one single approach. There are two types of hybrid methods: process and IO-based hybrid analysis.
Freon Gas	It is mainly used as the refrigerant of an air-conditioner and chiller, and a foaming agent of thermal insulation. CFC is abolished in the Montreal Protocol and HCFC will also be abolished in 2020. Freon gas is shifting to HFC now. However, as for HFC, since GWP is large, reduction is called for.

Term	Definition
(EN15978) **Reference Study Period (RSP)**	Period over which the time-dependent characteristics of the object of assessment are analyzed
Actor	Refers to any building construction related stakeholder
Design professionals and consultants	Includes architects, engineers and quantity surveyors among others. MAIN ACTOR
Construction products manufacturers	Annex focuses on small and medium-sized manufacturing enterprises. MAIN ACTOR
Procurers	Actors dealing with the procurement of buildings and construction products. MAIN ACTOR
Policy makers	Actors dealing with the law or policy-making. MAIN ACTOR

1. Introduction

1.1. Setting the landscape

In general, the building sector is responsible for more than 40 percent of global energy use and contributes approximately 30% to total global Green House Gas (GHG) emissions (UNEP, 2009; IPCC, 2014). Efforts to reduce resource depletion and global warming would make a significant contribution to reductions in energy consumption and GHG emissions in this sector (UNEP, 2009). Given high construction rates in rapidly developing nations and emerging economies coupled with the inefficiencies of the existing building stock worldwide, the percentage of these contributions will likely rise further in future if nothing is done. Under these circumstances, intensifying the efforts for conserving the resources and reducing the adverse effects on the environment becomes increasingly important in the building sector and decision makers are called to take a much more vigorous approach compared to previously.

In the past, the attempts of the different actor groups involved in the building and construction industry to respond to the need for less resource-intensive and less polluting buildings and equipment were often focused only on reducing the operational energy consumption and the resulting GHG emissions. As significant efforts in this area continue, the accuracy of the assessment of the operational impacts (energy and GHG emissions) of buildings increases and their regulation becomes more elaborate and stringent making the design and application of more energy-efficient building envelopes and systems in new and retrofit buildings a norm in the building and real estate industry. This means that the weight of the energy consumption and GHG emissions caused by the non-operational stages of a building (from material extraction, manufacturing, construction, maintenance including repair, replacement and refurbishment, and eventual demolition and disposal) is becoming relatively larger, and thus their calculation and assessment methods will be more important in the future. Depending on the particular building in question, these impacts can range between nearly 0 per cent (e.g. earth buildings) to nearly 100 per cent (e.g. nearly zero energy buildings). The average share of embodied impacts varies significantly from one country to another worldwide.

Since their consideration in every aspect of the design, construction, and use of buildings may contribute to significant reductions in resource use and environmental pollution, and therefore is regarded as critical to the implementation of sustainable development principles, they need to be understood better and assessed in a targeted manner. However, in contrast to operational impacts, embodied impacts are currently not regulated in most countries (Annex 57 ST4 report). Although they are receiving increased attention at an international level (for example, embodied energy is covered as an issue in the latest IPCC report (2014)) and current research has started to explore these aspects more systematically, there are still no clear and commonly accepted definitions, system boundaries and accounting methods in the building and construction sector (Annex 57 ST2 report). Thus, despite the good intent and progress shown by the building supply chain, there are still a lot of unresolved issues, misunderstandings and uncertainties when it comes to the assessment of embodied impacts. This underlines the need for stakeholders in the building and construction industry to come together and look at ways of addressing the embodied impacts in buildings.

Recognising this opportunity for energy and emissions savings that are being missed, progressive clients, investors, developers, designers and contractors are increasingly determining, assessing and reducing the embodied impacts in building projects, as well as construction product manufacturers are increasingly reporting their impacts in the form of Environmental Product Declarations (EPD's) (Appendix 1.C). Especially, procurers (clients) and designers have a key role to play in reducing the embodied impacts of buildings, as they are the ones who mainly decide what is designed and built. For example, design professionals and consultants are now faced with the new challenge of dealing with this issue already in the early design stages. At the same time, construction product manufacturers now have a responsibility to develop new data in order to support this task, as well as to optimise their corporate processes to develop materials with low embodied impacts (Annex 57 guidelines for manufacturers). However, without explicit and sustained policies to address these aspects in the entire supply chain of buildings and their products around the world, this opportunity for savings cannot be fully unlocked and realised (Annex 57 guidelines for policy makers).

1.2. Tasks and objectives

Although the importance of embodied energy and GHG emissions has been gradually recognized, the calculation and assessment methods at a building level (scope, system boundaries, sources of data, etc.) vary greatly depending on the country or researcher, and consequently the calculation results differ widely from one study to the next.

This report is the main result of the activities of the working group ST1. It presents a comprehensive framework that can be used by design professionals and designers (and other interested parties) for determining, assessing, influencing and reporting embodied energy and embodied GHG emissions at the building level. It considers the various stages of design, system boundaries, definitions, indicators, sources of data and tools. Recommendations for other important stakeholder groups are also provided here to facilitate their decision-making

Therefore, the specific tasks and objectives of the report include the following:

- An analysis of the current situation and debates considering the progress of scientific knowledge, standardization, data development, and practical application among others, in the field of embodied impacts in the life cycle of new and existing buildings with an emphasis in the areas of embodied energy and embodied GHG emissions
- An analysis of the decision making situations for which the aspects of embodied energy and embodied GHG emissions are important
- An analysis of the methodological issues and practical considerations that need to be clarified in the case of an assessment of embodied impacts at the building level and the identification of the need for methodological foundations
- The development of recommendations for definitions, system boundaries, indicators and other methodological foundations that make it possible to assess embodied energy and embodied GHG emissions at the building level
- The development of recommendations for identified key stakeholder groups other than the designers and consultants respecting their specific decision-making context for further work

Apart from the analysis and further development of scientific foundations, the support and provision of assistance of decision makers and actors in their practical application is the aim here.

1.3. Foundations and starting points

The current situation is characterized by numerous and diverse activities to improve the energy and resource efficiency and to reduce impacts to global and local environment in the life cycle of buildings and in the renovation of building stocks worldwide. The overall aim is to improve the environmental performance of buildings. IEA EBC Annex 57 focuses on the stages of production, construction, maintenance, repair, replacement, replacement and EoL.

Thus, the work done by the members of the ST1 working group (and its contributors) and its outcomes are closely related to the following international activities:

- The results of previous IEA activities; in particular, EBC Annex 31 with a focus on "Energy-Related Environmental Impact of Buildings" (1996-1999),
- The EBC's Strategic Plan 2007-2012 "Toward Near-Zero Primary Energy Use and Carbon Emissions in Buildings and Communities",
- The EBC's Strategic Plan 2014-2019 "Energy in Buildings and Communities Programme",
- The status of international standardization for LCA and sustainable construction; especially the standards worked out within the ISO TC 59 SC 17 group,
- The work of the UNEP-SBCI's Task Force on Greening the Building Sector Supply Chain summarized in the report "Greening the building supply chain",
- The results of parallel IEA activities (direct exchange of results and knowledge); in particular, EBC Annex 56 with a focus on "Cost-Effective Energy and Carbon Emission Optimization in Building Renovation" (2011-2015),
- The results of ongoing IEA activities (direct exchange of results and knowledge); in particular EBC Annex 65 with a focus on "Long Term Performance of Super-Insulating Materials in Building Components and Systems" (2013-2017).

1.4. How the report is structured

The report is mainly divided into a theoretical part, giving an overall picture of what is the current situation and debates, forming the basis of the Annex 57 recommendations outlined in the second part. Designers for informing their assessments, as it is the core component to be used also in practical applications, can use the recommendations part independently.

Chapters 2 and 3, constituting the theoretical part, describe the current status in terms of the availability of standards, guidelines and data, as well as clarify all the methodological issues related to the terms, definitions and system boundaries for the assessment of embodied energy and embodied GHG emissions at the building level. Chapters 4 and 5, constituting the practical part, provide specific recommendations developed within the scope of IEA EBC Annex 57 aiming at more transparency in reporting and documentation of different parameters on the one hand, and at promoting harmonisation among studies on the other hand. Additionally, they present recommendations for selected group of actors in relation to the integration of embodied impacts into their decision-making. Specifically:

Chapter 2 investigates the question of why it is important to deal with “embodied energy” and “embodied GHG emissions” nowadays and what is the background information related to these two aspects. The current status of standardization, data availability and practical application is also analysed.

Chapter 3 delves into the underlying methodological problems and trends related to the assessment of embodied energy and embodied GHG emissions for buildings.

Chapter 4 outlines specific recommendations developed by Annex 57 in detail aiming at facilitating the resolving of the existing methodological issues related to the assessment of “embodied energy” and “embodied GHG emissions” for buildings

Chapter 5 outlines recommendations for selected group of actors (mainly construction product manufacturers, policy makers and procurers) in relation to the integration of embodied impacts into their decision-making.

Chapter 6 provides open questions on a number of issues that came out to during the course of IEA EBC Annex 57 project and should be addressed in future projects.

2. State of the art and supporting information

2.1. Embodied energy and emissions worldwide

Estimates of future trends in the use of resources (in this case energy resources) and the impacts on the global environment (here the greenhouse effect caused by rising greenhouse gas emissions (GHG)) show that the consumption of resources and environmental pollution, unless countermeasures are adopted, could significantly increase in the coming years and decades. The situation is very different in individual countries and regions. Particularly in regions where both the standard of living and the economy are still developing, there is a strong demand for energy with corresponding implications for resource consumption and GHG emissions - see Figure 1-1 & 1-2.

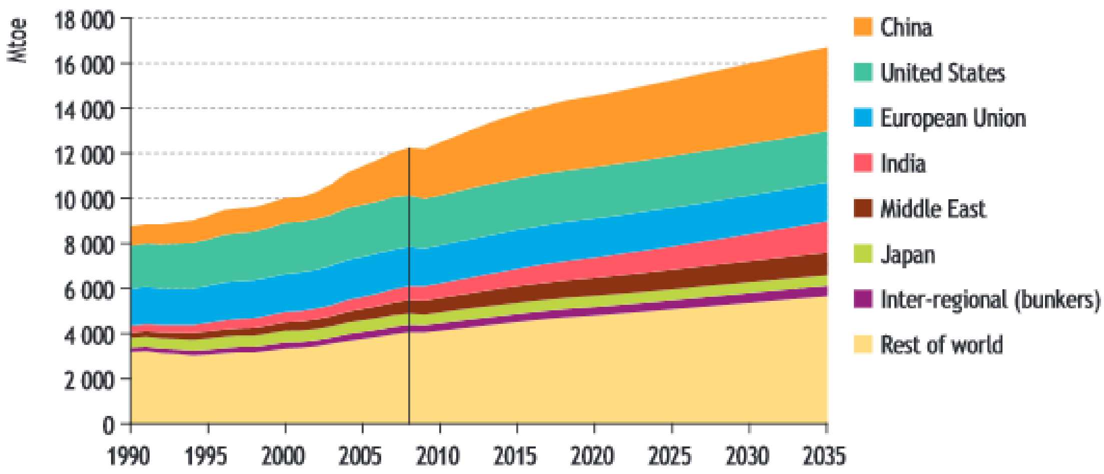
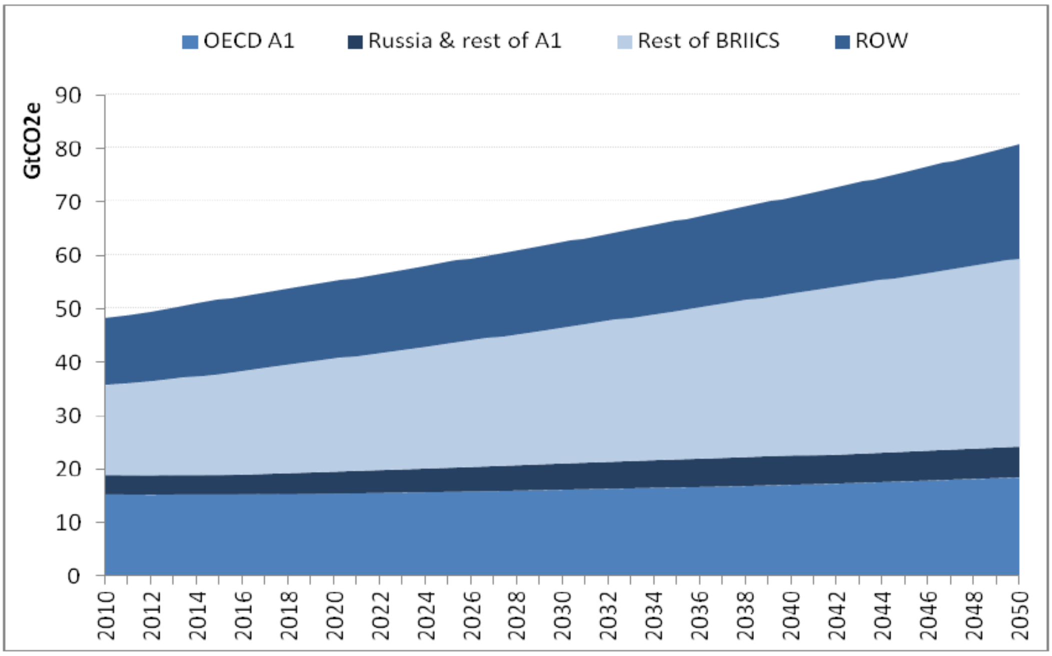
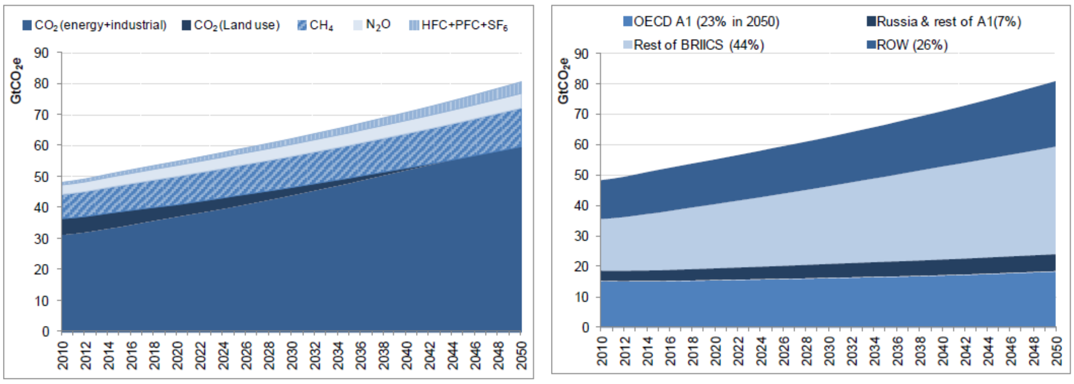


Figure 1-1: Projected growth in primary energy demand between 2010–2035 worldwide (New Policies Scenario). (IEA, 2011)



Note: "OECD AI" stands for the group of OECD countries that are also part of Annex I of the Kyoto Protocol. $GtCO_2e$ = Gigatonnes of CO_2 equivalent.

a. By gases b. By regions



Source: OECD Environmental Outlook Baseline; output from IMAGE/ENV Linkages.

Figure 1-2: GHG emissions by region according to the Organisation for Economic Co-operation and Development (OECD): baseline scenario 2010-2050 (Marchal et al., 2011).[6]

The (partially) still-growing demand for energy is affected by the increasing rate of construction of new buildings among others. Figure 1-3 shows that not only the operation of residential and office buildings has an impact on the global energy consumption and emissions but also the manufacture of construction products (e.g. cement and steel). Energy consumption and emissions associated with the production and construction of buildings and constructed assets (sometimes including maintenance and repair) are classified as "gray share" or "embodied share". Depending on the region, this share is varied - see Figure 1-4 (Oka et al. 2014).

[6] In the figure, where: BRIICS - Brazil, Russia, India, Indonesia, China and South Africa, and ROW – Rest of the World

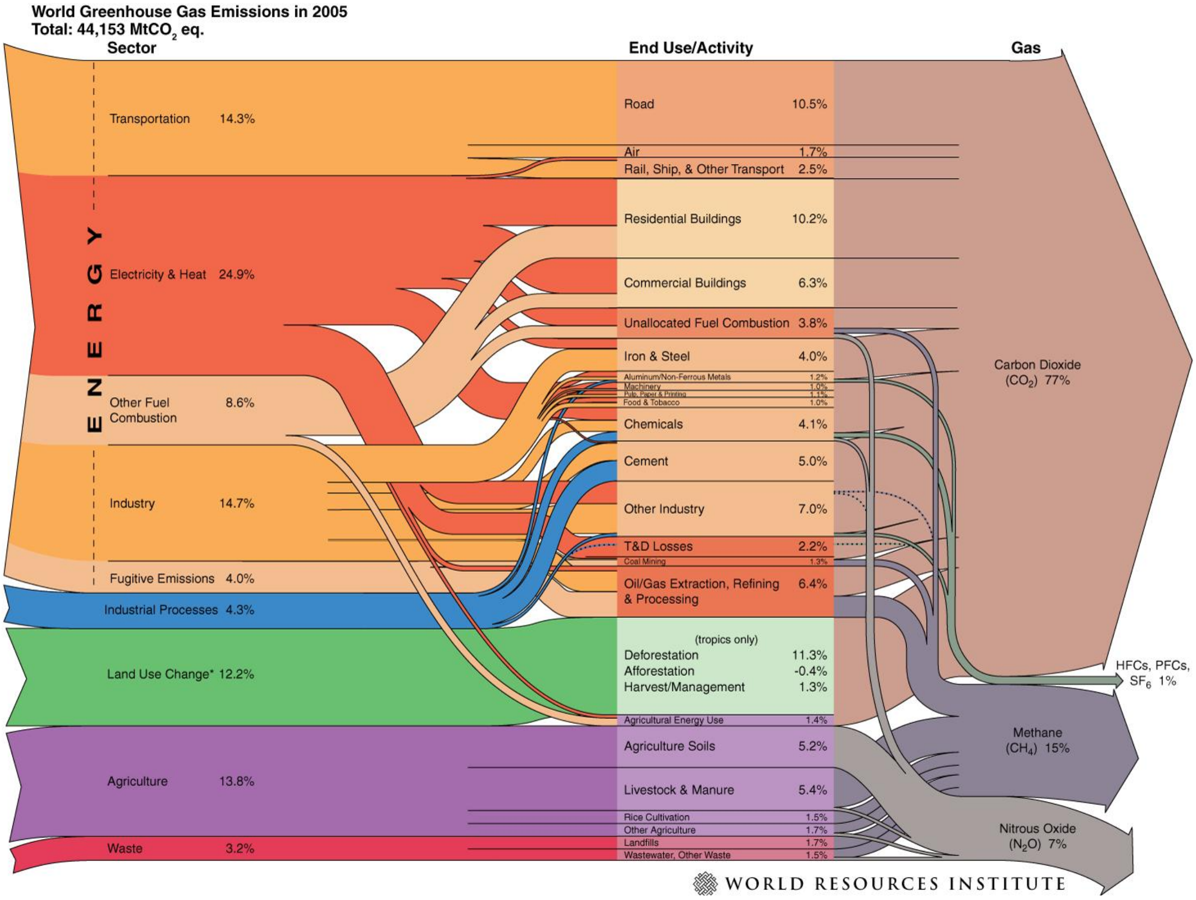


Figure 1-3: World Greenhouse Gas Emissions in 2005 per sector according to WRI (Herzog, 2005).

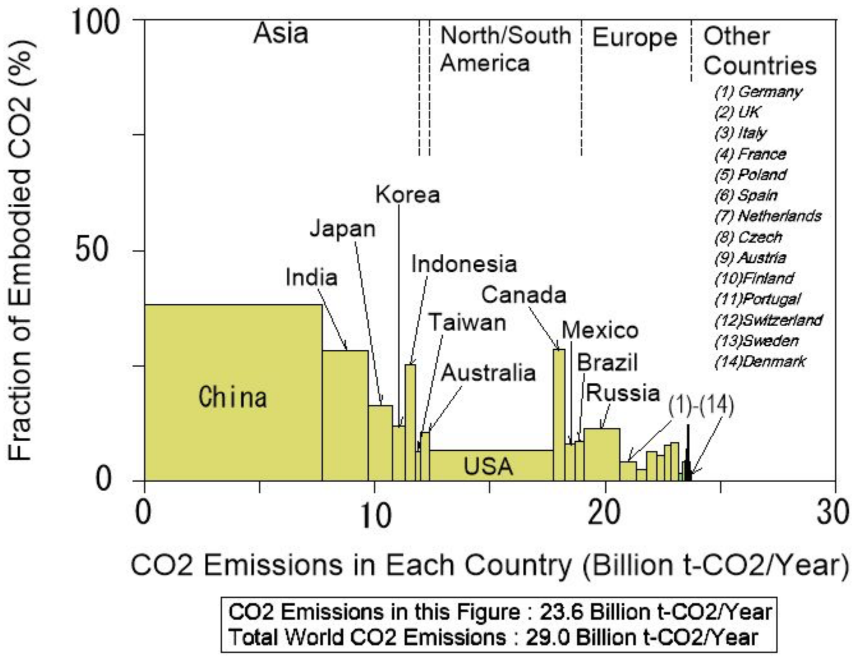


Figure 1-4: Total CO_2 emissions in each country and the fraction of embodied CO_2 (Oka et al., 2014).

With respect to resource conservation and environmental protection, an additional task is to influence this share in a targeted manner. This requires the development of methods for its determination and calculation, the demonstration of good examples for design strategies and realized buildings, as well as the development of recommendations for selected groups of actors/stakeholders involved in the construction sector. This is the task and aim of IEA EBC Annex 57.

2.2. Why to deal with "embodied energy" and "embodied GHG emissions" today?

Various actors in the building and construction industry have recently recognised the growing importance of embodied energy (EE) and embodied greenhouse gas emissions (EG). However, a significant, and still considerably untapped, opportunity to limit these impacts along with the operational impacts of buildings remains. Nevertheless, why is the assessment and management of EE and EG of buildings much more *important* and *urgent today* than it was in the past?

a) Life cycle thinking

Over the past few years, the consideration of the full life cycle in the analysis and assessment of building solutions has prevailed worldwide. This means that subject areas traditionally focused on the stages of production and construction (e.g. the determination of costs) are now also calculated for the use phase. This has resulted, among others, in an increased application of life cycle costing (LCC) to building projects. Similarly, for topics traditionally focused on the use phase (e.g. determination of energy consumption) are now also calculated for the stages of production and construction (e.g. cumulative energy expenditure). Both trends proceed gradually and are built on early examples dating already many decades back. However, they started being increasingly applied across the full breadth of the market in connection with the development of the sustainability discussion – see *d) sustainability assessment*)

b) Increase in the ratio of embodied to operational energy and GHG emissions:

Generally, reducing the embodied energy of a building is regarded as important primarily for energy conservation reasons, as this type of energy is an integral and unavoidable part of the building's total life cycle energy use. Until recently, embodied energy assumed proportionally insignificant when set against the operational part of the life cycle energy. Thus, achieving operational energy savings was normally considered more important than reducing the embodied energy. However, the proportion of embodied energy and emissions in total life cycle depends highly on the geographic location and climate (Nebel et al., 2008). For example, Plank (2008) concluded that in heating dominated regions EG account for only 10% of the total lifecycle emissions. On the other hand, for traditional buildings in developing countries, the embodied energy can be large compared to the operational energy, as the latter is quite low (Levine et al., 2007).

For example, table 1-1 summarizes the most frequently cited research from a variety of geographical backgrounds investigating trade-offs between embodied energy and operational energy, or embodied emissions and operational emissions, over the total lifecycle of buildings. The differences in the ratios are significant, but no comparisons can be performed, if no information is given on the building type, usage type, construction method, main building materials and energy standard. In the same manner, no comparisons can be performed if it is not clear what are the system boundaries considered in each study and what has been included in the calculation of EE or EG. This highlights the current problem that there is no generally accepted method available to calculate EE and EG accurately and consistently (Cabeza et al., 2013), and therefore, wide variations in results are inevitable (Pacheco-Torgal et al., 2013; Langston and Langston, 2008).

In any case, table 1-1 shows that this ratio and its further development varies in each individual country, as it is highly influenced by the methods of construction used in each region and climate zone among others. These developments and trends are very heterogeneous - but each one has implications on the resource use and environmental impacts associated with the production, construction and maintenance of buildings - even in moderate climate regions with little or no heating or cooling requirements.

Table 1-1: Examples for variation of embodied energy and emissions versus operational energy and emissions in different buildings and infrastructure from literature (partly adapted from Ibn-Mohammed et.al, 2013).

Country/Region	Study	RSP (years)	Relationship between embodied and operational energy or GHG emissions in different buildings
UK	Yohanis & Norton (2002)	25	EE is **67%** of life cycle energy
	Eaton & Amato (1998)	60	EG is **37-43%** of life cycle GHG emissions
	CIBSE (2010)	60	EG is **42-68%** of life cycle GHG emissions
Sweden	Thomark (2002)	50	EG is **45%** of life cycle GHG emissions
Portugal	Pacheco-Torgal et al. (2013)	50	EE is **25%** of life cycle energy
US & Canada	Webster (2004)	50	EE is **2-22%** of life cycle energy demand
	Engin & Francis (2010)	60	EG is **10-35%** of life cycle GHG emissions
Australia	Treloar (2000)	30	EE is **9-12%** of life cycle energy
Israel	Huberman & Pearlmutter (2008)	50	EG is **60%** of life cycle GHG emissions

However, there is a global trend towards tightening up building regulations in terms of operational energy consumption, especially in climate zones with high heating and cooling energy demand. This leads the importance of EE and the associated EG to become increasingly large (Selincourt, 2012a; Balouktsi & Lützkendorf, 2016). For example, EE in new, well-insulated energy efficient buildings can add up to 40% of the total energy consumption in the life cycle, and can even exceed the operational energy (Dixit et al., 2010). In addition, considering the ambition of nearly zero energy buildings by 2020 (Directive 2010/31/EU), this means theoretically that in the near future embodied energy will make up close to 100% of a building's total energy demand in Europe. An example of how the ratio of embodied to operational energy changes as the UK Building Regulations are revised is presented in (RICS, 2012). Finally, the pressure to reach zero operational carbon emissions will affect adversely embodied emissions by, for example, requiring the increasing use of thermal mass and insulation as well as low and zero carbon technologies (Vukotic et.al., 2010; Selincourt, 2012a).

In any case, it is clear that the importance of EE and EG increases. This is a good reason for many designers and investors, but also for legislators and standards developers to intensify the discussion on this topic.

c) Life Cycle Assessment (LCA)

The growing importance of the concept of life cycle thinking in the construction industry has led to the broad application of LCA methods in practice for decision-making. LCA method usually considers damages to three “areas of protection” (AoP): human health, ecosystem and resources. The assessment of EE and EG can be considered as part of an LCA, as they are quantified by the LCA indicators assessing the use of energy resources (renewable and non-renewable) and climate change, and thus they are linked to the AoP “resources” and “ecosystem” respectively.

d) Sustainability assessment

The last decade, there has been a shift worldwide (from predominantly qualitative approaches) to the adoption and standardization of predominantly quantitative and life cycle oriented approaches to assessing building sustainability. For example, considering the recent standards elaborated by the ISO TC 59 /SC 17 committee at an international level, and the CEN TC 350 working group at a European level, Life Cycle Assessments (LCA) are required to be performed in the course of an environmental performance assessment included in an overall sustainability assessment. In this sense, estimated values of EE can be fed into the assessment of the lifecycle use of energy resources and EG values into the assessment of the lifecycle GHG emissions (expressed in GWP) as part of an LCA, or the determination and assessment of a carbon footprint of buildings (EG is a partial carbon footprint). These estimated values of EE and EG are therefore an essential piece of information that can support sustainable development through both a full sustainable assessment of the environmental performance of buildings and a complex evaluation of the contribution of individual buildings. There are already certification systems around the world considering LCA for their assessment criteria and utilizing relevant national LCI databases (Balouktsi et al., 2014).

It is clear that there are various reasons for an increased engagement with the issues of embodied energy and embodied GHG emissions; however, these contribute to a general trend towards a more intensive consideration of such topics.

2.3. Brief history

It has now been more than 40 years since the recognition of embodied energy has been established as an important environmental parameter in the building sector. First, it started as a scientific interest in looking at life cycle aspects of products and materials. First scientific studies focused on some stages of the life cycle of certain products date from the late 60s and early 70s. On the one hand, Leontief’s input-output model developed in the late 20s started being adapted to embodied energy analysis to describe ecosystem energy flows (Tennenbaum, 1988). This provided suitable data for the determination of embodied energy consumption. On the other hand, researchers were interested in addition to the energy consumption during the use phase, also for the energy required to produce buildings.

Then, in the late 70s, early 80s energy conservation became a publicly recognised issue in developed nations due to the oil (price) crisis. Particularly, questions came to the fore dealing with the trade-off between, on the one hand, the energy consumption for heating and lighting of buildings, and on the other hand, the energy consumption for the manufacture of building elements (Haseltine, 1975; Hill, 1983). Additionally, questions related to the energy payback period of additional energy efficiency measures (e.g. application of additional insulation) were in focus. In this respect, an important partial aspect was the search for the optimum thickness of insulation from the perspective of the overall primary energy consumption. This is also when the first studies looking at life cycle aspects of products and materials focusing on issues such as energy efficiency and raw materials consumption started.

However, the debate on issues of embodied energy in the construction sector in some countries was brought forward nearly a century ago. For example, in Germany, there were already in the 20s requirements for new buildings when selecting building materials based on how much energy is required for their production. There have been publications - comparable to today's building component/element catalogues - in which the energy required for heating was compared to the energy required for production of the building components. The required amount of coal was used as the unit to describe the energy consumption (Friedrich et al., 1922). Even later, in the 70s, 80s and 90s, the embodied energy in components and structures was often given in different studies in tons of coal equivalent, lignite equivalent or oil equivalent. More information about the different energy units can be found in Appendix 1.A.

It was not until mid-80s, early 90s that a real wave of interest in Life Cycle Assessment (LCA) swept over a much broader range of industries, design establishments and retailers (Jensen et al., 1997) – "embodied energy" and "embodied GHG emissions" were part of this. The first attempts to harmonise the LCA methodology and develop a suitable structure was realised by the Society of Environmental Toxicology and Chemistry (SETAC). The results of these attempts were published in the SETAC "Code of Practice" (SETAC, 1993). Within the context of this report, LCA indicators for environmental performance assessment are and should be derived from the so-called "areas of protection" (AoP) (the entities that need protection, usually human health, ecosystems and resources). Besides the resources, also the ecosystem including the climate is considered an area of protection. A few years later, the International Organization for Standardization (ISO) published the ISO 14040 standard series taking over what SETAC had initially developed. At the same time, dealing with climate change and its mitigation was an essential part of the discussion. The interest in research on GHG emissions, as well as ways of reducing the trade-off between emissions in the use phase and emissions resulting from the manufacture of building elements and construction of buildings started to grow.

Since then, LCA has established itself as a holistic approach to research and standardization. Only a holistic approach can meet the requirements for describing and evaluating the effects on the environment. A one-sided focus on individual aspects leads to a loss of information and evidence. Nevertheless, a part of the active actors in the construction and real estate industry consider LCA to be complicated and complex, especially when it comes to assessing the environmental performance of buildings, since they are products with a great life span involving complex and dynamic processes (Ramesh et al., 2010, Dixit et al. 2012). Therefore, the considerable effort required for data collection and interpretation of the results, has led them to look for single indicators, like carbon footprint (recently standardised in ISO/TS 14067), carbon metric (recently standardised in ISO 16745:2015), grey energy (specific to Swiss context, defined in SIA 2032) or others. This has led and leads among others to a revival of the topic “embodied energy” and subsequently to a growing interest in “embodied GHG emissions”.

It is now generally recognised that EE and EG are important indicators that provide the different stakeholders with useful information to use in their decision-making. For many actors this offers a first step into the subject of energy resource use and the resulting effects on the global environment for the non-operational stages of the buildings. However, for giving a complete picture of the life cycle environmental impacts of a building, these two indicators must be supplemented by others and be integrated into a complete life cycle assessment.

Looking at the trends in publications (figure 1-5) in the area of EE and EG (usually referred to as embodied carbon or embodied carbon dioxide in the literature), it can be said that in the beginning the greater part of research was related to “embodied energy”. This was mostly seen as a component of the question of resources protection, which was and still is one of the focus areas for many specialists and researchers. However, more recently a new stream of research started, being related to EG as an issue of high political importance, as their reduction has a direct relationship with the climate change mitigation. At the same time, the last years, carbon footprint (CF) has started winning an incredible popularity as an easy to understand and measure indicator among stakeholders coming mainly from real estate industry. However, there are also here different understandings (and misunderstandings) with regard to the definitions, scopes and interpretations of these aspects.

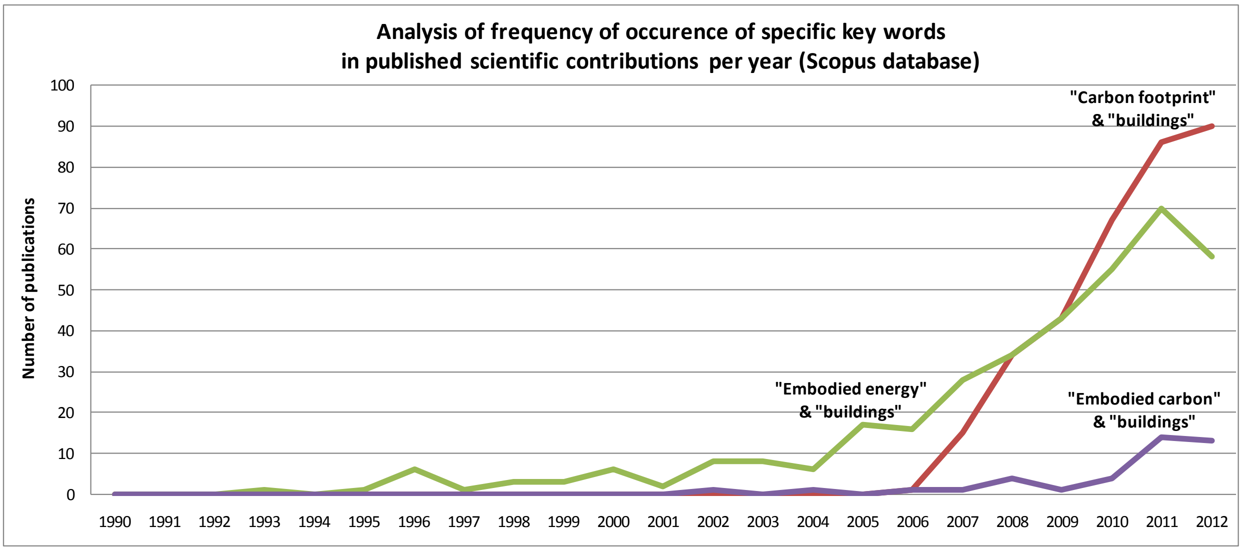


Figure 1-5: Investigation of the trends in research using the key words “carbon footprint”, “embodied energy” and “embodied carbon” combined with the key word “buildings”.

Additional information can be found in Annex 57 ST2 report.

2.4. Trends in environmental performance assessment

An assessment of the environmental performance of buildings is usually not focused exclusively on primary energy and GHG emissions, but covers a broad range of environmental issues. Within the context of LCA embodied GHG emissions (EG) would normally be reported as a part to the contribution to climate change or global warming potential (GWP) and embodied energy (EE) would be reported as a part of the use of primary energy resources (also materials resources, when energy resources are used as feedstock), alongside other environmental indicators (e.g. acidification, eutrophication, etc.). Thus, the indicators assessing EE and EG are included in a long list of indicators as presented in table 1-2.

More recently, many building practitioners and decision makers choose to focus on a single issue rather than a long list of environmental impacts. Therefore, although *Carbon Footprint* is not a new indicator, it was not until recently that it has gained tremendous popularity over the last few years. The embodied GHG emissions for the building over its whole life (including the ones embodied in "replacement parts") can be added together with the operational GHG emissions to create a carbon footprint for the building. Thus, EG can be considered as a *partial carbon footprint* of selected processes of the building system. Currently, in most cases carbon footprint is expressed in carbon dioxide (CO_2) equivalent, identical to the global warming potential (GWP) indicator used in life cycle assessment (LCA).

The term *environmental footprint*[7] relates to the more established term "carbon footprint" and denotes the various environmental impacts or the aggregated environmental impact of a product over its full life cycle, instead of climate impact alone. Thus, a carbon footprint is typically one element of an environmental footprint (PCF World Forum). In Europe, the discussed/planned introduction of a Product Environmental Footprint (PEF) for products is already at a pilot phase (Manfredi, 2012). In PEF, a more extended list of indicators than in typical Environmental Product Declarations (EPD) will be included. Again, GWP and the use of energy resources will be taken into account in this extended list of indicators.

<u>Table 1-2</u>: Placement of the indicators GWP (as result of GHG-emissions) and primary energy consumption in the international standards related to the environmental performance assessment of buildings and the description of the environmental performance of construction products (EE and EG related impacts are highlighted here).

ISO 21931-1:2010 (building level)	ISO 21930:2007 (product level)
Global impact	**Environmental impacts expressed in terms of the impact categories of LCIA**
Global warming potential Depletion of stratospheric ozone layer Acidification of land Acidification of water sources Eutrophication Formation of photochemical oxidants	**Climate change (greenhouse gases)** Depletion of the stratospheric ozone layer Acidification of land and water sources Eutrophication Formation of tropospheric ozone (photochemical oxidants)

[7] The term "environmental footprint" should not be confused with the term "ecological footprint". The indicator ecological footprint is land based and measures the amount of planetary biocapacity a system uses, compared to the regenerative capacity available.

ISO 21931-1:2010 (building level)	ISO 21930:2007 (product level)
Local Impact	
Impact on biodiversity and ecology Load on infrastructure Change of microclimate Impact on surface drainage	
General aspect	**Use of resources and renewable primary energy — Data derived from LCI**
Use of non-renewable primary energy resources Use of non-renewable material resources Use of renewable material resources **Use of renewable primary energy resources** Consumption of fresh water Hazardous waste Non-hazardous waste Land-use related to building site	**Depletion of non-renewable energy resources** Depletion of non-renewable material resources Use of renewable material resources **Use of renewable primary energy** Consumption of freshwater Hazardous waste Non-hazardous waste
Local Aspect	
Sun shading and glare Wind effect Risks and emissions to surface water Risks and emissions to ground water Risks and emissions to soil	

2.5. Current state of standardisation

In terms of different standardization activities, there are already various standards that can be used for “embodied energy” and “embodied GHG emissions” assessments.

Internationally, the existing standards related to the environmental assessment of buildings and building products are:

- ISO 21931-1:2010 – Framework for methods of assessment of the environmental performance of construction works - Part 1: Buildings
- ISO 21929 -1:2011 – Building Construction Sustainability in Building Construction - Sustainability Indicators. Part 1 - Framework for the development of indicators for buildings and core indicators
- ISO 21930:2007 – Sustainability in building construction - Environmental declaration of building products
- ISO 14025:2006 – Environmental labels and declarations - Type III environmental declarations - Principles and procedures

Other standards that can be used related specifically to carbon footprint of products are:

- ISO/TS 14067:2013 – Carbon Footprint of Products - Requirements and guidelines for quantification and communication
- Greenhouse Gas Protocol - Product life cycle accounting and reporting standard

Situation in Europe

In Europe, it is hoped that the voluntary standards developed by the CEN/TC 350 committee will be adopted to ensure some consistency and comparability across studies. CEN/TC 350 is the Sustainability of Construction Works group of the European Committee for Standardization. The standards aim to describe a harmonized methodology to assess the life cycle environmental, economic and social performance of buildings.

Out of the suite of CEN TC 350 standards, the ones dealing with the description and assessment of environmental related issues for buildings and their products are:

- EN 15643-2:2011 Sustainability of construction works - Assessment of buildings – Part 2: Framework for the assessment of environmental performance
- EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method
- CEN/TR 15941:2010 Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data
- EN 15942:2011 Sustainability of construction works - Environmental product declarations - Communication format business-to-business
- EN 15804:2012 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

The key standard for calculating embodied energy and embodied GHG emissions in buildings is EN 15978:2011, while EN 15804:2012 is the standard to be used for calculating the indicators at building product level. The standards developed under this framework do not set the rules for how different assessment methodologies may provide valuation methods, nor do they prescribe levels, classes or benchmarks for measuring performance.

Additionally, the European Commission's Joint Research Centre has developed recently a harmonised LCA-based methodology for the environmental footprint of products:

- EU Product Environmental Footprint Guide (pilot phase)

Country specific examples

Some countries have developed and applied their own national standards and regulations. Examples are:

- the German standard VDI 4600 – Cumulative energy demand (*KEA*):Terms, definitions, methods of calculation (2012)
- The Swiss standard SIA 2032 – Grey Energy of Buildings (2010)
- SIA 2040 - SIA Energy efficiency Path
- The British standards PAS 2050:2011 – Specification for the assessment of life cycle greenhouse gas emissions of goods and services, and PAS 2060:2010 - Specification for the demonstration of carbon neutrality
- The American ANSI/ASHRAE/IES/USGBC Standard 189.1-2014 – Standard for the Design of High-Performance Green Buildings

There are e.g. both international and European standards for the calculation of energy consumption and GHG emissions of buildings. The same applies to the provision of data and information for construction products. In this sense, the standards can also be applied for determining EE as part (or selected modules) of the cumulative primary energy consumption used to describe the use of resources, and EG as part (or selected modules) of the whole life GWP (or alternatively referred to as carbon footprint in some standards). Depending on the approach and system boundaries, the stages of production, construction, maintenance and EOL are included in the assessment. In particular, the uniform basis for the development and publication of environmental product declarations (EPDs) has contributed significantly to the improvement of data availability for construction products related to EE and EG (more information in section 2.6).

2.6. Current state of data availability

The availability and accessibility of data and information on embodied energy and embodied GHG emissions of building materials and products constituting the building is the most important requirement for the assessment of embodied energy and embodied GHG emissions of a building. However, this information should be reliable to allow useful comparisons between building products, or between building materials.

At present, not all construction product data are collected using consistent boundaries of assessment, and product specific data from manufacturers are not always comparable with the more generic product data. This is also due to the different data sources. A distinction can be made between

- data and databases for scientific purposes that comply with high quality standards
- data from the literature with unclear origin
- freely accessible databases that were created and are being maintained with public funds, and therefore they are subject to a quality control
- commercial databases with/without (external) quality control
- information published by professional associations with/without (external) quality control
- information published by individual manufacturers with/without (external) quality control

The transparency and traceability of the available published data cannot always be sufficiently ensured. One example of consistent generic and manufacturer specific LCI data is the KBOB-recommendation 2009/1:2014 in use in Switzerland (KBOB, 2014). This system is described in more detail in Annex 57 ST3 Report. In general, many countries are in the process of developing or have already developed EE and EG data for building products. Most of data exist as life cycle inventory (LCI) data format rather than EE or EG itself. An overview of the publicly available databases around the world is given in ST3 report. A list of third party databases is also provided by the Greenhouse Gas Protocol (Greenhouse Gas Protocol, 2012), including also the commercial databases. Also within the context of ST1 activities, a detailed analysis of different data sources was performed – see Appendix 1.B.

In case national LCI data are not available, another source of product data is an Environmental Product Declaration (EPD). These are a standardized and independently verified declaration of environmental performance of materials or products encompassing all stages of the life cycle or parts of it (only the inclusion of cradle to gate data is mandatory, while the full life cycle is voluntary). Their standardization process is defined in EN 15804:2012 and EN 15942:2011 at a

European level, and ISO 14025:2006 at an international level. However, system boundary settings, modelling approaches (e.g. allocation) and background data may still vary and by that exerting a substantial influence on the resulting environmental impacts.

Therefore, EPDs are not comparative assertions and are either not comparable or have limited comparability when they cover different life cycle stages, are based on different product category rules or are missing relevant environmental impacts. EPDs may be produced for specific materials or products (product-specific EPDs) or an “average product” of many companies within a clearly defined sector (sector or generic EPDs). Some comprehensive examples of construction product related EPDs from different countries could be found catalogued on the web (see ST3 report).

Still problematic is the case of complex product systems including many different components, such as technical building equipment and machinery, since there is still a lack of EPDs (examples can be found in Ökobau.dat and EPD International among others), or in the case of general LCA data, these are usually insufficient or incomplete (Balouktsi & Lützkendorf, 2016). For this reason, in most LCA studies of buildings the influence of building technical equipment and systems in terms of their EE and EG is hardly considered and evaluated (Passer et al. 2012). In view of the current trend towards energy-efficient and net-zero energy buildings, it is important the development and provision of good quality LCA data for technical building systems, including PV systems and other electricity generation systems (Balouktsi & Lützkendorf, 2016).

Focusing on design professionals and consultants as a special and important actor group, apart from good quality data, they also need effective and easy to use tools allowing them to link material quantities with values from databases, or tools with already integrated databases (designers are not required to aggregate data and perform LCAs manually). The function of these tools is to take input in the form of materials take-off, convert them into mass and attach this mass value to the LCA data available from an LCA database, e.g. figure 1-6 (Bayer et al., 2010). In general, a diverse range of tools is available that can be used at different stages of the design process. A comprehensive list is provided by the European Platform on LCA (European Commission, JRC & IES). However, the selection of calculation tool is less important than the selection of appropriate data, standard or methodology, as the latter are more likely to lead to diverse and inconsistent results.

At the same time, Building Information Modeling (BIM) can help in minimizing the time consumed in the LCA process, as it has the capability to generate automated quantity take-offs (Bayer et al., 2010). Combining BIM with modern LCA tools seems to be an ideal way to streamline the process of LCA. Since LCA data are mass related, BIM software tools could easily include also LCA information. Although the concept sounds simple, the integration of LCA data into BIM environment is not common yet. Lots of such new applications are expected to be developed over the next years (Ariyaratne & Moncaster, 2014).

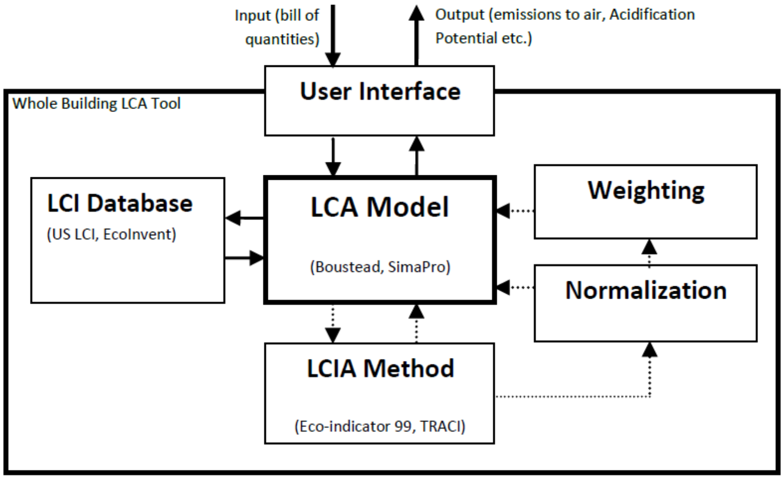


Figure 1-6: Example of a typical function of an LCA tool (Bayer et al., 2010).

However, tools normally do not provide specific base values for benchmarking purposes. There is a need for database-oriented tools gathering and making accessible information on building projects after their completion with the aim to inform on how the embodied impacts of a new design will compare to a typical building of the same typology and structural system (De Wolf, 2012). The Waste Reduction Action Program (WRAP) has recently launched such a project-based database in the United Kingdom (WRAP, 2016). Such benchmarks can support the early stages of the decision making process, when the quantities of materials are still not known (Balouktsi & Lützkendorf, 2016).

In some cases, also national benchmarks and target values exist, e.g. in Switzerland in SIA-efficiency path energy (SIA, 2011a).

2.7. Analysis of groups of actors/stakeholders and decision-making situations

In the building and construction value chain, a diverse group of actors is involved, with varied or diverse concerns and priorities related to the aspect of embodied impacts. On the grounds of their different roles, table 1-3 provides an analysis of their decision-making contexts (indicative examples). Understanding their underlying concerns and decision-making contexts will help to evaluate the possibilities and challenges of integrating this additional aspect into their decision-making (Balouktsi et al. 2015; 2016). The typology of actors (A), their primary roles (R) and decision-making contexts (DM) was developed based on a survey carried out within the scope of IEA EBC Annex 57 project (Appendix 1.C).

For instance, the different roles and decision-making contexts for a designer might include, among others (table 1-3):

- When providing support to the client/owner (R1), he/she assists in terms of building requirements planning, the basic construction-related decisions and the formulation of the task (the “brief”) and requirements related to the environmental performance of the building (DM – A1/R1).

- when designing and assessing a building (R2), he/she selects the building products and construction methods, optimizes building elements in terms of their structural and environmental performance, develops a plan for future maintenance and repair of the building, as well as for future decommissioning of the building (ease of dismantling and recycling) (DM – A1/R2).
- When carrying out the object documentation (R), he/she compiles information on the type and quantity of installed materials including their environmental information (DM – A1/R3).

Section 5 of this report presents specific recommendations for selected groups of actors.

Table 1-3: Typology of actors (A), their primary roles (R) and decision-making contexts (DM) in relation to their influence on embodied impacts – selected examples (Balouktsi et al. 2016). Annex 57 considers actor groups A1, A2, A3 & A4 as the most important for influencing the embodied impacts, and thus, are further analysed in table 1-4.

Type of Actor	Primary Roles	Decision making contexts in relation to their primary roles
Design Professionals (A1)	Provision of support to the client/ owner (R1) Building design and assessment (R2) Object documentation (R3)	(A1/ R1) – Provision of assistance to the client in terms of the building requirements planning, the basic construction-related decisions and the formulation of the task (the "brief") (A1/ R1) – Provision of assistance to the client in the formulation of requirements related to the environmental performance (A1/ R2) – Selection of building products and construction method, as well as optimisation of building elements in terms of their structural and environmental performance through the comparison of different variants (A1/ R2) – Development of a plan for future maintenance and repair of the building (A1/R2) – Development of a plan for future decommissioning of the building (ease of dismantling and recycling) (A1/ R3) – Compilation of information on the type and quantity of installed materials including their environmental information
Construction Product Manufacturers (A2)	Product manufacture (R4) Product recycling (R5) Product description and certification (R6)	(A2/ R4) – Continuous improvement of building products through the optimization of "in-house" (corporate) processes and a change in the procurement of their primary products and energy sources (A2/ R4) – Continuous improvement of the technical quality of products (durability, ease of maintenance, ease of deconstruction and recyclability) (A2/ R5) – Development of structures and solutions to support the recycling (implementation of effective take-back of products, e.g. a "product stewardship" model) (A2/ R6) – Provision of transparent information on their product's performance (e.g. EPD, safety data sheet)
Procurers (A3)	Procurement of buildings and construction products (R7)	(A3/ R7) – Requirements-setting for the contract specification (A3/ R7) – Contribution to Green Public Procurement (GPP) and Sustainable Public Procurement (SPP) in terms of the formulation of requirements on the environmental performance (A3/ R7) – Definition of robust metrics and KPIs
Government (A4)	Law- and policy-making (R8) Funding provision (R9) GPP (as a special form of procurement) (R10)	(A4/ R8) – Development of new requirements, targets and benchmarks for embodied impacts to be integrated into national policies, regulations and/or laws related to energy and resource efficiency, and/or building performance (A4/ R9) – Development of new funding programmes incorporating considerations for embodied impacts (A4/ R10) – Inclusion of requirements on embodied impacts in Green Public Procurement (GPP) and Sustainable Public Procurement (SPP)

Type of Actor	Primary Roles	Decision making contexts in relation to their primary roles
Contractors/ Builders (A5)	Construction management (R11) Waste management (R12) Documentation and monitoring (R13) Maintenance (R14)	(A5/ R11) – Reduction of energy consumption on the construction site (A5/ R11) – Use of construction products being produced close to the construction site to reduce the amount of transport (A5/ R11) – Selection of sources of supply of the building materials and mechanical plant (A5/ R11) – Quality management to ensure a long service life of the building and avoid defects (A5/ R12) – Waste management at the construction site (A5/ R13) – Provision of information (installed products, durability, longevity of the construction works) (A5/ R14) – Development of concepts for the life cycle related services to maintain the building
LCA experts and consultants (A6)	Provision of expert advice to other stakeholders (R15)	(A6/R15) – Provision of advice and assistance on matters related to the preparation of detailed LCA calculations and generation (or sourcing) of LCA data.
Professional Associations/ Organisations (A7)	Provision of technical guidance (R16) Development of regulations (R17)	(A6/ R16) – Publication of information and guideline documents (A6/ R16) – Sharing/provision of data, tools and experiences or case studies (S6/ R17) – Development of rules for integrating the tasks into the scope of work and fee determination
Real Estate Appraisers/Valuation experts (A8)	Appraisal of building value (R18)	(A8/ R18) – Estimation of the “cost” of the environmental impact as part of a property valuation (A8/ R18) – Consideration of the “environmental value” of existing buildings in their valuation
Scientists (A9)	Development of methods and benchmarks (R19)	(A9/R19) – advancement of the methods of LCA (A9/R19) – prognosis of changes in data due to technical progress (A9/R19) – development of benchmarks through the working out of case studies
Tool/ database developers/ providers (A10)	Data and tool provision (R20)	(A10/ R20) – Collection of data in the database, evaluation of their quality and update of older data (A10/ R20) – Provision of average values to be used at the early design stages

According to the related survey undertaken by ST1 (Appendix 1.C), the state of knowledge and perception of the different actors is very heterogeneous. While some industries (construction industry) and actors have already a long experience in the subject of EE and EG, to others (e.g. investors, part of the public sector) this was introduced as a new topic. The discussion of this topic was especially initiated and driven by the increased demand for sustainability assessment of buildings and green public procurement. This fact is also reflected in the literature. Figure 1-7 shows the trends in publications related to these situations and tools. It can be said that the concept of EE was and still is of great concern mostly in relation to design process and decision-making process. This is now being supplemented by EG – this also helps users in connection with net zero emission concepts. However, it can be also said that EE has started being integrated more and more into the procurement.

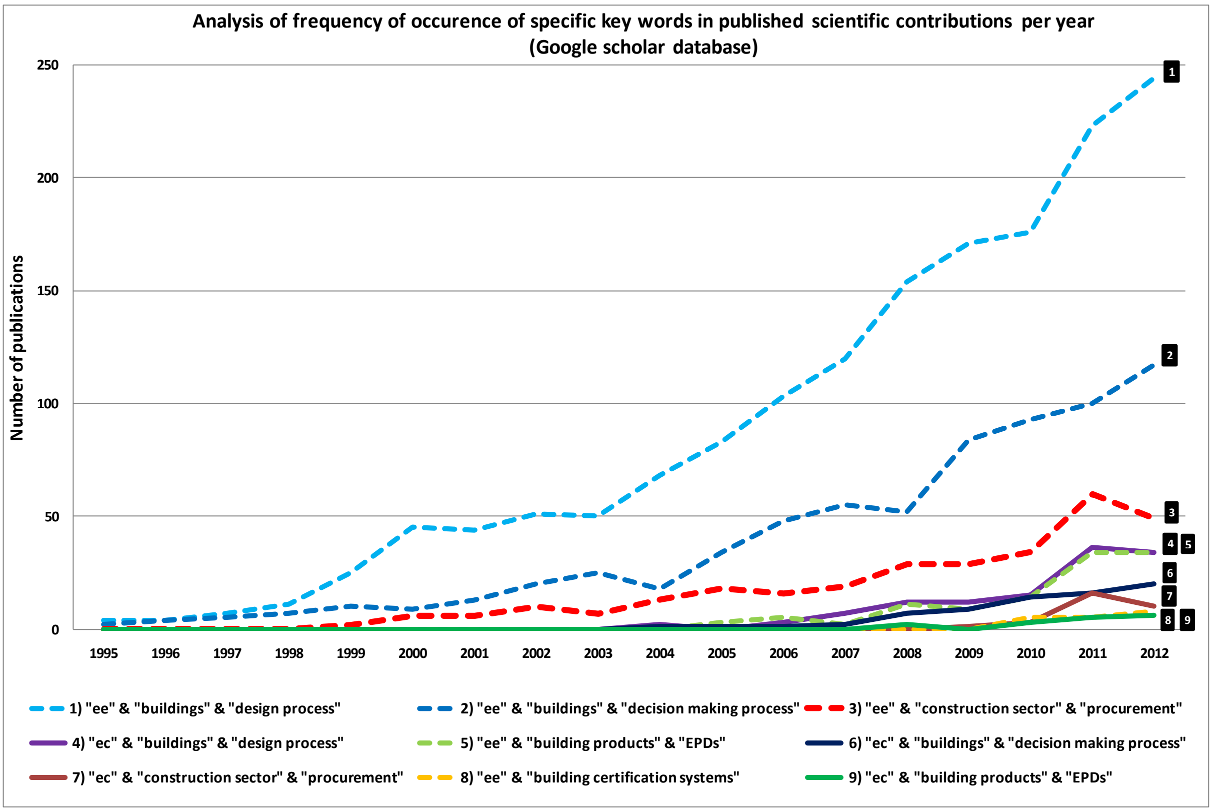


Figure 1-7: Investigation of the trends in research using the key words "design process", "procurement", "decision making process", "building certification systems" and "EPDs" together with "buildings" or "construction sector" and "embodied energy" (dashed lines) or "embodied carbon".

As a summary, table 1-4 gives an overview of the most important stakeholders/actors, their typical object(s) of assessment, their typical work tasks in relation to EE and EG and the data needs.

Table 1-4: A sampling of stakeholders and actors in building and construction, and their diverse decision-making contexts and concerns.

Stakeholder/ Actor	Object of assessment (Typical)	Typical work tasks in relation to the aspects of EE and EG	Consequences for data needs
Designer (Professionals and consultants)	Product Element/component Building (whole)	- in the early design stages: * decision on new construction or refurbishment * selection of construction method and main building materials * energy concept - in the design development stage: * selection of specific products and technologies - At completion * object documentation	In the early design stages, national or regional **average** data on construction products are required. In the design development stage, **company specific** data of construction products are required. In the stage of documentation, **company specific** data of construction products are required, including information on aspects such as ease of deconstruction, recyclability, or take-back guarantee obligation of the manufacturer

Stakeholder/ Actor	Object of assessment (Typical)	Typical work tasks in relation to the aspects of EE and EG	Consequences for data needs
Product manufacturer (Building, construction and allied industries)	Product	– Selection of raw materials and suppliers (of other materials needed for production) – Selection of energy sources for in-house processes – Selection of technologies for in-house processes – Optimisation of in-house processes – Optimisation of resource efficiency and recycling of the construction products	EE and EG data for raw materials and other supplied materials are required, as well as PE and GWP data for the energy carriers and services - **company specific** data are required For the optimisation of construction products during the product development and the continuous improvement in relation to EE and EG, the impact of raw materials, energy carriers and in- house processes must be identifiable in the analysis - **company specific data** are required (from upstream and from own process)
Procurer (Owners and investors)	Building (Specific product, e.g. new or innovative technology)	– Procurement of constructed assets (e.g. GPP) – Specifications for the selection of construction products	Average data or benchmarks for EE and EG data for constructed assets or construction products are required Benchmarks (whole system/building level) are required as a basis for assessment and decision-making
Policy maker	National/regional policies National/regional legislation and regulation National economy	– Analysis of sectors and industries, improvement of the national statistics – Formulation of targets and requirements for the different sectors – Development of laws (e.g. for product labelling) – Development of incentives and funding programmes (e.g. consulting programmes for the industry, scientific funding, publication of data sets, etc.)	An overview across the industries and sectors is required A suitable methodology is the I/O Analysis based on the national economy

Another relevant group of actors is data providers. As commercial providers of information they provide a service. They can play an important role in ensuring the quality of data.

2.8. Current state of practical application

The aspects of EE and EG as part of a full LCA have started attracting more and more interest from different actors in the building and construction supply chain. This happens in different ways. For example, some local authorities have already included mandatory embodied carbon assessment as part of the planning process (Brighton and Hove City Council, 2011), designers and engineers have started looking into embodied impacts as part of LCA to develop design options (Bayer et al., 2010), and quantity surveyors are now invited to calculate embodied carbon and add this dimension to their reports (RICS, 2012). At the same time, progressive clients and developers in their attempt of adopting leading sustainability practices have started looking at ways for considering and reducing the embodied impacts of their developments (UK GBC, 2015). As far as the data supply side is concerned, construction product manufacturers both in EU and internationally are increasingly requested to develop and communicate credible and transparent LCA data to purchasers in the form of Environmental Product Declarations EPDs (ISO 14025:2006, EN 15804:2012), or even more specifically to communicate the carbon footprint of products (ISO/TS 14067:2013).

A new stream of various publications in the form of guidelines specific to different building-industry stakeholder groups dealing with LCA as a whole, or specifically with the aspects of embodied energy and embodied carbon partially facilitates the practical application of these new aspects. This reflects the increasing interest in the consideration of embodied impacts in everyday work of these stakeholder groups. Table 1-5 presents examples of EE and EG related guidelines published by different associations and organisations to be used by their members.

Table 1-5: List of existing guidelines published by various associations and organisations.

Title of document	**Year**	**Main target group (Secondary target group)**	**Scope of application and limitations**
RICS - Methodology for the calculation of embodied GHG as part of the life cycle carbon emissions for a building	2012	Quantity Surveyors (Decisions makers in the design team)	Europe (particularly UK) *Information paper*
UK CPA (Construction Products Association) - Guide to understanding the embodied impacts of construction products	2012	Construction Product Manufacturers (Design professionals and consultants)	Europe (particularly UK) *Information paper*
BSRIA (Building Services Research & Information Association)- Inventory of Carbon & Energy (ICE) summary guide	2011	Building services engineers	Europe (particularly UK) *Guide*
ENCORD (European Network of Construction Companies for Research and Development) – Construction CO2e Measurement Protocol - A Guide to reporting against the Green House Gas Protocol for Construction Companies	2012	Construction Companies acting as a main contractor or a large subcontractor (construction companies who manufacture materials or construction companies who operate buildings)	Europe *Measurement Protocol*
AIA (The American Institute of Architects) – AIA Guide to Building Life Cycle Assessment in Practice	2010	Architects	United States *Guide*
WRAP (Waste & Resources Action Programme) **–** Guidance for low carbon building projects and estates management	2011	Construction clients, Property owners, Building managers **(**Design teams, contractors and facilities managers when appointing their supply chains)	UK *Guidance for low carbon building projects and estates management*
European Commission – EeBGuide Guidance Document - Operational Guidance for Life Cycle Assessment Studies of the Energy-Efficient Building Initiative	2012	LCA practitioners, LCA tool developers (Experts responsible for the definition of calculation rules for building labelling systems and for EPD programmes)	Europe *Guidance document*
UK GBC – Tackling Embodied Carbon in Buildings	2015	Clients and Developers	UK *Guide for the client sector*
ICE (Institution of Civil Engineers) – Energy Briefing Sheet: Embodied Energy and Carbon	2015	Civil engineers	UK (also operates around the world) *Briefing sheet*

The examples presented above have been identified and analyzed within the context of a survey conducted as part of ST1 - see Appendix 1.C. Although the information and guidance contained in these guidelines is internally consistent, they do not follow a uniform approach all together. In all these publications, there are no uniform views on definitions, system boundaries and the job-sharing and exchange of information between stakeholders. This became an essential work item for IEA EBC Annex 57.

2.9. Summary of current needs

The current development of life cycle approaches and design methods to improve the overall sustainability of buildings makes necessary the explicit incorporation of the aspects of embodied energy and embodied GHG emissions into the assessment of the environmental performance of buildings as part of a complete sustainability assessment. However, limited attention has been paid so far to the embodied impacts compared to the focused efforts of building and construction industry on reducing the operational part of life cycle energy of buildings. The influence of these aspects becomes even more critical for energy-efficient, low-energy or net-zero energy building concepts, since these are usually linked with the integration of energy and carbon-intensive materials and products. However, as Langston and Langston (2008) suggests, while measuring operating energy is easy and less complicated, determining embodied energy is more complex and time consuming. Investigating the current situation and conditions, the assessment of EE and EG at the building level is now possible, as

- the scientific knowledge and basis exists since decades
- the currently available life cycle oriented international and European standards form the basis for a quantitative assessment of EE and EG among other parameters,
- the increasing integration of LCA approaches into widely known sustainability assessment and certification systems for buildings facilitates the spread of life cycle thinking in the building industry,
- the current availability and access to LCA data, EPD’s and tools worldwide is sufficient to support an assessment of EE and EG, even from the early design stages of building projects.

Nevertheless, these standards, data and tools, do not always define clearly the system boundaries, indicators, etc. leaving a broad scope for interpretation and creating uncertainty. There is still a lot of confusion partly owning to the fact that there are no clear and commonly accepted definitions and system boundaries. The spectrum of definitions ranges from accounting only for initial EE and EG of construction products (production stage) to accounting for the whole life cycle (production, construction, maintenance and end of life of the building) plus sometimes even the end of life recycling and recovery benefits. It is a fact that not one size fits all and usually system boundaries are defined subjectively in each study to fit specific purposes. To address areas of confusion, Dixit et al. (2012) brought forward the need for an embodied energy measurement protocol for buildings. In addition, there is also a need for available, accessible and region-specific data, appropriate design and assessment tools, benchmarks and target values, as well as methods for integrating this aspect into the design and decision-making processes (Balouktsi et al. 2016). All these fundamental conceptual and methodological issues will be clarified and discussed in the following chapters.

3. Assessment of embodied impacts at the building level: current discussion and practical considerations

This section aims to identify important issues and discuss the basis and the state of development on how to account for and assess embodied energy (EE) and embodied GHG emissions (EG) during the design process of buildings. Initially, it presents the starting points for the integration of embodied impacts assessment into the design process, and later it analyses practical considerations for the assessment itself.

Below important issues related to the integration of EE and EG in the design and decision-making process are discussed, the current state of the discussion is explained and what problems need to be solved. Specifically, one must answer certain key questions in order to conduct a meaningful assessment of EE and EG across the building design process:

a) What EE and EG related decisions are important at each design stage?
b) How these decisions are linked across design stages? (e.g. how early decisions are refined in later design and construction stages)
c) At what stage of design should comparisons be performed? Conceptual? Schematic? Design development?
d) What components of the building to consider in the analysis? How these can be documented and how completeness of the building description can be ensured and checked?
e) What life cycle stages of the building to consider in the analysis? How the description of the life cycle of the building can be documented and how its completeness can be ensured and tested? Should the analysis be based on the expected service life or the reference study period?
f) What is the scope of the indicators selected for the assessment?
g) What type of data are needed for the assessment and how accurate are they? In what form is this data available? Are they freely accessible? Are there specific data providers that process and make this data available? Do the manufacturers make this data available?
h) How to compare design alternatives? Are there absolute benchmarks? Are specific targets already defined by the clients/developers/investors or they are a requirement for awarding subsidies?
i) Are there already appropriate design and assessment tools that are or can be used or if not, what type of tools need to be developed to this end?
j) Are there already well-documented case studies and examples?
k) What general design recommendations can be given?

This section explores the background behind these questions and section 4 of this report provides detailed recommendations on how to find solutions for these questions in practice.

3.1. Assessment of embodied impacts – a subtask in the design process

The integration of embodied impacts into the design process can help design teams carefully consider and manage both high-level (e.g. selecting building assemblies) and low-level (e.g. selecting specific products) material and product decisions that influence the environmental impacts of the building project. Certainly, embodied impacts will never be the sole consideration of decision-making, not even the full spectrum of environmental impacts. Beyond environmental concerns, designers must also balance factors such as cost, design and construction time, building and process related quality/performance, social aspects, and other specific client's goals. The aim of integrating embodied impacts into the building design is rather to prompt design teams to think broadly about picking the right materials and systems for the project, optimizing these systems and selecting preferential final building products, than neglecting other aspects necessary for achieving a holistic picture of the sustainability of the project in both space and time. Decisions related to the ease of maintenance, the flexibility and adaptability of the building, as well as the easy deconstruction and recycling of its parts have also an influence on the resource use and effects on the environment across the life cycle of buildings.

A guide of how to include sustainability considerations into the building work stages has been produced in the UK by the Royal Institute of British Architects (Gething, 2011). A similar discussion will be developed here focusing on embodied impacts. Section 4.1 of this report gives specific recommendations derived from this discussion.

3.1.1. Considerations of the design process and specific design stages

The assessments of embodied energy (EE) and embodied GHG emissions (EG) cannot be conducted in isolation, but instead they must be integrated into the design process and involved in decisions affecting the overall performance of the building. These assessments are not one-off analyses but inform the design and decision-making process by highlighting areas that need action. The assessment process of EE and EG has a lot in common with the cost planning process that provides an inventory of all the materials, products, assemblies and elements within a building (e.g. using methods like Life Cycle Costing (LCC)).

Assessments should progress along the design process and should contribute to the appraisal of different design solutions, as well as to better informed decisions and procurement choices. The division of the project development process into work stages helps structuring the progress from initial planning to completion, while identifying typical tasks included in each distinct stage. Although each country follows a different system (some systems are divided into more stages than others are), for the purposes of the analysis here the design is simplified into the following key work stages:

a) Pre-design stage (usually includes preparation and brief)
b) Preliminary design stage (usually includes concept or schematic design)
c) Design development stage (usually includes detailed and coordinated design)
d) Preparation for construction
e) Construction stage (usually includes quality control)
f) Handover and documentation

The “pre-design stage” and “preliminary design stage” are typically characterized as the “early design stages”.

3.1.1.1. Pre-design stage (requirement planning and task formulation)

The pre-design stage should mainly provide the design teams with goals and metrics for achieving the required embodied impacts levels in the building. The client does the preliminary goal/target-setting for the building. Questions to be asked at this stage are:

- Are there information about relevant benchmarks to be used as a reference?
- What are the core environmental indicators to be considered for the environmental targets? What are the assessment methods to be used (e.g. ISO or EN)?
- Are the requirements based on national requirements or requirements from possible sustainable building certification schemes (e.g. CASBEE, LEED, BREEAM, DGNB/BNB, HQE, etc?)
- What are the priorities here? The targets reflecting the priorities are qualitatively (preferred strategy of using recycled products, using wood etc.) or quantitative (specified limit values or target values for EE and/or EG) described?

By discussing and determining the general project goals and requirements upfront, the design team is able to develop a clear picture of the end goals of the building and to ensure that these goals are met through evaluation. The definition of project objectives is of particular importance. Thus, EN 15643-1:2010 recommends the formulation of requirements on the environmental performance already in the client’s brief. This may also include limit or target values for EE and EG. Therefore, an embodied impacts assessment may start off with a target of EE and EG (in the same manner as cost estimates), which is usually estimated at an early stage and assessed and refined as the design evolves.

However, investigating EE and EG of different types of buildings is a relatively new research area. Therefore, there are limited sources for comprehensive peer-reviewed benchmark values (e.g. regulatory standards or academic studies) for use at the initial work stages of a project to support the decision-making process (e.g. target-setting and prediction), when the quantities of materials are still not known (RICS, 2014). Regulatory benchmarks and target values already exist in Switzerland in SIA-efficiency path energy (SIA, 2011a) – see table 1-6. One example of developing benchmarks for a specific type of building is the London Olympic Park Learning Legacy case study, where benchmarks for embodied carbon are set for different types of sporting venues (Cullen et al. 2011).

Some examples of additional important requirements also usually formulated at this stage are
* Service life of the building and the building components
* Requirements for easy maintenance
* Requirements for flexibility and adaptability
* Requirements for easy deconstruction and recyclability

Table 1-6: Benchmarks and target values regarding non-renewable primary energy demand (called grey energy in the Swiss context) and GHG emissions for new and existing buildings according to SIA efficiency path energy (SIA, 2011a). This is based on a share of energy available for housing at 840 Watts/ person and an average reference area of 60 m^2/person (SIA, 2011b).

Benchmarks for residential buildings	Primary Energy non-renewable (MJ/m^2a)		Global warming potential (CO_2 equivalent kg/m^2a)	
	New	**Existing**	**New**	**Existing**
Benchmark for construction	110	60	8,5	5,0
Benchmark for operation	200	250	2,5	5,0
Benchmark for mobility	130	130	5,5	5,5
Target value	440	440	16,5	15,5

In each case, the stipulated building requirements at this stage have both a direct and indirect impact on the life cycle EE and EG of the building.

3.1.1.2. Preliminary design stage (concept/schematic design)

Current research suggests that decisions made in the preliminary design stage usually have the largest impact on the final overall performance of the building (Basbagill et al. 2013; Shi & Yang, 2013; Häkkinen et al. 2015). Common steps during the preliminary design stages are among others to decide on new construction or refurbishment, to select the type of foundations and main structural systems, as well as the construction method and main building materials and services. Research has found that structural building materials contribute significantly to a building's embodied impacts (e.g. Häkkinen et al. 2015). Questions to be investigated at this stage are:

- What type and quantity of main materials does the project really need?
- What is the building form (spatial configuration of structural systems) that maximally reduces the embodied impacts of the project?

Usually, during this stage, the consequences of design decisions on EE and EG can only be considered with the help of existing expertise and reference knowledge (Häkkinen et al. 2015). This means that at this stage one can assess the effect of such principal choices with the help of reference data (without case specific calculations) or the help of specialized tools for early design stages. For example, such a tool is the Swiss SNARC (Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt/ methodology for the evaluation of sustainability in architectural projects in an environmental context) developed to be used for the architectural competition in order to compare and evaluate the ecological impairments of the different designs (SIA, 2004). In this tool, EE is estimated for the production and construction that is based on assumptions used for the construction method, as well as to the components (elements) of building envelope, windows, etc. Thus, the method followed is based on the "building elements". In Germany, LEGOE has also a similar function; specifically it uses a catalogue of building elements containing all necessary life cycle information.

The type of data needed at this stage is usually average data for EE and EG for buildings, building components or construction products, as well as average data for the service life of the different components and the maintenance/or repair cycles.

3.1.1.3. Design development stage (detailed/coordinated design)

By the time this stage is reached, the design team is ready to select specific building components and materials, as well as specific building services for the developed energy system concept (e.g. lighting, HVAC systems, etc). Especially product-level assessments at this point can shed light on the environmental impacts of various product choices. For example, if the designer chose concrete over steel for the structural system and optimized the amount of concrete required during the concept design, this is now the point where the comparison of different types of concrete should be performed. This is also the stage during which the construction strategy is designed and the different scenarios for the post-construction stages of the building are assessed.

Questions to be investigated at this stage are:

- Which products are the best for the specific design program of the project defined during the preliminary design stage? How the selected products influence the EE and EG for maintenance and end-of life stages?
- What are the systems (electrical, mechanical, plumbing, etc) to be included based on the energy efficiency concept defined at this stage? How to minimize at the same time the embodied impacts and the operational impacts?
- How to optimize construction and transportation processes?

Ultimately, designers wishing to select the less impactful materials for their design are dependent upon the availability of data and transparency from manufacturers. During this stage when the design becomes more and more detailed, the average data from either databases or manufacturers can gradually be replaced by product specific data in the assessment of embodied impacts.

3.1.1.4. Preparation for construction (tendering and contracting)

Typically, the tendering phase deals with finding specific materials, construction technologies or treatment methods for certain parts of the building. From the EE and EG viewpoint, this is a delicate issue since economic preferences tend to dominate and because material tendering is often given to competing construction companies. The design team seldom has a strong influence on their choices. The client (as the procurer) has to play an active role here and ensure that EE and EG goals are not jeopardized at this phase. Typically, this can be achieved by determining specific procurement requirements with respect to embodied impacts in the invitation to tenders.

Questions to be investigated at this stage are:

- What to ask for in the invitation to tenders? How exactly can requirements for EE and EG as well as for the service life, ease of maintenance and recyclability of products and systems be integrated into a tender document?

- How to assess the credentials of construction product manufacturers against the requirements for embodied impacts?
- Should the initiative of selecting specific products come more from designers (in different countries there are different traditions and procedures in relation to the initiative of selecting specific products – usually the owner/client has the final call on these types of decisions)?

In the UK, there are already published guidelines on how to set requirements for low-carbon buildings when procuring design, construction and refurbishment of new and existing buildings (WRAP, 2011).

3.1.1.5. Construction stage (including quality control)

At this stage, material-related changes that might alter the EE and EG levels are less likely than changes that are related to construction work. Changes in construction work may require deconstruction of wrongly built parts, replacement of broken components or similar tasks. Therefore, special attention must be paid to the supervision of the building site. Possible losses, surplus orders of materials, mistakes or accidents will inevitably lead to greater embodied impacts than planned (related Annex 57 case study: UK3 – check ST4 report). Here, it is also important the documentation of the actual installed products according to the type, quality and quantity.

Another key factor influencing EE and EG at this stage is the selection of construction processes and the design of the site equipment. To some extent, relevant analyses and studies exist for the estimation of the energy required for different building construction processes (e.g. Sharrard et al. 2007). The energy consumption for the site itself is strongly influenced by the time of the execution (season, time of the day) with consequences for heating and lighting – depending on the location and climate.

Questions to be investigated at this stage are:

- How to influence the energy consumption for construction processes and site facilities/operation considering the choice of technologies and manufacturing processes (e.g. processing on site versus prefabrication)?
- How important is the energy consumption for construction processes and site facilities/operation? Can it be neglected or taken into account in general terms (e.g. as percentage allowance), if necessary?
- How can different types of losses be avoided during the transportation and processing of the different products on the construction site? How high is the percentage of these losses occurring in individual processes (e.g. transport of cement – loose/bulk versus packed)?
- How can a quality assurance prevent building damage and ensure the durability/ longevity of the building?
- How to detect and document the actual installed products (including the collection of delivery notes) in an effective way?

3.1.1.6. Handover and documentation

The Handover of the building and the object documentation are usually regarded as the end result of the planning process and important tasks for the designer. Usually, they are also partly involved in the commissioning of the building and the clearance of defects. At this stage, the production and dissemination of a good and complete building file (as a result of the object documentation) and the formulation and passing on of instructions on how to use/ operate, inspect, maintain and repair the building are of great importance. At this point, typically questions arise such as:

- Can the information on the type and quantity of installed materials included in a building documentation at this stage be used later for exploring opportunities for future recycling/ urban mining (building file/ resource-pass)?
- Should instructions for use/operation, inspection, maintenance and repair be developed and handed over to the users/facility managers?

Over the course of the next stages of the life cycle EE and EG may be indirectly influenced by the quality of maintenance and repair. It may also be an issue of consideration whether the service life of the existing building or existing supporting structure can be extended through an adaptation/conversion. Finally, another decision influencing EE and EG coming in the later stages of the life cycle is how to organize the deconstruction process in such a way that recycling at the end of life is possible (the potential for component recycling is usually exploited before the potential for material recycling).

3.2. Object of assessment

A prerequisite for accurate interpretation and comparability of embodied impacts results is the transparent demonstration and documentation of the completeness of the description of the building (in terms of the included building elements) and its life cycle (in terms of the included life cycle stages and processes). Specific recommendations derived from this discussion are given in section 4.2 of this report.

3.2.1. Functional equivalent

According to EN 15978 (2012) "*The functional equivalent is a representation of the required technical characteristics and functionalities of the building. It is the means by which the characteristics of the building are rationalised into a minimum description of the object of assessment.*" According to the same standard, the functional equivalent of a building (or an assembled system) shall include the following aspects: building type, relevant functional and technical requirements, pattern of use, and required service life. Thus, the concept of a full description of a functional equivalent goes far beyond the specification of a functional unit. This term commonly used in the LCA can be misunderstood as being a simple selection of the reference unit.

However, it is obvious that, as every building has different functionalities and different intrinsic characteristics, a specific and unique functional equivalent can be found for every building. The comparison between these buildings might be feasible according to EN 15978 guidance, if the basis for comparison is clear. In this sense, transparency in the description of the functional equivalent is essential here. The more transparent the description is, the fairer the comparison will be. This is also true for the selection and use of benchmarks.

The detailed and comprehensive description of the object of assessment is a prerequisite for ensuring transparency and comparability.

3.2.2. Description of the building

The spatial boundary specifying the part of the physical building that is included in an assessment may range from single building elements to neighbourhoods. This is referred to as the "object" of an assessment. Different studies use different building description models with different levels of aggregation (from the product level to the building element level) and different elements from the defined building models are included in the embodied impacts calculations. Usually, such building models listing and defining different building elements and products can be found in relevant cost planning related national standards, thus, they differ from country to country (e.g. the New Rules of Measurement (NRM) by RICS in the UK, DIN 276 standard in Germany, etc.) An example of structuring the building information using different levels of aggregation is also included in EN 15978 (2012) – see figure 1-8 as an example for the possible description of the façade of the building.

Different building parts and elements are chosen to be included in different studies depending on the purpose of the assessment and the available data at the point of the time of the assessment. For example, technical equipment installed in the buildings is responsible for large shares of the EEG (up to 46 %). However, the technical equipment is not always included in the assessments (check Annex 57 case studies for more information). One reason could be that if the assessment is performed at the preliminary design stage, such information is still unknown.

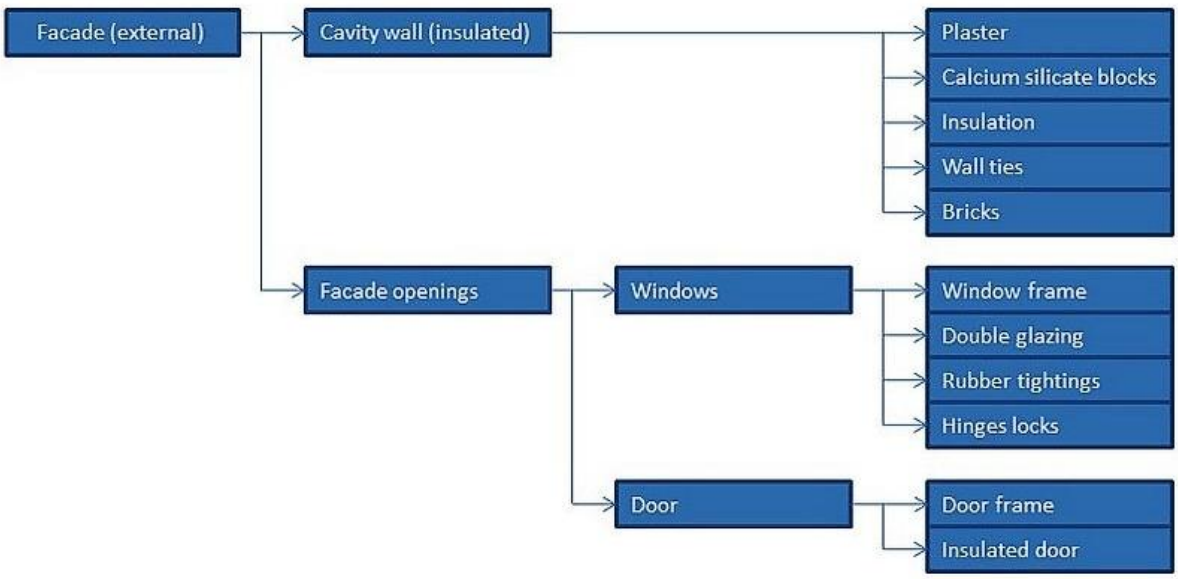


Figure 1-8: Example of a structuring of building information using the different level of aggregation specifically for foundation, frame wall and facade (EN 15978:2011).

Generally, the main variations of included building parts identified in the different studies are:

- only the building shell (e.g. foundations, frame and façade)
- the complete building structure (building shell plus internal walls), excluding building services as well as fittings, fixtures and furniture
- the complete building structure (building shell plus internal walls and building services), excluding fittings, fixtures and furniture
- the complete building structure (whole building)

Clearly, a basis is needed for the declaration of the completeness of the description of the building structure.

The transparent declaration of the building parts, elements, components and products included in an analysis of embodied impacts is an important parameter that influences the comparability between studies. Different variations of included building parts are identified in the different studies based on the available data and the point in time of the assessment. In early design stages simplifications and omissions is a common practice due to lack of information. Section 4.2 of this report presents a comprehensive and transparent way of describing and reporting the system boundaries regarding building parts and elements at the early design stages.

3.2.3. Description of the building's life cycle

As a rule for drawing clear system boundaries, it is important to identify the relevant life cycle stages and included modules/processes in each stage. This means that establishing a model for describing building's life cycle is essential. Currently, studies have shown that there are great uncertainties with regard to the system boundaries. The standards developed within the groups of ISO/TC 59/SC 17 (Sustainability in buildings and civil engineering works) and CEN TC 350 (Sustainability of construction works) provide a modular and standardized concept for the life cycle description.

3.2.3.1. Selection of appropriate life cycle model

There are different ways of describing a building's life cycle. The most usual way to establish an understanding between stakeholders is to use a process (or project) related way of describing the building's life cycle (project management phases, from conception to construction, combined with project life cycle stages) as presented in figure 1-9. Here, each stage is related with a different decision making situation. However, to translate this into a physical model is not an easy task. There is already an established physical model in Europe developed by the CEN TC 350 group in EN 15978:2012 (figure 1-10), and based on the modular setup first developed by international ISO/ TC 59/ SC 17 group in ISO 21931-1:2010 (the setup is alike for construction products and buildings). According to this model a building's life cycle consists of four main stages: product stage (A1-3), construction process stage (A4-5), use stage (B), and end-of life stage (C). There is also an additional and separate information module (module D: benefits and loads beyond the system boundary). Each stage is further divided into several modules. All the modules, apart from those related to “operational energy use” (B6) and “operational water use” (B7), could be included in an embodied impacts analysis. However, this model uses a linear way to describe the life cycle of the building, not showing clearly that there is also production, construction and end of life disposal or recycling of replacement products and components during the use stage (although it is described in the standards).

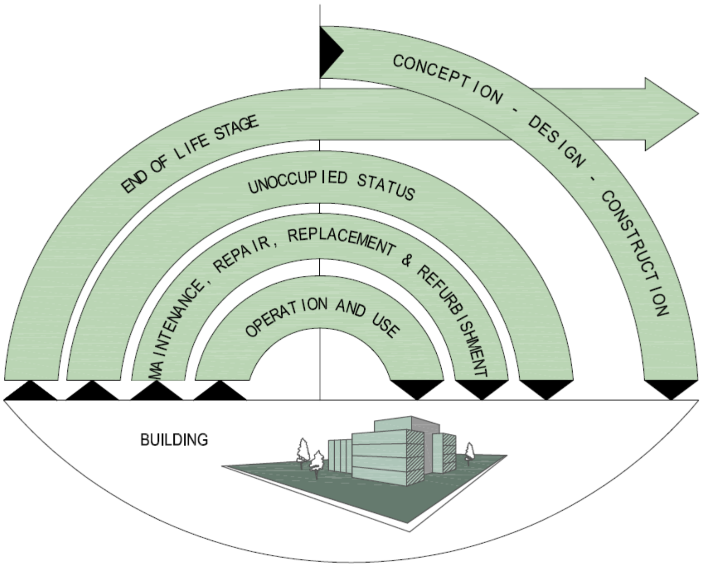


Figure 1-9: Model for describing a buildings’ life cycle (adapted from the German Facility Management Association GEFMA (GEFMA, 2004).

	BUILDING LIFE CYCLE																ADDITIONAL INFORMATION
	PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				POTENTIAL BENEFITS & LOADS
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
	Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use, installed products	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water use	Deconstruction	Transport	Waste processing	Disposal	Recovery – Reuse – Recycling - potential
Embodied	✓	✓	✓	✓	✓	✓*	✓	✓	✓	✓			✓	✓	✓	✓	(✓)
Operational											✓	✓					(✓)

* is relevant for materials or products emitting or binding GHGs in the use stage

Figure 1-10: Building life cycle stages according to EN 15978:2011. The life cycle stages related to embodied impacts are indicated separately than the ones related operation impacts.

Besides the type and extent of the inclusion of the life cycle stages, also other aspects can influence the EE and EG assessment result. These are, among others,

* Assumptions for the useful service life and the reference study period
* Assumptions about the type and intensity of the actual use

* Scenarios for maintenance
* Scenarios for deconstruction and disposal

3.2.3.2. System boundary variations

The embodied energy (EE) and embodied GHG emissions (EG) associated with a building can be categorised into various system boundaries based on the parts of the full life cycle included in the assessment. Interestingly, there are some boundary variations commonly used in the industry (Hammond & Jones, 2008b; Frey 2008; Menzies, 2011; RICS, 2012; European Union, 2013). The common system boundaries for buildings and building components are described below:

''Cradle-to-Gate'' – this boundary includes only the production stage of the construction products integrated into the building. Processes taken into account are the extraction of raw materials, transport of these materials to the manufacturing site and the manufacturing process of the construction products itself. Thus, in the case of a building the impacts of this stage are accounted for as the sum total of the "cradle to gate" impacts of its individual components. This is the most commonly used system boundary in studies and the only mandatory to be presented in EPDs according to ISO 21930 and EN 15804.

"Cradle-to-Site" – The cradle to site system boundary covers, in addition to the cradle to gate boundary, transportation of finished product to the construction site using real or average transport distances. There are different definitions of this type of system boundary, as in some cases also the construction and assembly processes on-site are included here (Frey, 2008). This already represents a transition to the next type of system boundaries (cradle to end of construction). It depends on the individual interpretation of the word "site" each time.

"Cradle-to-Handover" – The cradle to handover system boundary includes all the processes that happen in cradle to site boundary plus the processes of construction and assembly of the building on site. This can also be called **"Cradle to End of Construction"**.

"Cradle-to-End-of-Use" – This boundary includes the cradle to handover boundary plus the processes of maintenance, repair, replacement and refurbishment, which constitute the recurrent energy and emissions. This boundary marks the end of first use of the building. This system boundary is a suggestion of the authors in order to cover the case of a description of the life cycle of the building, where the phase of decommissioning and disposal are not included. This is partially uncovered by the literature.

"Cradle-to-Grave" – The cradle to grave system boundary provides a whole life cycle perspective, including the "cradle to end of use" boundary plus the end of life phase with processes such as building deconstruction or demolition, waste processing and disposal (grave).

"Cradle-to-Grave, including net benefits and impacts beyond the system boundary" – The Cradle to Grave including net benefits and impacts beyond the system boundary includes the cradle to grave impacts and the separate reporting of the loads and benefits beyond the system boundary. These loads and benefits are related to recycling, reusing or combustion of construction waste after the end of life stage of the building, as well as the effects of carbon sequestration.

A schematic overview of the various existing system boundary types using as a basis the modular building life cycle model developed by the CEN TC 350 group (according to EN 15978) is given in Figure 1-11.

However, within each life cycle module several diverse building processes exist that can be included in an EE and EG analysis. Standards give a more detailed description of what processes should be included in each module.

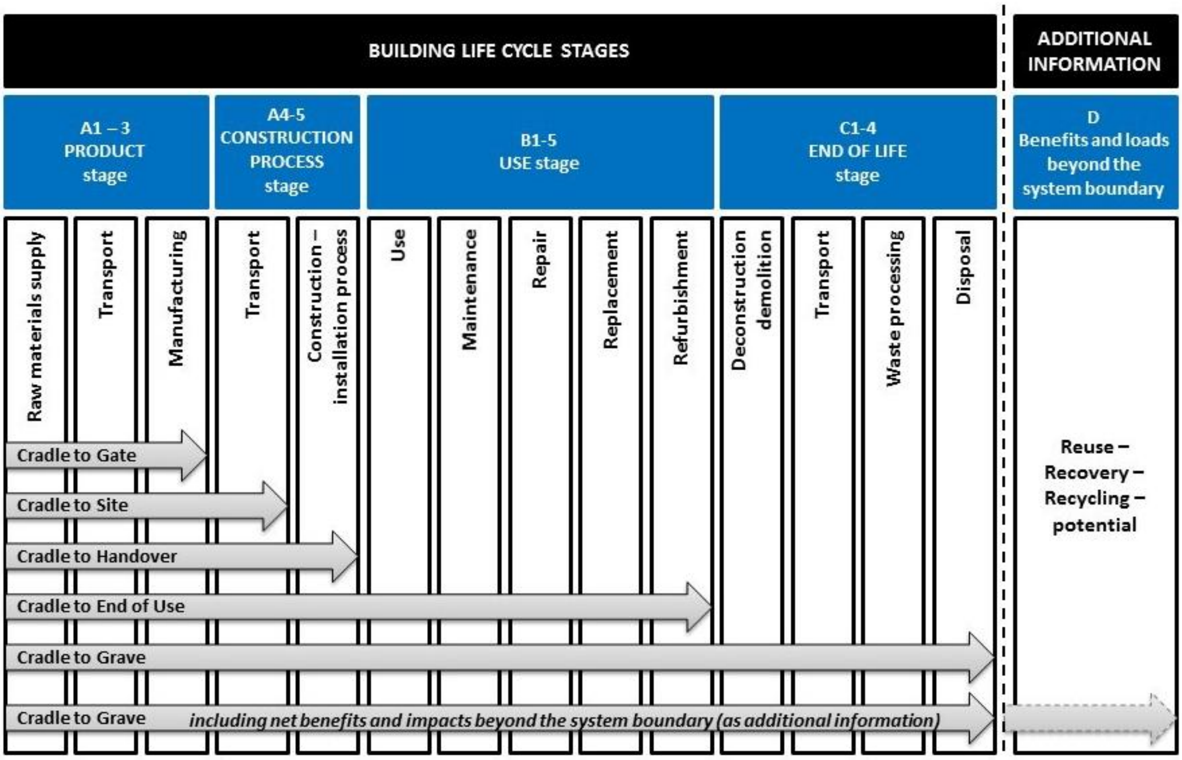


Figure 1-11: Overview of the various existing system boundary types using the respective modules of building life cycle model developed by the group CEN TC 350 (EN 15978:2011). (Balouktsi & Lützkendorf, 2016)

There is already a well-established modular life cycle model from ISO 21931-1:2010 or EN 15978:2011 (follows more or less the same concept, figure 1-10) describing the different system boundaries in a consistent and widely accepted way. However, different variations of system boundaries can be found in different studies, ranging from "cradle to gate" to "cradle to grave". Besides the selection of system boundaries, also the estimated service life and the reference study period are important parameters that can significantly influence the results. These parameters are usually a source of uncertainty.

3.3. Concepts and considerations for the indicators dealing with embodied energy

The amount of embodied energy (EE) in the life cycle of a building has become an important criterion in the environmental performance assessment. Appropriate indicators are needed for its quantification and assessment. These should be easy to understand, transparent and easy to interpret, but also these must be able to be determined within a reasonable amount of time and cost. Here, it is a matter of question whether a single indicator is sufficient for expressing the use of resources (in this case of energy) or the use of more indicators or an indicator system is needed. In addition, the division of labor between EE and EG related indicators will be clarified. Specific recommendations derived from this discussion are given in section 4.3 of this report.

3.3.1. Existing definitions

The development of indicators for the quantification and assessment of EE is closely linked to the respective definition. It can be said that the energy consumed in life cycle stages of a building other than the operation (space conditioning, water heating, lighting, operating building appliances and other similar operational activities) is the so-called "embodied energy" of the building (Dixit et al., 2013). These life cycle stages can be the production of building materials and components (raw material extraction, transport, and manufacture), the onsite construction (assembly and installation), the post construction stages such as renovation and refurbishment and the final stages of the building's life cycle such as disassembly, demolition and disposal.

However, defining the term "embodied energy" is not so simple. Different authors give different interpretations and definitions, representing differences of opinion about the system boundaries to be adopted and type of energy to be included in embodied energy evaluation. Some indicative examples of existing definitions are given in table 1-7. Sometimes "embodied energy" is referred to in literature as "embedded energy" (European Commission, 2012) or "grey energy" (SIA, 2010) among others.

Table 1-7. Examples of existing definitions of "embodied energy" in the literature.

Source	**Definition**	**System boundary**
Sustainable Homes, 1999	"The *embodied energy* of a building is therefore the total energy required to construct it - that is to win the raw materials, process and manufacture them as necessary, transport them to site and put them together".	Cradle to End of Construction
Crowther, 1999	"The *embodied energy* of the building can be defined as the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy, that is required to manufacture the materials and components of the buildings."	Cradle to End of Construction
Uptona et.al., 2008	"*The embodied energy*… includes those associated with obtaining raw materials, manufacturing building materials, transporting materials to construction sites, and building the structures". In addition, Embodied energy is "computed as total embodied energy and as non-renewable embodied energy (total minus hydro and biomass)"	Cradle to End of Construction

Source	Definition	System boundary
SIA 2032, 2010	*Grey energy* is **“**the total amount of nonrenewable primary energy required for all upstream processes from the raw materials extraction to the production, construction and disposal including the necessary transport. This is also indicated as cumulative non-renewable energy consumption.” (translated)	Cradle to Grave
European Commission, 2012	*Embedded energy* is defined as the “energy use linked to the manufacturing of construction products”.	Cradle to Gate

When dealing with a definition of “embodied energy” concept, and therefore the development of an appropriate indicator for its quantification, there are specific important parameters that are usually open to misinterpretations and unclearly defined across studies. An analysis of the following parameters is presented in detail in the following section (3.3.2):

- Type of energy: Primary or delivered? Renewable or non-renewable?
- Inclusion of the feedstock energy of materials
- The aggregation of different forms of primary energy resources

3.3.2. Questions to consider

3.3.2.1. Type of energy: Primary or delivered? Renewable or non-renewable?

Often it is debatable whether “embodied energy” should be expressed in delivered (final) or primary energy, as well as whether EE comes from non-renewable or renewable resources. It would be also helpful if there was greater clarity about whether the energy should be described from the side of the demand or from the side of the consumption of energy resources to cover this demand (here renewable sources are not included). The differences between these individual perspectives and viewpoints are embedded in the different definitions.

According to Fay et al. (2000) primary energy can be defined as “*the energy required from nature (for example, coal) embodied in the energy consumed by the purchaser (for example, electricity)*” and delivered energy as “*the energy used by the consumer*.” In other words, delivered energy is measured at the final use level, while primary energy is measured at the natural resource level, including losses from the processes of extraction, transformation and distribution of these resources, and so it expresses the real impact on the energy resources (like resource depletion) caused by a building (Sartori & Hestnes, 2007).

Considering the rate of exploitation of fossil and nuclear fuels, the known reserves, and the growth of emerging countries and population in general, there is an obvious threat of depletion of non-renewable energy resources, and this will happen in the relatively short term, that is several dozens of years (except for coal). It is important to consider primary instead of delivered energy consumption. Thus, from a resource depletion point of view, it is necessary to evaluate the use/consumption of primary energy (Nibel et al., 2011).

In addition, from a methodological point of view when energy data is based upon delivered energy consumed, the results could prove to be misleading and inconsistent. For example, while the same hypothetical building placed in different countries but with similar climates is likely to have similar figures of delivered energy, however, in terms of primary energy, the variations can be significant because of the different energy carriers per country and/or because of the different ways to produce electricity (Sartori & Hestnes, 2007).

Thus, in most of the cases the key indicator for assessing “embodied energy” is the non-renewable primary energy consumption. However, what about renewable energy needs? Should these also be accounted for in the “embodied energy” calculation? Some assessment systems and standards (e.g. EN 15978, Swiss 2000-Watt-Society concept) consider this indicator. There is no reason to waste this type of energy, because renewable does not mean cost-free nor impact free (e.g. use of land surface for windmills) (Nibel et al., 2011).

Currently, this issue is handled with different approaches. An embodied energy indicator may express

- Only fossil primary energy (the inclusion of feedstock energy here shall be also clarified, as explained later in section 3.3.2.2)
- Only non-renewable primary energy (fossil + nuclear)
- Total primary energy (non-renewable + renewable)

At the moment, in most of the cases the key indicator for assessing “embodied energy” is the non-renewable primary energy consumption. However, some assessment systems and standards either consider also the renewable part of energy separately or in an indicator expressing the total primary embodied energy. Based on the analysis here, section 4.3 of this report presents a detailed description of the character and calculation of the recommended indicators.

3.3.2.2. Inclusion of feedstock energy of materials

Often, some primary energy resources can serve two different purposes; their consumption can be both energy-related and non-energy-related (feedstock energy). In the first case, the primary energy resources are consumed as a fuel (e.g. fuel oil or gas is burnt and as a consequence CO_2 is released to the atmosphere). This type of energy is not a physical part of the product, but is associated with it; therefore, it is embodied in a “metaphorical” sense as a way to describe and allocate the impacts caused by the life cycle stages of a product to the product. On the other hand, feedstock energy is the primary energy (resources) which is not consumed as a fuel, but used as a raw material. This applies to specific products embodying fossil materials without using them as a fuel, e.g. petrochemicals may be used as feedstock to make plastics and rubber, or biomass may be used as feedstock to make timber products. This energy (calorific value) is not released but retained (contained in the product) throughout the product lifecycle, and therefore, is available for use as fuel energy outside the system boundary. Thus, the energy is not released but retained and therefore feedstock energy may often be (partially) recovered at the end of product lifetime (e.g. through incineration) (Jones, 2011). This type of energy is a physical part of the product, and thus, is embodied in a “real” sense.

Feedstock energy consideration is one of the least stated parameters by most of the existing studies (Dixit et al., 2010). Commonly feedstock energy is considered in the calculation of the total embodied energy of a material, only if represents a permanent loss of valuable resources, such as fossil fuel use, e.g. fossil fuels utilized as feedstock for the petrochemicals used in the manufacturing of plastics (Hammond & Jones, 2010). On the other hand, some argue that when fossil fuel is acquired from the ground but not burnt, it remains as an energy resource that might be burnt later. The only significant difference is that it resides on the surface of the planet, rather than beneath it (Alcorn, 2003). However, it is important to take into account during the production stage of the building any extraction and conversion of the fossil fuels into a useable product considering the fact that the underlying goal of such an analysis is the protection of non-renewable energy resources. A similar goal can be defined in the case of bio-based renewable resources. The aim here is to avoid the overexploitation of their regeneration ability, as well as to base their cultivation and production on the principles of sustainable production and sourcing. In the scientific discussion, resistance has grown against defining wood as a renewable energy source. However, still in most of the cases wood is considered a renewable energy source, but only if the volume used does not exceed the volume regrown.

In any case, feedstock energy is an important variable that causes variations in "embodied energy" results and its inclusion or exclusion should be clearly stated and reported. The ISO/TC 59/SC 17 SC standards (similar approach in CEN TC 350 standards) do not use the term "feedstock energy", but do include different indicators (among others) to describe these two cases (energy and non-energy related) of resource use. Examples of such indicators are:

- Use of non-renewable primary energy excluding energy resource used as raw material
- Use of non-renewable primary energy resources used as raw material
- Use of renewable primary energy excluding energy resource used as raw material
- Use of renewable primary energy resources used as raw material

Non-renewable feedstock energy, considering that it is counted as it represents a permanent loss of fossil energy resources, is also part of the environmental impact related indicator "abiotic resource depletion potential for fossil fuels (ADP_fossil)" within the CEN TC 350 group of standards.

The approach of accounting for "resource use" (resource depletion) might be suitable to overcome the contradictions described above and combine in an indicator or a system of indicators both the energetic and material use of resources (separately for non-renewable and renewable). This can be considered as a more radical approach, which has not found yet the required consensus. Here, energy (in MJ) is only used as an intermediate size/value to determine the use of energy resources.

In addition, since any feedstock energy from a building product may result in an energy benefit through its recovery, this is usually identified and reported separately in Module D as additional information. However, care must be taken to ensure that there is no double counting here.

Feedstock energy (both renewable and non-renewable) in an important parameter in an embodied energy analysis. Usually, it is reported separately from the overall embodied energy result. A detailed description of how to do this is presented in section 4.3 of this report.

3.3.2.3. The aggregation of different forms of primary energy resources

The calculation of primary energy can be done in mainly two ways. Either process- information about the amounts of primary energy resources extracted from nature is used or energy values are attached to these primary energy resources. Or the amounts of final energy consumed are multiplied with national or specific primary energy factors.

The first approach can further be subdivided into an energy harvestable and an energy harvested approach (see Frischknecht et al. 2015). The two concepts differ by the conversion efficiency of the energy collecting facility. An overview of the different methodologies in different countries is given in Appendix 1.B.

Frischknecht et al. 2015 compares five different approaches based on the cumulative energy demand of a newly constructed building of the city of Zürich covering the whole life cycle, including manufacturing and construction, replacement and use phase, and end of life – see figure 1-12.

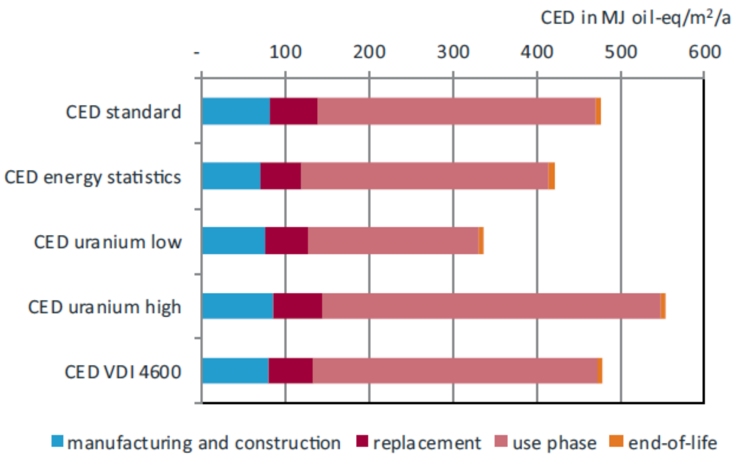


Figure 1-12: Cumulative energy demand of the life cycle of the building Rautistrasse in Zürich, differentiating between manufacturing and construction, replacement, use and end of life of the building (Frischknecht et al. 2015).

The results show that the type of the selected approach for aggregating the different forms of primary energy resources has a great influence on the CED (Cumulative Energy Demand) result – however, for EE these differences are proved less significant.

3.4. Concepts and Considerations of the indicators dealing with "embodied GHG emissions"

The preservation of the Earth's ecosystem (being the natural foundation of life) is a central task in the design of buildings. Thus, it is necessary to determine, assess and influence in a targeted manner the effects on the global environment. It is useful to consider this as a criterion of environmental performance and to develop appropriate indicators for its quantification. In the past, these effects were mainly assessed indirectly through the assessment of energy consumption, but nowadays it has become increasingly important – even in connection with the results from COP 21 in Paris – to measure in a direct way the contribution of buildings to the greenhouse effect. Currently, there are many ongoing initiatives around the subject of carbon footprint. Section 4.4 of this report provides specific recommendations about the use of appropriate indicators for the quantification of embodied GHG emissions (EG) derived from this discussion.

3.4.1. Existing definitions

Embodied GHG emissions (EG) represent the GHG emissions associated with the energy consumption for the production, construction, maintenance, repair, replacement, refurbishment and EoL of the building (embodied energy consumption) and also sometimes, the GHG emissions arising as a result of specific chemical processes as part of the manufacturing process of specific construction materials. However, defining EG is not so simple. Different authors give different interpretations and definitions, representing differences of opinion about the system boundaries to be adopted and type of emissions to be included in the evaluation. Some indicative examples of existing definitions are given in table 1-7. Sometimes "embodied GHG emissions" is referred to in literature as "embodied carbon" (RICS, 2012; Anderson and Thornback, 2012), or "grey GHG emissions" (SIA, 2010) among others.

Table 1-7. Examples of existing definitions of "embodied GHG emissions" in the literature

Source	Definition	System boundary
SIA 2032, 2010	"*Grey GHG emissions* is the cumulative quantity of greenhouse gases (CO_2, methane, nitric oxide, and other global warming gases), which are produced during the all upstream processes from the raw materials extraction to the production, construction and disposal including the necessary transport. This is expressed as CO_2 equivalent that has the same greenhouse effect as the sum of GHG emissions."	Cradle to Grave
Knight and Addis, 2011	*Embodied carbon dioxide* "is a measure of the carbon dioxide emissions arising from the energy used to extract raw materials, manufacture components and assemble them into a building – that is, from cradle to site."	Cradle to Site
Monahan and Powell, 2011	*Embodied carbon* is "the CO2 emissions produced during the extraction of resources, transportation, manufacture, assembly, disassembly and end of life disposal of a product. In construction the majority of CO2 is produced from the burning of fossil fuels. Significant amounts of CO2 are also released through chemical conversion processes during the manufacture of cement. Embodied carbon is given as kg or tonnes of CO2."	Cradle to Grave
Anderson and Thornback, 2012	"*Embodied carbon* is the Carbon Dioxide (CO2) or greenhouse gas (GHG) emissions associated with the manufacture and use of a product or service. For construction products this means the CO2 or GHG emission associated with extraction, manufacturing, transporting, installing, maintaining and disposing of construction materials and products."	Cradle to Grave
RICS, 2012	*Embodied carbon* is the "carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products. Embodied carbon can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO2e per kilogram of product or material."	Cradle to Gate[8] Cradle to Site Cradle to end of construction Cradle to grave Cradle to cradle

[8] Here it should be noted that in life cycle of a building there is not only one "gate". Thus, in reality this boundary expresses the use of cradle to gate LCI data for different building products.

When dealing with a definition of “embodied CO_2 emissions” concept there are important parameters that are usually open to misinterpretations and unclearly defined across studies. These are among others:

- types of GHG emissions included in the calculation
- the characterization factors for the conversion of greenhouse gases in CO2 equivalents
- the different sources of GHG emissions
- carbon sequestration or storage in materials

3.4.2. Questions to consider

3.4.2.1. Types of GHG emissions included in the calculation

In literature, the term “carbon” contained in the concepts of “embodied carbon”, “grey carbon”, “carbon footprint”, and other related concepts, is often used as a catch-all term and can mean:

- carbon dioxide (CO_2) alone;
- the six main (groups of) gases identified in the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6);
- the numerous GHGs specified by the fifth IPCC report (2013);
- the numerous GHGs specified by the fifth IPCC report (2013) including also the fluorocarbon (F-gases) regulated under the Montreal Protocol.

GHG emissions are generally reported, using the global warming potentials of the individual GHG gases expressed in units of kg carbon dioxide equivalent (kg CO_2e), taking account of the different impact of GHGs on global warming. GWP is a relative measure of the amount of CO_2 that would need to be released to have the same effect on radiative forcing as a release of 1 kg of the GHG over a particular period (Anderson & Thornback, 2012). For example, methane has a global warming potential of 28 according to the latest IPCC report AR5 (2013) – this means that 1 kg of methane causes the same radiative forcing like 28 kg of carbon dioxide and thus 1 kg of methane would count as 28 kg of CO2 equivalent.

The most common time period, also indicated in different standards (e.g. ISO/TS 14067:2013, CEN TC 350 standards, Greenhouse Gas Protocol and others), over which GWP is measured is 100 years (GWP100). However, other time horizons i.e. 20 or 500 years are also used. As molecules have different lifetimes in the atmosphere, the GWP20 or GWP500 of a gas is different to that of GWP100, with the exception of the reference gas CO_2 which always has a GWP of 1 (Anderson & Thornback, 2012).

3.4.2.2. Sources of GHG emissions

In general, the majority of embodied GHG emissions associated with construction products arise directly from the use of energy – for example from the combustion of fossil fuels in power stations, boilers, furnaces, kilns and engines (Anderson and Thornback, 2012). These are the **fuel-related GHG emissions**, which are the most significant. However, these do not give the whole picture. There are also the **non-fuel related CO_2 emissions** from:

a) the manufacturing processes (process emissions) as a result of specific chemical effects (e.g. CO_2 is emitted as a chemical reaction in cement manufacture)

b) construction materials during their use in the building's operation or the leakage of the F-gases (halocarbons and SF_6), also called "refrigerants", during the use of refrigeration and air conditioning appliances (also known as "hidden embodied GHG emissions").

a) Process emissions

Process emissions account for roughly half of sector CO_2 emissions in the iron and steel and the cement sectors of many countries (UNFCCC, 2011). For example, in cement production the process related emissions are due to calcination, whereby limestone releases CO_2 as it is heated in the kiln and transformed into clinker, the main component of cement. These make up usually 50% of total production emissions. There is an important technological difference between omitting process and combustion emissions. While combustion based emissions can be reduced by increasing energy efficiency or fuel switch, mitigation of process emissions can only be achieved by switching to a low emission production process, or by reducing activity. Thus, reduction of process-based emissions requires a switch in production technology, often not readily available at reasonable costs.

b) Embodied GHG emissions caused during the use phase due to the use of specific insulation materials and refrigerators

There is the potential for some materials and products to emit Fluorocarbon gases (F-gases) during their use in the building's operation. F-gases such as HCs, HFCs, HCFCs, etc. can be used as blowing agents in insulation materials for buildings and as refrigerants in cooling systems. These gases are released into atmosphere from the insulation material and leak from the cooling systems over the building life, and have a significant influence in specific areas of the world. At present, implementation efforts for zero energy buildings (ZEB) are promoted throughout the world, and the further the implementation efforts extend, the greater the influence of F-gases becomes on environmental loads due to buildings during their life cycle.

In the case of F-gases due to insulation materials, particularly extruded Polystyrene (XPS) and Spray Polyurethane Foam (SPF) have a high GWP potential, in case where HFCs are used as blowing agents in their manufacturing. 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). However, in some developing countries, the use of HCFCs has increased (UNEP, 2014). 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 analysis for building 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.

In the case of F-gases used as refrigerants, these are released into the atmosphere due to leaks such as from piping in operation and improper recovery at the time of disposal. According to UNEP's (2014) latest report on the issue, the current trends in the use of refrigerants are that in developed countries, R410A and R-407C are mainly used for air-conditioning and R404A for refrigeration. In developing countries, R22 is mainly used. According to the latest IPCC report (2014), these emissions are projected to grow in the coming decades, mostly due to increased demand for cooling and because they are the primary substitutes for ozone-depleting substances. However, in Germany, almost all new refrigerators use natural refrigerants (isobutene, HC-600a, and propane, HC-29), which have great potential to reduce emissions during the operation and servicing of HFC-containing equipment (IPCC, 2014).

Hence, EG of a building is largely affected by fluorocarbon gas. It is, therefore, necessary in planning a building to fully examine the specifications for fluorocarbon gas since life cycle CO_2eq greatly depends upon whether or not such specifications are taken into account. However, their use in insulation materials saves heating and cooling related CO2 emissions and thus their use in these materials still typically has a net benefit to GHG emissions, but a lifecycle assessment is required to determine the net effect on a case-by-case basis (IPCC, 2014). It is also necessary to examine how to recover fluorocarbon gas at the time of abandonment in the future since the amount of refrigerants for air conditioner leaking at the time of equipment abandonment is large.

So far, there is no clear guidance as to whether these emissions should be considered embodied or operational. The way these gasses are considered differs depending on the stakeholder group. More detailed information on the scale of the impact in terms of GWP due to the use of XPS and SPF insulation materials and leakage of refrigerants from HVAC systems, as well as calculation rules and examples, are given in ST3 report.

EG has become an important and independent factor in the description and assessment of the environmental performance of buildings. This has resulted in a strong demand for suitable indicators. Currently, in the application and interpretation of the different indicators ambiguities and uncertainties still exist with regard to the type and scope of the greenhouse gases considered, whether or not the process-related emissions are taken into account, or how to deal with the F-gases emitted from the insulation and cooling systems during the use stage among others. In this sense, an urgent need for clear definitions, system boundaries and possibilities of interpretation exists.

3.4.2.3. Carbon sequestration or storage

Accounting for the carbon absorbed during the growth of biomass can make for an interesting challenge in interpreting the embodied impacts results of bio based products, such as timber products. In simple words, biomass based materials like wood absorb the carbon during growth and lock it away safely in the wood product as installed in the building until the building is demolished (or the product is replaced) and the biomass incinerated. Thus, here the carbon is a physical part of the product, and thus, is embodied in a “real” sense. This type of carbon is usually described as “sequestered” or “stored”. It differs from the term “embodied GHG emissions”, used in practice as a convention to express the impacts of a product (a material, a building component or the whole building), which are emissions emitted in the manufacturing of both the product and the materials it uses and not the ones contained in the body of a product.

Stored carbon is one of the main arguments for using natural materials that, on the other hand, could falsely give comfort to those supplying or purchasing timber from unsustainable sources (Selincourt, 2012b). It is a highly debatable issue how to treat biogenic carbon stored in wood-based products and involves complications. Over the full life cycle of a wood product, this can only emit as much carbon as it originally absorbed from the atmosphere, therefore, it can be considered "carbon neutral". However, others consider sequestered carbon as negative emissions of CO_2 simply because it is a benefit to lock up temporarily an amount of carbon dioxide in products until their disposal.

There is not one common approach. Some researchers exclude the effects of carbon storage of timber products, while others include these effects. Therefore, this part of methodology gives rise to large variations in the final results of carbon footprint studies (Jones, 2011). There are justifications behind both of these different approaches.

According to Jones, 2011 there is a particularly important reason for excluding carbon storage especially from the "cradle to gate" studies. Carbon storage should be integrated into a study only when appropriate end-of-life assumptions of the product under study are made. One of the reasons for this is because a quantity of the timber is lost during different processes, and therefore this part has no carbon storage benefit. For example, when a building is constructed timber is cut to shape and some of it is lost to waste streams. The carbon stored in this timber is released back into the atmosphere and this depends directly on the selected disposal route. Therefore, the argument in favor of accounting for carbon storage is valid only when the assessment is conducted on a "cradle to grave" basis.

Current LCA methodologies and product rating systems deal with "sequestered" CO_2 emissions in different ways, though none of the formal systems simply subtract this part from the overall footprint (Selincourt, 2012b). A more direct approach might simply keep the information on these elements separate from overall assessment. For example, according to ISO 14067:2013 "*If any carbon storage in products is calculated, it shall be documented separately in the CFP study report but not included in the CFP*". Another interesting statement found in ISO 14067:2013 is that "*Carbon storage in products may also be provided for information when performing cradle-to-gate studies when this information is relevant for the remaining value chain*".

In Europe, already special rules for this case apply. According to EN 16485:2014 (rules for EPDs for wooden products), in case the biomass used can be assumed to originate from sustainable forest sources, biogenic carbon emissions can be regarded as zero based on the idea of biogenic carbon neutrality. In this sense, carbon storage in wood products is balanced during natural decay or incineration of the products. However, it can also be included in the assessment result as additional environmental information (EN16449:2014).

Alongside the treatment of carbon that is taken from the atmosphere by biomass as it grows, questions related to the treatment of biomass in disposal arise. This is still the subject of ongoing research; some studies suggest that the (biggest part of) biomass will stay intact, whilst others suggest that a significant proportion will decay to produce a mix of CO2 and methane (which has 25 times the global warming potential of CO2), with varying degrees of collection for flaring or energy recovery (Anderson & Thornback, 2012).

Dealing with stored CO_2 in bio-based products is an important issue. Solutions must be developed to address it appropriately. However, according to the prior discussion, it is clear that a separate consideration of this effect from the overall assessment results is necessary.

3.5. Other Practical Considerations

Below selected issues are presented and discussed. Specific questions are investigated regarding how to handle in an assessment of EE and EG the

- recycling potential at the end of life,
- materials with high thermal mass such as concrete,
- decision on refurbishment vs replacement of existing buildings,
- prediction of data for future energy supply and production processes
- imported products, and finally
- background data and information

Answering these questions has a great influence on the calculation and interpretation of EE and EC results. Specific recommendations derived from this discussion are given in section 4.5 of this report.

3.5.1. Recycling potential at the end of life

During the full life cycle of a building or product, materials may be available for re-use (crushed concrete as a roadway bed) or recycling (scrap steel used in rebar manufacturing). In the former, the material has lower performance characteristics (down-cycled). In the later, (recycled steel can be used to create as strong or stronger structural steel shapes (up-cycled). It is often debatable whether these processes should be included in the building's life cycle, as these are dependent on the next use. However, steel recycling is usually identified as the most common practice for this kind of processes that make a considerable difference to the results. The manufacturing processes of steel from virgin materials are notably energy intensive processes, and after the end of life of the buildings most of the scrap steel is recovered and used to make new products. Thus, exclusion of this information may lead to unfair comparisons (RICS, 2014).

There are various methodologies that can be used to assess the benefits of recycling (these are described in more detail in ST3 report). Varying how recycling is modelled in the databases can significantly change the LCA results (ST3 report). Roughly two distinctly different approaches are currently used in daily life cycle assessment (LCA) practice (Frischknecht, 2010):

- Recycled content approach (also known as the cutoff approach) and
- End of life recycling approach (also known as the avoided burden approach).

The benefit of the "recycled content approach" focuses on the share of recycled material (metal) in the manufacture of the product to be used for the building (commonly used in cradle to gate databases), while the benefit of the end of life recycling approach focuses on how much material is recycled at the end of life (this is the one recommended by the World Steel Association). Specifically, the share of metal recycled after the use phase of a product replaces the need for the production of primary metal. In short, post-consumer recycling avoids primary metal production, and the environmental impacts of the avoided primary metal production are credited to the product that sends the metal to recycling (Frischknecht, 2010). In some cases, there is also the 50:50 method, which is the one followed by the product environmental footprint recommendation of the European Commission (Manfredi et al., 2012), taking half the benefit of recycled content (during production) and half the benefit of recyclability (end of life).

In the life cycle assessment of the building, designers cannot take both of these benefits into account. Double counting is a concern here; if the savings for recycling the metal are claimed, then the purchaser of the recycled steel cannot also assume the same benefits. At the same time, data produced on these different methodologies is not comparable and thus interpreting the results requires an understanding of the recycling allocation methods used.

Another approach is the one followed by the recent EN 15804:2012 standard (developed by CEN TC 350), which is open to and supports both approaches, but at the same time it does not allow including credits in the final results, rather it recommends the benefits to be reported separately using the voluntary Module D – "Benefits and loads beyond the system boundary". Specifically, according to EN 15804:2012 "*the informative module D declares potential loads and benefits of secondary material, secondary fuel or recovered energy leaving the product system. Module D recognises the "design for reuse, recycling and recovery" concept for buildings by indicating the potential benefits of avoided future use of primary materials and fuels while taking into account the loads associated with the recycling and recovery processes beyond the system boundary"*. Thus, module D aims at transparently reporting net benefits resulting from reusable products, recyclable materials and/or useful energy carriers leaving the product system under study as secondary materials or fuels and in this sense is essential for encouraging design for reuse, recycling and recovery of building materials, as well as better end of life treatment strategies.

In the case of energy recovery option, waste materials for energy recovery are usually considered only those with energy recovery efficiency rate higher than 60% (this depends on existing legislations). Timber combustion is usually identified as the most common practices for this kind of processes that make a considerable difference to the results.

Although the benefits of recycling may seem obvious, their accounting over the building life cycle is complex. Various methodologies are used around the world to assess these benefits, making data produced on these methodologies incomparable. The easiest way – following the current state of the discussion and standardization (e.g. EN 15804:2012) – is, no matter what the approach followed is, to report these benefits separately as additional information.

3.5.2. High thermal mass materials

Thermal mass is a property that enables building materials to absorb, store and later release significant amounts of radiant heat. Concrete can absorb thermal energy slowly and hold it for much longer periods than less massive materials do. Materials commonly used in construction to provide thermal mass have high-embodied energy (EE) and high-embodied carbon GHG emissions (EG). Thus, adding large thermal mass materials in the design may increase the impacts of production stage, while lowering at the same time the impacts of operational stage due to reduced cooling/heating demand. Studies have shown that concrete materials may reduce heating and cooling energy demand more than 20% due to its high thermal mass (Van Geem and Marceau, 2008), or that the annual operational energy consumption in concrete-construction buildings is 12% less than in steel-construction buildings if similar occupant behaviour exists (Su et al. 2008). For this reason, the impacts of design decisions should be considered on embodied and operational carbon together rather than separately (RICS, 2014).

3.5.3. Refurbishment vs replacement of existing buildings

Every existing building “contains” or represents embodied energy (and associated embodied GHG emissions) related to its erection and maintenance, as well as the extraction, manufacture and transportation of the construction materials. Through the refurbishment, modernization or reconstruction of existing buildings their useful life can be extended and so their embodied energy can be utilised for a longer period. This can contribute to the reduction of energy and material flows.

However, the decision to refurbish an existing building instead of replacing it, and the level of intervention required to improve its performance, requires many factors to be taken into account (Clark, 2013):

- Does the existing building (or do parts of the building) have heritage or cultural value that makes its preservation important?
- Is the existing structure (or parts of the structure) suitable for the intended use or can it be practically adapted (altered/repaired) for this use?
- What is the estimated design life before and after refurbishment for each component (structure, facade and services)? This will determine if they should be kept as found, upgraded or replaced.
- Will refurbishing the building save time and cost compared to new build?
- Can the existing building be made energy efficient? What is the energy payback period for the additional products installed in the building
- Can the existing building provide the required quality of indoor environment (comfort, daylight, acoustics and air quality)?
- How will the refurbished building respond to the potential impacts of future climate change – increased wind loads and more severe weather events?

If the building is to be demolished, then it is a matter of question whether its discrete component parts or building materials can be reused or recycled. In the case of recycling, the energy required to manufacture new products to be installed in a new building is reduced. Although demolition may seem a relatively minor issue for practitioners concerned mainly with residential projects, in the case of office buildings this is a much more important issue, as these are often replaced after only 20 or 30 years of service life. It should be further noted that the replacement of building components does not take place only at the end of life but also during the use stage.

It is therefore essential for designers to pay attention to an effective design for deconstruction and recycling. These issues are further analysed in ST4 report.

An example of how embodied energy may be taken into account, when deciding whether to refurbish or replace is illustrated in figure 1-13. A comparison of both variants, however, makes sense only in case the full life cycle, including operation (and operational energy demand) and end of life treatment is included in the calculation.

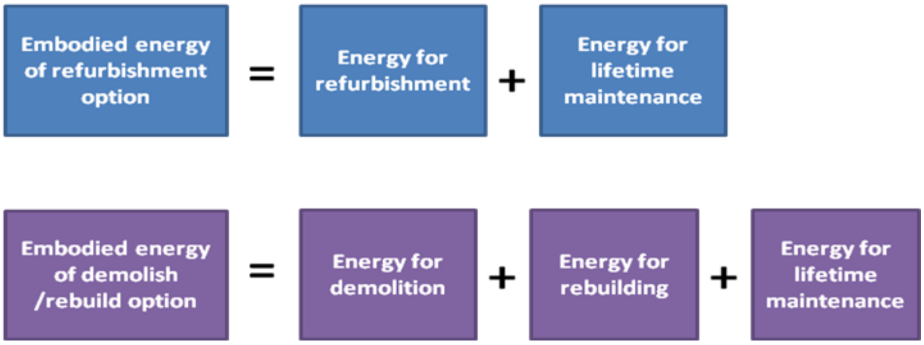


Figure 1-13. Examples of types of energy included in embodied energy (or GHG emissions) calculations when comparing refurbishment with demolish/ rebuild scenarios.

When a decision has to be made between replacing an existing building by new one or refurbishing it, many factors are taken into account besides embodied energy and embodied GHG emissions.

3.5.4. Prediction of data for future energy supply and materials production

One of the most significant parameters causing variations in the data derived from different databases is the electricity mix considered in the calculation. Thus, it is of great importance when estimating the embodied energy and embodied GHG emissions of buildings to state clearly which electricity mix was used for the production of building materials and components. Usually, data can be based either on an electricity mix specific to the enterprise, the region, the country of origin or specific to a larger area (e.g. EU average mix). However, when the production-related data are taken from existing databases, information related to the electricity mix should be transparently reported.

Primary energy and carbon emission factors are not physical constants; instead, they may develop with time, creating uncertainties about assumptions for the future. As changes may occur in electricity mix during the service life of a building, it is considered important the development of the grids to be reflected into the calculations. This can happen by analysing different scenarios on the possible evolution of electricity grid in different regions. However, due to the complexity of the grid infrastructure, it is only possible to estimate average values for a period. In addition, there is no international consensus on how to deal with the different scenarios in relation to this subject.

In countries such as Norway and Finland, this subject is intensively discussed among scientists. There are already examples of cases for which the consequences of the use of dynamic LCA data have been analysed. Scientists in other countries reject such an approach, since this requires too many assumptions and involves potential risks of manipulation of data. Thus, it becomes important for designers when selecting data from the different sources to check the year of publication and the period for which the data remains valid.

3.5.5. The case of imported products

When calculating embodied energy (EE) and embodied GHG emissions (EG), an important question is whether the portion of imported materials in new construction should be included in the calculation or not. In general, imported materials are considered to be less environmentally friendly than the locally available building materials, since significant amounts of energy is consumed (and associated emissions occur) for their transportation. For this reason, many designers think that these should be included in a building assessment. However, it is difficult to actually calculate them because the intensities of EE and EG are often not available in the exporting countries. Therefore, these may be estimated, for convenience, under the hypothetical condition in which the imported materials were produced in a country where the construction takes place. More information of imported materials are considered in different databases is given in Appendix 1.B and ST3 report.

Typically, for designers, there are two possible solutions when dealing with imported materials in their calculations; one way is to try to investigate the origin of a material, to estimate the transport distance between the importing and exporting country and finally to contact the manufacturer for obtaining the EE and EG related information. Alternatively, data can be used from national databases. This is helpful particularly in the early design stages, when the origin of the material is still unknown. Considering the importance of the subject, further efforts are needed from the side of scientists and data providers.

3.6. Background data and other information

The quantification of embodied impacts at a building level usually relies on background data taken from different sources. Depending on the point of the time of the assessment, there are different types of data and information representing the object of assessment that can be used. As the design progresses, the availability of data increases, as well as the accuracy of results increases (e.g. figure 1-14).

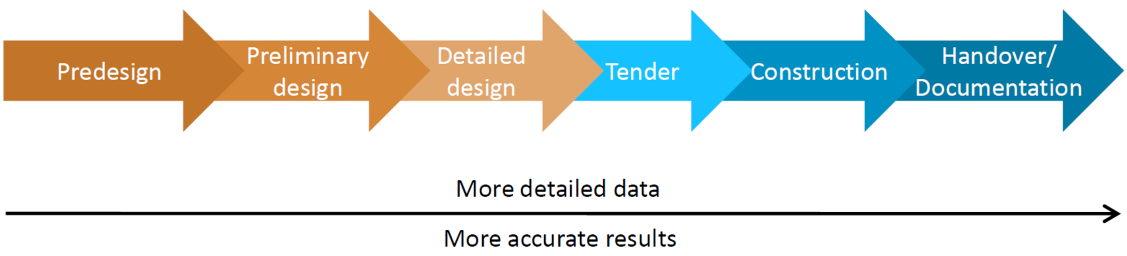


Figure 1-14. The availability of data increases as the design process progresses.

More specifically, different types of background data are:

a) *Quantity of materials*

These may range from rough estimates based upon the design description of the object of assessment (drawings) to predicted, or even actual, bills of materials. Building Information Modelling (BIM) can assist already from the preliminary design stages of a project in determining the quantities of primary building materials. The losses and damages of materials are usually accounted for in the quantities of materials as percentage allowances (percentage). These percentage values can be usually found in national waste databases or obtained from contractors' historical data.

b) *Process based LCA databases*

EE and EC coefficients can be sourced from such databases (A full list can be found in ST3 report). These can be either in-house, or free third party (e.g. national databases), or commercial (e.g. Ecoinvent, GaBi, etc.). The data derived from these databases may be *average* (combined from different manufacturers or production sites for the same product), *product collective* (e.g. LCA at the association level established for a type or a category of similar products), or *product specific* (LCA at the manufacturer level). However, the quality of the available databases in each country varies. Thus, the assessment of the quality of the data set to be used in an assessment is very important. A few questions to ask when selecting a database are listed in the report of GHG Protocol "*Product Life Cycle and Accounting and Reporting Standard*". In the same report it is recommended that once an appropriate database(s) is selected, a data quality and "fit-for purpose" assessment of the individual secondary data chosen from the selected databases is also important in terms of the technological representativeness, temporal representativeness, completeness, etc. One example of consistent generic and manufacturer specific LCI data is the KBOB-recommendation 2009/1:2014 in use in Switzerland (KBOB, 2014). This system is described in more detail in Annex 57 ST3 Report.

c) *EPD data library*

Another source of product data is an Environmental Product Declaration (EPD). These are a standardized (the process is defined in EN 15804:2012 and EN 15942:2011 at a European level, and ISO 14025:2006 at an international level) and independently verified declaration of environmental performance of materials or products, encompassing all stages of the life cycle or parts of it (only the inclusion of cradle to gate data is mandatory). However, system boundary settings, modelling approaches (e.g. allocation) and background data may still vary and by that exerting a substantial influence on the resulting environmental impacts. Therefore, EPDs are not comparative assertions and are either not comparable or have limited comparability when they cover different life cycle stages, are based on different product category rules or are missing relevant environmental impacts. Different countries and programmes define different sets of Product Category Rules (PCR). EPDs may be produced for specific materials or products (product-specific EPDs) or an "average product" of many companies within a clearly defined sector (sector or generic EPDs). Some comprehensive examples of EPD data libraries are: the International EPD system, ökobau.dat in Germany, INIES in France, Green Book Live in the UK, etc. – for more information check ST3 report

d) *IO Tables*

Country-specific input output (IO) tables is another tool providing EE and EG data for products and buildings with monetary based unit (e.g., tCO2e/US$1million). The data usually covers cradle to gate of construction industry sectors. However, it is necessary to know to which industry sector the construction products being installed into the building belong in order to determine the EE and EG intensities to be applied to the product (more information in ST3 report) Many national statistical offices publish IO-tables on a more or less regular basis, while international datasets of harmonized input-output and trade data are presented by GTAP (Global Trade Analysis Project) and the OECD.

e) *Transport mode data*
In many countries, there are data in litre/km for different transport modes and tables with average distances.

f) *Service lives of materials/ components for replacement (years)*
This type of data usually depends on the in use conditions and the type of servicing applied to the component. If such data is not available, ISO 15686 series provides a method for the estimation of service life (the factor method).

g) *Construction process*
Data for the various construction processes are usually obtained by a contractor's historical data on similar projects.

3.7. Comparability of data and results

In overall, apart from defining the system boundaries in terms of the building components and life cycle processes to be included in the analysis, the data sources for embodied energy GHG emissions factors, and the quantification method (selected indicators), also other parameters need to be specified in order the results of different case studies to be comparable.

For example, such a parameter is the **reference study period** of the building. This affects the use phase of the studied building. The frequency of maintenance and replacement of building parts varies depending on the defined service life. Usually fifty years are selected as the service life of a studied system building for practical LCA.

In addition, **reference unit** is an important parameter**,** since it provides a reference to which all input and output data are normalized. For buildings, the reasonable functional units are the following: entire building, per m² of gross floor area/ net floor area/ rentable floor area, or even m² of the building element according to the purpose of the study. But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That is why a clear definition of different floor area calculations is important.

Ensuring the transparency and comparability is a fundamental requirement for the determination, assessment and interpretation of EE and EG. This requires the clear description and declaration of the object of assessment and the reference study period, as well as the databases used and all the assumptions made. For this purpose, there is a need for a generally accepted structure/framework that is not only accepted by the scientific community, but also implemented by the practitioners.

4. Recommendations for the assessment of embodied impacts at the building level

In the previous sections, it was explained that there are still various views and approaches in relation to the selection and application of indicators and system boundaries, as well as the handling of different methodological issues, when assessing embodied impacts at a building level. Therefore, specific recommendations were developed within the scope of IEA EBC Annex 57 aiming, on the one hand, at providing more transparency in reporting and documentation of different parameters in the assessment of environmental performance of buildings and on the other hand, at promoting harmonisation among studies. The ultimate goal is to assist designers and other stakeholders in the assessment of design alternatives in a way that the aspects of resource conservation and environmental/ climate protection are effectively incorporated into the decision-making processes. These recommendations are presented in the following paragraphs.

4.1. Integration of embodied impacts into the design process

The assessment of embodied impacts (here EE and EG) should start early in the design process. The client should do target setting for embodied impacts already at the pre-design phase. In particular, the public sector as a client for projects can undertake an exemplary role towards this end. When building owners do not see themselves in a position to formulate such goals, designers should use their expertise to actively advise them in respect of their choices or to pursue this goal independently as part of their responsibility towards the environment and society. Benchmarks, data, and appropriate design and assessment tools can support different stages of the design process.

In the early design phase the available information is often not sufficient for making a detailed assessment of embodied impacts. Table 2-1 lays out the key work stages of the design and construction of a building project and the most common decisions and tasks of design professionals and consultants associated with these project stages, while demonstrating in simple steps the potential for design professionals and consultants to influence the embodied impacts of a building.
Particularly, the third column of table 2-1 provides the recommended by Annex 57 course of action throughout the different phases, specifically related to the calculation and reporting of embodied impacts, and the forth column the type of instruments that can be used to assist design professionals and consultants in the fulfillment of their tasks.

Table 2-1: Steps on how design professionals and consultants can influence the embodied impacts of a project according to the stage of the design process

Phase	Designers' task	Course of action in relation to embodied impacts	Type of instruments
Pre-design stages (Client's brief)	Definition of general project goals and requirements, as well as formulation of building performance targets	Provision of assistance to clients via a discussion or checklist for the setting of project-specific targets, either more quantitative (e.g. "budgets" for EC and/or EG in the same manner as economic budgets or benchmarks) or more qualitative (e.g. specifications for the selection of construction products and methods), for the reduction of embodied impacts;	Benchmark values (e.g. sourced from within the design team/firm or the public domain/national standards) or validated rules-of-thumb/empirical values at building level
	Selection of assessment methods	Provision of assistance to clients in terms of reviewing options for formal assessment of embodied impacts (and other sustainability aspects)	National/international standards or building assessment/certification systems
	Decision on new construction or refurbishment	Provision of assistance to clients via a comparison and assessment of the two variants based on embodied impacts considerations along with operational impact considerations to support them in their decision-making	Reference values for building structures, construction methods, construction products, construction processes or case studies
Preliminary design stages (concept/ schematic design)	Decision on the underground construction/ size of the foundations	Examination of alternatives **at the building level** including considerations of embodied impacts	Systems providing average values of embodied impacts for various types of foundations and construction method
	Decision on the construction method and main building materials		
Design development (detailed/ coordinated design)	Optimisation of structural and environmental performance of building components	Examination of alternatives **at the component level** (e.g. load bearing structure, facade, windows) including the consideration of embodied impacts (e.g. web-based element catalogue)	Web-based element catalogue
	General material selection	Examination of alternatives **at the product groups level** including the consideration of embodied impacts (e.g. web-based information on building products and databases)	Product comparison tools Product databases
Preparation of contracts/ Tendering	Preparation of tender documents	Integration of requirements to reduce embodied impacts into the tenders for individual works; Demand for product and manufacturer specific EPDs or LCAs from manufacturers and suppliers	
Construction monitoring	Supervision of works	Determination of the actual installed products according to the type, quality and quantity Collection of specific EPDs or LCAs, quality assurance	Information on the type, quality and quantity of the installed products, EPD's

Phase	Designers' task	Course of action in relation to embodied impacts	Type of instruments
Object documentation	Preparation of building documents	Compilation of information on the type and quantity of installed materials including also information on the respective embodied impacts into a final document, as well as compilation of instructions for inspection, servicing and maintenance, as well as instructions for deconstruction and recycling	

Table 2-2 shows in more detail the choices that influence the embodied impacts in the course of design and tendering process with the most important being highlighted in red. The final column includes embodied impacts "checkpoints" to better incorporate specifically embodied impacts considerations into the process.

Table 2-2: Main design tasks and embodied impacts checkpoints during the design and tendering process

Phases	Main Tasks	Checkpoints
Preliminary design stages	**1. Choice of project (demolition, new construction, refurbishment)** 2. Choice of site and local interfaces (climate, utilities) **3. Choice of design concept (relation to the site, geometry, configuration of the premises, zoning, glazed parts)** **4. Choice of constructive systems** **5. Choice concerning the building's durability and adaptability** 6. Choice of the thermal performance of the envelope 7. Choice of energy supply systems	- Consider the embodied impacts of decisions 1-7 - Consider embodied impacts trade-offs - Set embodied energy and emissions target ("budget")
Design Development	**8. Choice of construction principle** **9. Choice of main building materials** **10. Choice of building components** 11. Choice of building concept (arrangement of rooms) 12. Choice of energy systems concept (e.g. optimization of façade) **13. Assessment of the consequences of end of life scenario** **14. Assessment of the consequences of maintenance cycles** **15. Choice of materials for surfaces and finishing elements** 16. Choice of building site equipment **17. Choice of construction and transport processes**	- Consider embodied impacts of choices 8-14 together with technical, commercial and other environmental criteria holistically to produce an overall design - Include embodied impacts assessment in all significant appraisals of design options - Update embodied impacts assessment based on the final cost plan - Incorporate embodied energy and embodied GHG emissions assessment into sustainability assessment
Preparation of contracts/ Tendering	**18. Choice of specific products (e.g. specification, sourcing)** 19. Choice of contractors (credentials)	- Determine procurement requirements with respect to embodied impacts - Check material specification, sourcing, documentation, etc. - Assess the credentials of contractors against the requirements for embodied impacts

4.2. Object of assessment

Here, the recommendations provided focus on improving the completeness of the description of the building and its life cycle and increasing the transparency level of this process. This is achieved by providing different checklists, which serve two purposes: one the one hand, to show the recommended approach of Annex 57 by highlighting specific items that need to be considered in an analysis of embodied impacts of a specific design solution or in the comparison of different variants, and on the other hand, to allow different stakeholders to define and report their assessment results transparently, in case they choose to follow another approach than the one recommended here.

The spatial boundary specifying the part of the physical building that is included in an assessment may range from single building components to neighbourhoods. That’s why this needs always to be clearly defined and reported. In the context of IEA EBC Annex 57 the object of assessment is only the building.

However, in early design stages simplifications and omissions should be allowed. It is advisable the initial calculations to be focused on the commonly recognized in most studies and standards high-impact building components that typically contribute to the biggest part of the overall embodied energy and embodied GHG emissions. In any case, it is advisable to include in an EE and EG assessment, if possible, the building elements crossed in Table 2-3.

A building or a part of a building (e.g. assembled systems) can have a number of possible functional and technical requirements. For this reason the functional equivalent (as the basis for the assessment) of the object of assessment shall be clearly specified. A clear description of the major functional and technical requirements together with the intended use allows the functional equivalency of different options and building types to be determined and forms the basis for transparent and reasonable comparison. The client’s brief and regulations can be a source of information for defining the functional equivalent. According to the EN 15978:2011 standard the functional equivalent shall include, but is not necessarily limited to, information on the following aspects:

- building type (e.g. office, factory);
- relevant technical and functional requirements (e.g. the regulatory and client’s specific requirements);
- pattern of use (e.g. occupancy);
- required service life.

In terms of the description of the different life cycle stages of the building under consideration, the adoption of the modular life cycle model from EN 15978:2011 is recommended in order to describe and declare the different system boundaries in a consistent and widely accepted way. A model of different system boundary selection possibilities according to the needs of each actor is proposed in figure 2-1:

- System Boundary type I: Cradle to Gate
- System boundary type II: Cradle to Site
- System boundary type III: Cradle to Handover
- System boundary type IV: Cradle to End-of-Use

- System boundary type V: Cradle to Grave
- System boundary type VI: Cradle to Grave, including net benefits and impacts beyond the system boundary

Table 2-3: List of building elements that should be included in the EE and EG analysis from the perspective of Annex 57. The vacant column should be filled out, in case the approach followed is different than the one proposed here.

Building Parts	Building Components	Recommended Approach	Own Approach
Substructure	Foundations	X	
	Basement retaining walls	X	
	Ground floor construction	X	
Superstructure	Frame	X	
	External walls	X	
	External doors	X	
	Windows	X	
	Internal walls	X	
	Floors	X	
	Ceilings	X	
	Roof	X	
	Stairs and ramps	X	
Building services	Water system	X	
	Sewage system	X	
	Heating system	X	
	Cooling system	X	
	Ventilation system	X	
	Electrical system	X	
	Conveying systems	X	
	Data system		
	Fire protection system		
Finishes	External finishes	X	
	Internal finishes	X	
	Fixed furniture		
	Furniture		
External	Balcony	X	
	Vegetation		
	Pavement		

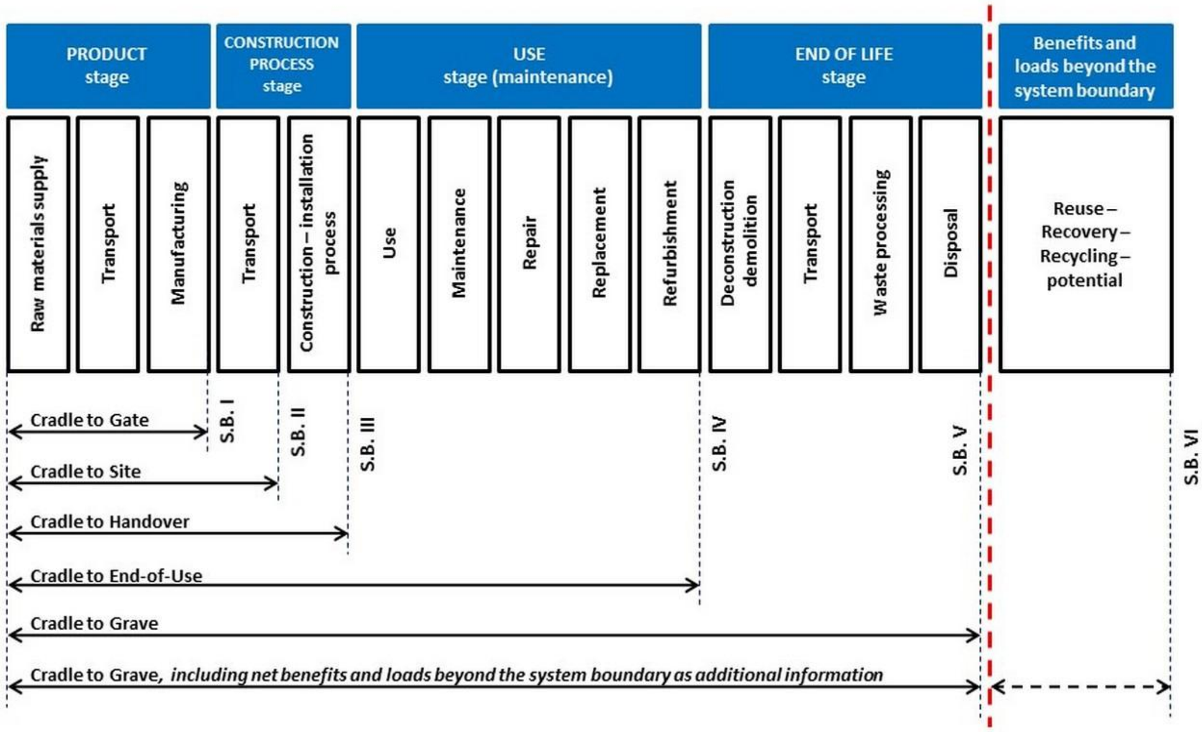


Figure 2-1: Proposed model for system boundary description and selection

Where possible embodied impacts from all life cycle stages should be considered (*type VI*), as it represents the comprehensive embodied impacts caused by the entire life cycle of the building under analysis. If this is not possible due to lack of appropriate data, the system boundary *Cradle to Handover (type III)* should be used at the minimum, as it represents the initial embodied impacts of the whole building. In addition to the respective results, also the partial results for each included module should be declared. When considering the system boundary type VI, the result of system boundary type III has also to be shown separately (initial EE and EG).

The *net benefits and impacts beyond the system boundary* (e.g. savings accruing to a second user from the use of recycled steel) may be quantified and if so they shall be reported separately as additional information. This is covered by module D as referred to in ISO 21929-1:2011 and further defined in EN 15978:2011. Under certain conditions and circumstances, such an information module (D) can be characterized as recycling potential of the building. This requires, among others, the declaration of an appropriate scenario for deconstruction and selective dismantling (to recover the materials to be recycled) in module C1 on building level.

A clear statement is needed in order to define which building elements and building life cycle stages are included in the studied system and to allow comparisons between design solutions. One could use figure 2-2 as a checklist for declaring transparently the overall system boundary, and in this way allowing comparisons between studies. As an example of how this can be done - the building components and life cycle stages highlighted in the figure are the ones to be always included in EE and EG calculations according to the recommended approach by Annex 57.

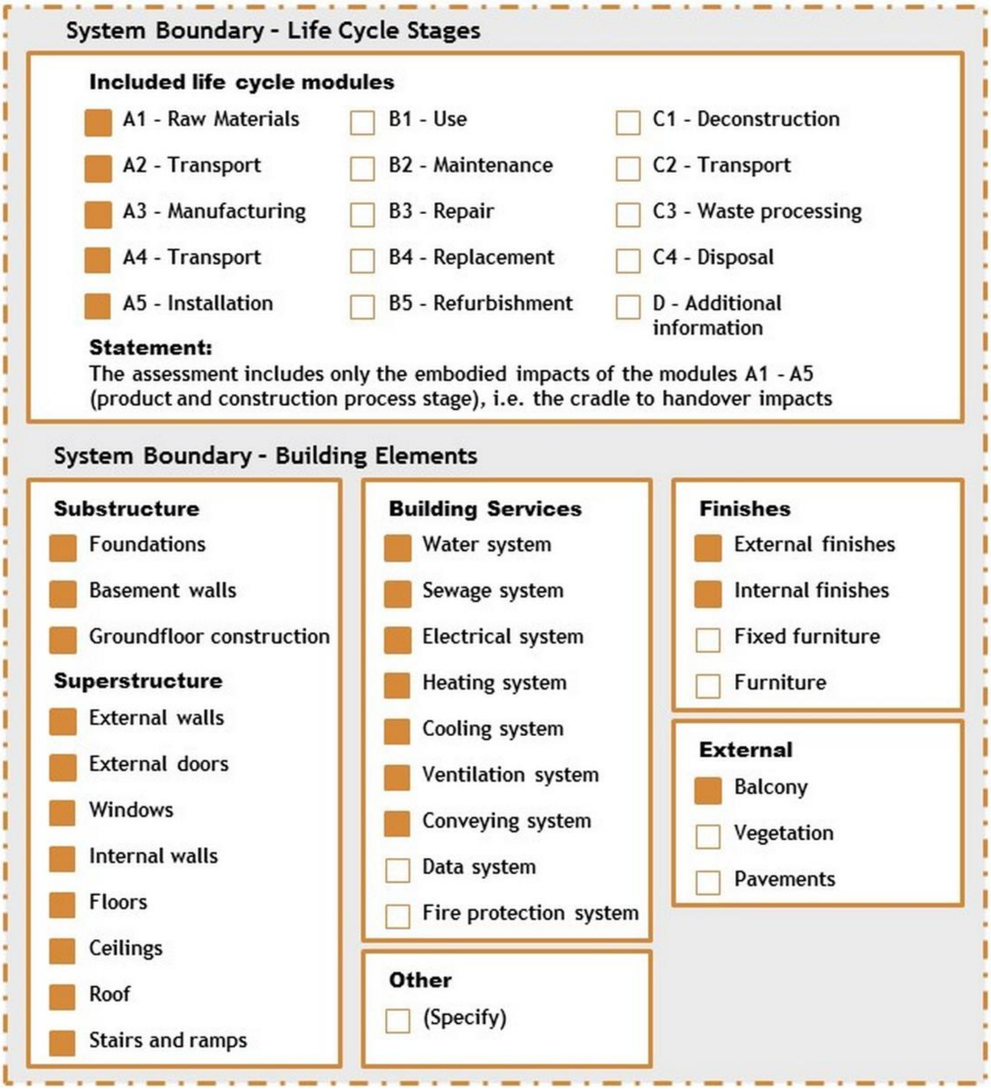


Figure 2-2: Example of a checklist to describe and report the system boundaries used in a study in terms of the covered life cycle stages and building elements

The description of the object of assessment must also include, but not be limited to, the following information:

- Location/climate;
- Building type;
- Pattern of use (e.g. occupancy);
- Relevant technical and functional requirements;
- Required service life or design life;
- Reference study period
- Scenarios for maintenance
- Scenarios for replacement
- Scenarios for recycling

More detailed information can be found in section 4.7 “comparability of results”.

4.3. Recommended indicators for the quantification of embodied energy (EE)

For the quantification of embodied energy (EE) it is recommended the use of three indicators:

- the primary energy fossil (PE_f), referred to as Embodied Energy 1 (EE1) inside Annex 57 group
- primary energy non-renewable (PE_{nr}) (fossil plus nuclear energy sources), referred to as Embodied Energy 2 (EE2) inside Annex 57 group, and
- the primary energy total (PE_t) that includes both the renewable and non-renewable part of energy, referred to as Embodied Energy 3 (EE3) inside Annex 57 group

The first two indicators are derived from considerations related to resource depletion, and thus the environmental targets covered here are the "protection of fossil energy resources" and the "protection of non-renewable energy resources". These are the two main indicators identified within Annex 57, covering the practical applications across the world – representing the supply side. The third indicator is an additional indicator and derived from considerations related to the total primary energy demand of a building – here as a partial term for production, construction, repair and replacement and EoL. Feedstock energy is included in all cases, but always separately reported.

A detailed description of each indicator individually including the recommended system boundaries is given in the tables 2-3, -4, and -5 respectively. If the recommended approach for EE1, EE2 and EE3 does not serve the purposes of an individual assessment, it is recommended to use table 2-6 as a checklist for describing in a transparent way the indicator intended to be used in the respective analysis. To assist the reporting process for each indicator recommended here, table 2-7 shows the items to be reported for EE1, EE2 and EE3 and illustrates their interrelationships.

Table 2-3: Recommendation of Annex 57 for the indicator Embodied Energy 1 (EE1)

EMBODIED ENERGY EXPRESSED AS PRIMARY ENERGY FOSSIL (PE_f)														
Name of indicator inside Annex 57	Embodied Energy 1 (EE1)													
Also known as	Embodied energy (EE), Embedded energy, Grey energy, Cumulative energy demand (CED)													
Name in LCIA	Abiotic Resource Depletion for Fossil Fuels													
Metric	Fossil primary energy consumption													
Target	Protection of fossil energy resources													
Definition	*Embodied energy 1 (EE1)* is the cumulative fossil primary energy demand (CED_f) for one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense, the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product.													
System boundaries	System boundary type V - "Cradle to Grave" Feedstock energy is included and may be reported separately. If calculated, benefits and loads beyond the life cycle of the building shall be reported separately – Module D													
Included Modules	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
	Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to Building Site	Installation into Building	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport to EoL	Waste Processing	Disposal	Reuse, recycling or recovery potential
	X	**(X)**[9]	**X**	**(X)**	**(X)**	**(X)**	**(X)**	**X**	**(X)**	**X**	**(X)**	**X**	**X**	**(X)**
Unit	MJ[10]/reference unit[11]/year (of the RSP)[12]													

Sub-information:
The embodied energy results should be presented in both an aggregated and disaggregated form for each module.
For the aggregated results, apart from system boundary type V - "Cradle to Grave", also the system boundary *"Cradle to Handover"* should be used as sub-setting at the minimum, as it represents the initial embodied energy of the whole building.
Following the idea of modularity of CEN TC 350 standards, at the highest level of disaggregation the results of the indicator should be expressed in 'information modules' recording the impact occurred in each module of each life cycle stage.

[9] The brackets mean that these activities are included only when there is data available.

[10] It can be expressed also in MJoil.eq. to highlight the nature of characterisation when aggregating different energy resources.

[11] Although the embodied energy figures are usually stated as $MJ/m^2/y$, the reference unit widely varies from country to country. The square meters may refer to gross internal, gross external or net internal area (or usable floor area). But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That's why all this information should be explicitly stated.

[12] The reference study period (RSP) is the period over which the object of assessment is analysed and may significantly differ from its design life. This parameter highly influences the use stage of the building as the longer the RSP is selected the more frequent the need for repairing and replacing different building components is. It also affects the loads and benefits reported separately. In most cases RSP is considered to be 50 years.

Table 2-4: Recommendation of Annex 57 for the indicator Embodied Energy 2 (EE2)

EMBODIED ENERGY EXPRESSED AS PRIMARY ENERGY NON-RENEWABLE (PE_{nr})	
Name of indicator inside Annex 57	Embodied energy 2 (EE2)
Also known as	Embodied energy (EE), Embedded energy, Grey energy, Cumulative energy demand (CED)
Name in LCIA	Use of non-renewable primary energy[13]
Metric	Non-renewable primary energy consumption (fossil + nuclear)
Target	Protection of non-renewable energy resources
Definition	*Embodied energy 2 (EE2)* is the cumulative non-renewable primary energy demand (CED_{nr}) for one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product.
System boundaries	System boundary type V - "Cradle to Grave" Feedstock energy (non-renewable) is included and may be reported separately. If calculated, benefits and loads beyond the life cycle of the building shall be reported separately – Module D

Included Modules

A1	A2	A3	A4	A5	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to Building Site	Installation into Building	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport to EoL	Waste Processing	Disposal	Reuse, recycling or recovery potential
X	(X)[14]	X	(X)	(X)	(X)	(X)	X	(X)	X	(X)	X	X	(X)

Unit	MJ[15]/reference unit[16]/year (of the RSP)[17]

Sub-information:
The embodied energy results should be presented in both an aggregated and disaggregated form for each module.
For the aggregated results, apart from system boundary type V - "Cradle to Grave", also the system boundary *"Cradle to Handover"* should be used as sub-setting at the minimum, as it represents the initial embodied energy of the whole building.
Following the idea of modularity of CEN TC 350 standards, at the highest level of disaggregation the results of the indicator should be expressed in 'information modules' recording the impact occurred in each module of each life cycle stage.

[13] The respective impact category in LCIA is "abiotic depletion potential for fossil resources (ADP-fossil fuels)" and is not comparable with the indicator "use of non-renewable primary energy", as the nuclear part of energy is not taken into account in the first case.

[14] The brackets mean that these activities are included only when there is data available.

[15] It can be expressed also in MJoil.eq. to highlight the nature of characterisation when aggregating different energy resources.

[16] Although the embodied energy figures are usually stated as $MJ/m^2/y$, the reference unit widely varies from country to country. The square meters may refer to gross internal, gross external or net internal area (or usable floor area). But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That's why all this information should be explicitly stated.

[17] The reference study period (RSP) is the period over which the object of assessment is analysed and may significantly differ from its design life. This parameter highly influences the use stage of the building as the longer the RSP is selected the more frequent the need for repairing and replacing different building components is. It also affects the loads and benefits reported separately. In most cases RSP is considered to be 50 years.

Table 2-5: Recommendation of Annex 57 for the indicator Embodied Energy 3 (EE3)

EMBODIED ENERGY EXPRESSED AS PRIMARY ENERGY TOTAL (PE_t)														
Name of indicator inside Annex 57	Embodied Energy 3 (EE3)													
Also known as	Embodied energy, Embedded energy, Grey energy, Cumulative energy demand													
Name in LCIA	use of non-renewable and renewable primary energy													
Metric	Primary energy total (renewable + non-renewable)													
Target	Reduction of primary energy demand, Protection of non-renewable and renewable energy resources													
Definition	*Embodied energy 3 (EE3)* is the cumulative primary energy (renewable and non-renewable) demand (CED_{nr+r}) one or more processes (depending on the scope of each study) related to the creation of a product, its maintenance and end-of-life. In this sense the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the product.													
System boundaries	System boundary type V - "Cradle to Grave" Feedstock energy (renewable + non-renewable) is included and may be reported separately. If calculated, benefits and loads beyond the life cycle of the building shall be reported separately – Module D													
Included Modules	**A1**	**A2**	**A3**	**A4**	**A5**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
	Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to Building Site	Installation into Building	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport to EoL	Waste Processing	Disposal	Reuse, recycling or recovery potential
	X	**X**	**X**	**(X)**[18]	**(X)**	**(X)**	**(X)**	**X**	**(X)**	**X**	**(X)**	**X**	**X**	**(X)**
Unit	MJ[19]/reference unit[20]/year (of the RSP)[21]													

Sub-information:
The embodied energy results should be presented in both an aggregated and disaggregated form for each module.
For the aggregated results, apart from system boundary type V - "Cradle to Grave", also the system boundary *"Cradle to Handover"* should be used as sub-setting at the minimum, as it represents the initial embodied energy of the whole building.
Following the idea of modularity of CEN TC 350 standards, at the highest level of disaggregation the results of the indicator should be expressed in 'information modules' recording the impact occurred in each module of each life cycle stage.

[18] The brackets mean that these activities are included only when there is data available.

[19] It can be expressed also in MJoil.eq. to highlight the nature of characterisation when aggregating different energy resources.

[20] Although the embodied energy figures are usually stated as $MJ/m^2/y$, the reference unit widely varies from country to country. The square meters may refer to gross internal, gross external or net internal area (or usable floor area). But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That's why all this information should be explicitly stated.

[21] The reference study period (RSP) is the period over which the object of assessment is analysed and may significantly differ from its design life. This parameter highly influences the use stage of the building as the longer the RSP is selected the more frequent the need for repairing and replacing different building components is. It also affects the loads and benefits reported separately. In most cases RSP is considered to be 50 years.

Table 2-6: Checklist for declaring the scope of the indicators quantifying embodied energy used for each individual study, in case the approach followed is different from the one recommended by Annex 57.

CHECKLIST FOR DEFINING THE CHARACTER OF THE INDICATOR(S) USED FOR EE:				
Included non –renewable energy resources	**PE_f**	**PE_{nr}**	**PE_t**	**Individual approach**
Fossil fuels as energy	X	X	(X)	
Fossil fuels as feedstock	(X)	(X)	(X)	
Fossil fuels, total	X	X	X	
Nuclear fuels		X	X	
Included renewable energy resources	**PE_f**	**PE_{nr}**	**PE_t**	
Biomass total			X	
Biomass as feedstock			(X)	
Solar energy			X	
Hydropower			X	
Wind power			X	
Geothermal energy			X	
Type of System Boundary	**PE_f**	**PE_{nr}**	**PE_t**	
Cradle to Gate				
Cradle to Site				
Cradle to Handover				
Cradle to End of Use				
Cradle to Grave	X	X	X	
Module D (only as information)	(X)	(X)	(X)	
Cradle to Cradle				
Unit of Measurement	**PE_f**	**PE_{nr}**	**PE_t**	
[22]MJ/reference unit/year of the RSP[23] (e.g. 50 years)	X	X	X	
MJ/reference unit/year of the RSL[24]				
MJ/reference unit (absolute)				
kWh/reference unit/year of the RSP (e.g. 50 years)				
kWh/reference unit/year of the RSL				
kWh/reference unit (absolute)				
If other, please declare				
Reference Unit	**PE_f**	**PE_{nr}**	**PE_t**	
Gross Floor Area (GFA)	X	X	X	
Net Floor Area (NFA)				
Energy Reference Area (ERA)				
Rentable Floor Area (RFA)[25]				
If other, please declare				
Included Processes in Detail / Modules	**PE_f**	**PE_{nr}**	**PE_t**	
A1 Raw Material Supply	X	X	X	
A2 Transport to Manufacturer	X	X	X	
A3 Manufacturing	X	X	X	
A4 Transport to building site	(X)[26]	(X)	(X)	
A5 Installation into building	(X)	(X)	(X)	
B2 Maintenance	(X)	(X)	(X)	
B3 Repair	(X)	(X)	(X)	
B4 Replacement	X	X	X	
B5 Refurbishment	(X)	(X)	(X)	
C1 Deconstruction/ Demolition	X	X	X	
C2 Transport to EoL	(X)	(X)	(X)	
C3 Waste processing	X	X	X	
C4 Disposal	X	X	X	
D Reuse, Recovery or Recycling potential	(X)	(X)	(X)	

[22] It can be expressed also in MJoil.eq. to highlight the nature of characterisation when aggregating different energy resources.
[23] where RSP = Reference Study Period
[24] where RSL = Reference Service Life
[25] Sometimes Rentable Floor Area (RFA) is equal to Net Floor Area (NFA) (relevant standard EN 15221-6).
[26] The brackets mean that these activities are included only when there is data available or if considered appropriate.

Table 2-7: Items to be reported for each embodied energy-related indicator

Items to be reported for each "embodied energy" related indicator *The items highlighted in gray are not subtracted from any sum*					**Product Stage**			**Construction Process Stage**		**Use Stage**[27]					**End of life stage**				**Add. Info D**
					A1	**A2**	**A3**	**A4**	**A5**	**B1**[28]	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	
Embodied Energy 1 (EE1)	**Embodied Energy 2 (EE2)**	**Embodied Energy 3 (EE3)**	**1a**	**due to energy-related use of fossil fuels** **$[PE_f]$**[29]															
			1b	due to non-energy related use of fossil fuels (feedstock)															
			2	Uranium															
			3	**Non-renewable (= 1a + 2)** **$[PE_{nr}]$**[30]															
			4a	due to energy-related use of renewable sources															
			4b	Due to non-energy related use of renewable sources (feedstock)															
			5	**Total (= 3 + 4a)** **$[PE_t]$**[31]															

[27] In a life cycle assessment, Use stage also includes modules B6 (operational energy use) and B7 (operational water use).
[28] For Annex 57 B1 is specifically relevant for materials or products emitting or binding GHGs in the use stage (e.g. specific insulation materials, refrigerators, etc.)
[29] Check the detailed description in table 3
[30] Check the detailed description in table 4
[31] Check the detailed description in table 5

4.4. Recommended indicators for the quantification of embodied GHG emissions

For the quantification of “embodied GHG emissions” the proposed indicator to be used is the Global Warming Potential (GWP 100), according to the most recent IPCC report and as described in table 2-8. Inside Annex 57, this indicator is referred to as Embodied GHG Emissions 1 (EG1). However, in some countries (e.g. Japan) only CO2 and F-gases are included in an indicator as being the emissions with the highest impact in the construction sector. For these cases, a special indicator has been developed, named Embodied GHG Emissions 2 (EG2) and described in table 2-9.

In all cases, process emissions (emissions occurred during the manufacturing processes of specific construction materials as a result of specific chemical effects, e.g. CO_2 is emitted as a chemical reaction in cement manufacture) are also included as far as considered relevant in the assessment.

It is suggested, if stored carbon is calculated, to separate fossil and biogenic carbon fluxes in the assessment results, thus to be reported separately.

In terms of the F-gases due to use of specific insulation materials and refrigerators or A/C equipment, although their release occurs during the use phase, the respective decision is taken during the construction phase. Thus, it is recommended to be taken into account, if relevant, and be reported separately.

It is suggested F-gasses due to the use of specific insulation materials to be reported separately in A3, A5 and B1 module, while F-gasses due to the use of specific equipment to be reported separately in B1 module. In this sense, regionalised or even national life cycle inventory data of manufacturing XPS and SPF shall be collected. Data on F-gas leakages during the life time of these insulation materials shall be compiled. At the same time, regionalised or even national information on leakage rates of commercial refrigerators, stationary and mobile chillers, residential and commercial A/C equipment and of regionalised or even national information on recovery rates of refrigerants in such equipment shall be collected. In countries where such substances are no longer used, such considerations may be omitted.

Again, a checklist is provided in table 2-10 for reporting the approach intended to be followed by an individual assessment report in relation to embodied GHG emissions, when this differ from the approach recommended by Annex 57. To assist the reporting process for each indicator recommended here, tables 2-11 and 2-12 show the items to be reported for EG1 and EG2 and their interrelationships.

Table 2-8: Recommendation of Annex 57 for the indicator Embodied GHG Emissions 1 (EG1)

EMBODIED GHG EMISSIONS EXPRESSED AS GLOBAL WARMING POTENTIAL (GWP)	
Name of indicator inside Annex 57	Embodied GHG emissions 1 (EG1)
Also known as	Embodied CO_2 emissions, Embodied carbon, Partial Carbon Footprint, Embedded Carbon, ECO_2.
Name in LCIA	Global Warming Potential, GWP for the creation, maintenance and end-of-life of the building
Metric	Global Warming Potential (GWP 100) (including the GHGs as presented in the 5th IPCC report)
Target	Prevent or reduce climate change
Definition	*Embodied GHG Emissions 1* is the cumulative quantity of greenhouse gases (CO_2, methane, nitric oxide, and other global warming gases included in the 5th IPCC report), which are emitted during one or more processes (depending on the scope of each study) related to the creation of the product, its maintenance and end-of-life. This is calculated and expressed as CO_2 equivalent.
System Boundaries	System boundary type V - “Cradle to Grave” Non-fuel related emissions are also included (e.g. due to chemical effects) If calculated, benefits and loads beyond the life cycle of the building shall be reported separately – Module D Carbon sequestration should be reported separately.

Included Modules	**A1**	**A2**	**A**	**A4**	**A5**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
	Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to Building Site	Installation into Building	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport to EoL	Waste Processing	Disposal	Reuse, recycling or recovery potential
	X	**X**	**X**	**(X)**[32]	**(X)**	**(X)**	**(X)**	**X**	**(X)**	**X**	**(X)**	**X**	**X**	**(X)**

Unit	$kgCO_2eq.$/reference unit[33]/year (of the RSP)[34]

Sub-information:
The results of embodied GHG emissions should be presented in both an aggregated and disaggregated form for each module. For the aggregated results, apart from system boundary type V - “Cradle to Grave”, also the system boundary *“Cradle to Handover”* should be used as sub-setting at the minimum, as it represents the initial emissions of the whole building.
Following the idea of modularity of CEN TC 350 standards, at the highest level of disaggregation the results of the indicator should be expressed in ‘information modules’ recording the impact occurred in each module of each life cycle stage.

---

32 The brackets mean that these activities are included only when there is data available.

33 Although the embodied GWP figures are usually stated as $kgCO_2eq /m^2/y$, the reference unit widely varies from country to country. The square meters may refer to gross internal, gross external or net internal area (or usable floor area). But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That’s why all this information should be explicitly stated.

34 The reference study period (RSP) is the period over which the object of assessment is analysed and may significantly differ from its design life. This parameter highly influences the use stage of the building as the longer the RSP is selected the more frequent the need for repairing and replacing different building components is. It also affects the loads and benefits reported separately. In most cases this is considered to be 50 years.

Table 2-9. Recommendation of Annex 57 for the indicator Embodied GHG Emissions 2 (EG2)

EMBODIED GHG EMISSIONS EXPRESSED AS CO_2 + F-GASSES	
Name of indicator inside Annex 57	Embodied GHG emissions 2 (EG2)
Also known as	Embodied CO_2 emissions, Embodied carbon, Partial Carbon Footprint, Embedded Carbon, ECO_2.
Name in LCIA	Global Warming Potential, GWP for the creation, maintenance and end-of-life of the building
Metric	Global Warming Potential (GWP 100) (including only CO2 and F-gasses)
Target	Prevent or reduce climate change
Definition	*Embodied GHG Emissions 2* is the cumulative quantity of CO_2 and F-gasses, which are emitted during one or more processes (depending on the scope of each study) related to the creation of the product, its use (excluding operation), maintenance and end-of-life. This is calculated and expressed as CO_2 equivalent.
System Boundaries	System boundary type V - "Cradle to Grave" Non-fuel related emissions are also included (e.g. due to chemical effects) If calculated, benefits and loads beyond the life cycle of the building shall be reported separately – Module D Carbon sequestration should be reported separately.

Included Modules	A1	A2	A	A4	A5	B2	B3	B4	B5	C1	C2	C3	C4	D
	Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to Building Site	Installation into Building	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport to EoL	Waste Processing	Disposal	Reuse, recycling or recovery potential
	X	X	X	(X)[35]	(X)	(X)	(X)	X	(X)	X	(X)	X	X	(X)
Unit	$kgCO_2eq$./reference unit[36]/year (of the RSP)[37]													

Sub-information:
The results of embodied GHG emissions should be presented in both an aggregated and disaggregated form for each module. For the aggregated results, apart from system boundary type V - "Cradle to Grave", also the system boundary *"Cradle to Handover"* should be used as sub-setting at the minimum, as it represents the initial emissions of the whole building.
Following the idea of modularity of CEN TC 350 standards, at the highest level of disaggregation the results of the indicator should be expressed in 'information modules' recording the impact occurred in each module of each life cycle stage.

[35] The brackets mean that these activities are included only when there is data available.

[36] Although the embodied GWP figures are usually stated as $kgCO_2eq /m^2/y$, the reference unit widely varies from country to country. The square meters may refer to gross internal, gross external or net internal area (or usable floor area). But even when all figures refer to the same type of area, definitions and measurement conventions can differ by country. That's why all this information should be explicitly stated.

[37] The reference study period (RSP) is the period over which the object of assessment is analysed and may significantly differ from its design life. This parameter highly influences the use stage of the building as the longer the RSP is selected the more frequent the need for repairing and replacing different building components is. It also affects the loads and benefits reported separately. In most cases this is considered to be 50 years.

Table 2-10. Checklist for declaring the scope of the indicator GWP used for each individual study, in case the approach followed is different from the one recommended by Annex 57.

CHECKLIST FOR DEFINING THE CHARACTER OF THE INDICATOR(S) USED FOR EG:				
Type of GHG emissions		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
Fuel related		X	X	
Non fuel related – process related emissions		X	X	
Non-fuel related – Freon gases due to insulation		(X)	(X)	
Type of System Boundary		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
Cradle to Gate				
Cradle to Site				
Cradle to Handover				
Cradle to End of Use				
Cradle to Grave		X	X	
Module D (only as information)		(X)	(X)	
Cradle to Cradle				
Unit of Measurement		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
$kgCO_2eq$ /reference unit/year of RSP[38] (e.g. 50 years)		(X)	X	
$kgCO_2eq$ /reference unit/year of the RSL[39]				
$kgCO_2eq$ /reference unit (absolute)				
$kgCO_2$/reference unit/year of the RSP (e.g. 50 years)		X		
$kgCO_2$/reference unit/year of the RSL				
$kgCO_2$/reference unit (absolute)				
If other, please declare				
Included GHG emissions in CO_2eq.		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
Only CO_2		X		
GHGs as identified in Kyoto Protocol				
GHGs as identified in the 3rd IPCC report				
GHGs as identified in the 4th IPCC report, Chapter 8				
GHGs as identified in the 5th IPCC report			X	
Freon gases as defined in Montreal protocol		X	X	
If other, please declare				
Reference Unit		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
Gross Floor Area (GFA)		X	X	
Net Floor Area (NFA)				
Energy Reference Area (ERA)				
Rentable Floor Area (RFA)[40]				
If other, please declare				
Included Processes in Detail / Modules		**CO_2 + F-gasses**	**GWP100**	**Individual Approach**
A1	Raw Material Supply	X	X	
A2	Transport to Manufacturer	X	X	
A3	Manufacturing	X	X	
A4	Transport to building site	(X)[41]	(X)[42]	
A5	Installation into building	(X)	(X)	
B2	Maintenance	(X)	(X)	
B3	Repair	(X)	(X)	
B4	Replacement	X	X	
B5	Refurbishment	(X)	(X)	
C1	Deconstruction/ Demolition	X	X	
C2	Transport to EoL	(X)	(X)	
C3	Waste processing	X	X	
C4	Disposal	X	X	
D	Reuse, recovery or recycling potential	(X)	(X)	

38 where RSP = Reference Study Period
39 where RSL = Reference Service Life
40 Sometimes Rentable Floor Area (RFA) is equal to Net Floor Area (NFA).
41 The brackets mean that these activities are included only when there is data available.
42 The brackets mean that these activities are included only when there is data available.

Table 2-11: Items to be reported for EG1

Items to be reported for each "embodied GHG emissions" related indicator *The items highlighted in gray are not subtracted from any sum*			**Product Stage**			**Construction Process Stage**		[43]**Use Stage**					**End of life stage**				**Add. Info**
			A1	**A2**	**A3**	**A4**	**A5**	**B1**[44]	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**D**
Embodied GHG Emissions (EG1)	1	Fuel related GHG emissions (latest IPCC report)															
	2	Process related GHG emissions (latest IPCC report)															
	3	**All GHGs as identified in IPCC AR5 expressed in CO2eq. (= 1 + 2)**															
	4	F-gasses as identified in Montreal Protocol (e.g. due to insulation and refrigerators)															
	5	Stored Carbon															

[43] In a life cycle assessment, Use stage also includes modules B6 (operational energy use) and B7 (operational water use).

[44] For Annex 57 B1 is specifically relevant for materials or products emitting or binding GHGs in the use stage (e.g. specific insulation materials, refrigerators, etc.)

Table 2-12: Items to be reported for EG2

Items to be reported for each "embodied GHG emissions" related indicator *The items highlighted in gray are not subtracted from any sum*			Product Stage			Construction Process Stage		Use Stage[45]					End of life stage				Add. Info D
			A1	A2	A3	A4	A5	B1[46]	B2	B3	B4	B5	C1	C2	C3	C4	
Embodied GHG Emissions (EG2) Special case for Japan	1	Fuel related CO_2															
	2	Process related CO_2															
	3	**Total CO_2 (= 1 + 2)**															
	4	F-gasses as identified in Montreal Protocol (e.g. due to insulation and refrigerators)															
	5	Stored Carbon															

[45] In a life cycle assessment, Use stage also includes modules B6 (operational energy use) and B7 (operational water use).

[46] For Annex 57 B1 is specifically relevant for materials or products emitting or binding GHGs in the use stage (e.g. specific insulation materials, refrigerators, etc.)

4.5. Practical considerations

4.5.1. Recycling potential

It is recommended the benefits related to recycling, reusing or combustion of construction waste occurring already during use stage (due to maintenance, repair, replacement and refurbishment), as well as after the end of life stage of the building, to be reported separately as additional information (module D).

4.5.2. High thermal mass materials

Adding large thermal mass materials in the design may increase the impacts of production stage, while lowering at the same time the impacts of operational stage due to reduced cooling/heating demand. For this reason, the impacts of design decisions should always be considered on embodied and operational impacts together rather than separately.

4.5.3. Refurbishment vs replacement of existing buildings

Every existing building “represents” embodied impacts related to its product, construction and maintenance. Through the refurbishment, modernization or reconstruction of existing buildings their useful life can be extended and so their embodied energy can be utilised for a longer period of time. This can contribute to the reduction of energy and material flows that would be consumed in a different case for the replacement of an existing building by a new one. However, the overall impact of the decision of replacing an existing building on the life cycle energy and emissions depend much on whether the new building provide a significant improvement in operating energy efficiency. Thus, note that when comparing the two variants, (refurbish or demolish and replace) the both – the demand for additional embodied energy and the specific energy consumption for operation should always be included in the calculation.

4.5.4. Prediction of future energy mixes

In order to avoid unnecessary uncertainty in the assumptions on future patterns in electricity mix, it is considered more feasible, and thus is recommended, to assume that the background LCI data underlying the building LCA is kept constant.

4.5.5. Imported materials

In case imported materials are planned to be used in a building, a designer should either:

- try to investigate the origin of the material, estimate the transport distance between the importing and exporting country and ask for EE and EG data from the manufacturer, or
- apply appropriate data from national databases

No matter what the approach followed is, designers should ensure this is documented and declared in a transparent way that allows comparability. The examination of import-export flows from a macroeconomic perspective is not considered as an option here.

4.6. Background data and other information

The determination of quantities of products, materials and components should be based on the best available data at the time of assessment. In any case, the most appropriate data sources are transparent LCAs established using the same protocol (modelling rules) or, if not available, quality-checked EPDs of construction products prepared with ideally the same product category rules. When this is not possible, relevant data from general databases should be used. Note that data, calculation methods, tools and benchmarks are strongly linked and can lead to reasonable assessment results only when used together as an inseparable unit.

4.7. Comparability of data and results

In overall, besides defining the building components and life cycle processes to be included in the analysis, the character of the indicators used for the quantification of the embodied impacts and the data sources used for determining the different energy and emissions factors, also other parameters need to be specified in order the results of different case studies to be comparable. The minimum documentation requirements are presented in table 2-13.

Table 2-13: Reporting template – minimum documentation requirements for better communication and comparability of results

Parameter	Description of the Characteristics of the Object and its Assessment
Location /climate and or heating degree days / cooling	e.g. Germany/ moderate climate
Building/ Usage type / intensity of use	school building, 200 students, hours of operation 08.00 –18.00, includes a sport hall
Energy-standard	(“net positive” during the use phase, expressed in “primary energy equivalents”)
Gross floor area/ Net floor area	e.g. 726 m^2/ 615 m^2
Gross volume/ Net volume	
Reference area for EE/EC	e.g. energy reference area … 535 m2
Construction method	e.g. Structural steel frame supporting precast concrete floor slabs
U-values of the building envelope	
Ventilation system	
Heating and cooling system	
Final energy demand electricity	Appliances, lighting, services, etc. (kWh/m2a)

Parameter	Description of the Characteristics of the Object and its Assessment
Final energy demand for heating and hot water / energy carrier(s)	(kWh/m2a)
Final energy demand for cooling	(kWh/m2a)
Purpose of assessment	e.g. to determine the energy and GHG emissions offsetting, when a net zero concept is applied
Assessment methodology	e.g. according to EN 15978:2011 guidance
Reference Study Period	e.g. 50 years
Included life cycle stages	e.g. cradle to handover (use a checklist, as the one shown in figure 2-2, to describe in detail which modules/ processes are included
Included parts of the building	e.g. use a checklist, as the one shown in figure 4, to describe in detail which parts of the building are included
Scenarios and assumptions used for construction process stage	....
Scenarios and assumptions used for use stage	....
Scenarios and assumptions used for EoL stage	e.g. recycling at the end of life
Databases used (if any)	e.g. KBOB-recommendation 2009/1:2014, ökobau.dat or EPD of program ...
Other data sources	e.g. EPD's from manufacturers
LCA Software used (if any)	e.g. LEGEP
Method of materials quantification	e.g. BIM Architecture
Name/type of the indicator(s) used	use table 4 for reporting the character of the indicator used
Additional indicators assessed	

5. Recommendations for selected groups of actors on the further development of the practical application of the assessment of embodied energy and $CO_{2eq.}$ for building construction

For the realization of objectives in the areas of resource conservation and environmental/ climate protection it is increasingly important for the actors involved in the building construction to recognize their respective responsibilities and duties and use their scope for action. This applies also to the procedures for dealing with embodied energy (EE) and embodied greenhouse gas emissions (EG). Recommendations are made below for specific stakeholder/actor groups to contribute to the development of foundations and to enhance their opportunities for action.

5.1. Actions for design professionals and consultants

a) Qualification and further training

- educate yourself in the field of identification and assessment of embodied impacts in order to expand and improve your design and consulting services, as well as your competitive position. It is a task for the universities and the associations to develop appropriate training and continuing education courses. It is the job of the designer and consultant to systematically qualify himself for this challenge.

b) identification and use of design tools and databases

- discuss intensively the use of tools and databases, as performing an LCA in the narrow sense is not required, but rather just to combine information from the materials quantification with information from databases and to interpret the result.

c) Active consultation of clients/owners

- Provide advice to the client regarding the embodied impact levels of different design solutions in an active way.

d) Integration of embodied impacts into the design process

- start the assessment of embodied impacts early in the design process
- in the early design stages use average values from database and replace them with manufacturer and product specific values as the design progresses
- perform a comparison of variants – considering, among others, the consequences of selecting specific materials (e.g. use of recycled products, wood, etc.) or construction methods (lightweight construction etc.)

- consider the flexibility and adaptability of the construction in the sense of a longer useful life
- consider the ease of maintenance and deconstruction of the construction, as well as its recyclability
- document the quantities of materials and the related embodied impacts

e) Contribution to the transparency and comparability of the results

- describe clearly the system boundaries (life cycle stages and building elements)
- describe/declare clearly the assumption and scenarios for future embodied impacts
- determine the quantities of materials based on the best available data
- describe/declare clearly the indicators
- describe/declare the sources of data used

f) collection and publication of reference values

- processing and publication of reference values for embodied impacts (in accordance with a publication of cost reference values)

5.2. Actions for construction product manufacturers

Manufacturers are increasingly integrating issues concerning the resource use and the adverse effects on the environment into their decisions on product development and optimization. LCA is an instrument that can help them in this direction. This leads also to a stronger competitive position, better profit prospects and an enhanced image for their enterprise (Balouktsi et al., 2016). The following actions for this group of actors are recommended/ advisable, among others:

a) Improvement/optimization of the corporate processes (production and procurement processes)

- use LCA results to identify opportunities for improvement in their manufacturing and corporate processes, including their supply chain and recycling of the product, and establish targets for performance improvement;
- use better raw materials
- use better energy sources
- use of external consultancy services for the process optimization

b) Further development of products

- development of new innovative products with improved characteristics;

c) Improvement of product information

- develop and publish LCAs of products and/or manufacturing lines (e.g. in the form of EPDs)
- include data for different scenarios in the EPD’s
- develop and publish LCAs for whole building systems(not only for materials), such as ETICS (External Thermal Insulation Composite Systems), drywall systems, HVAC systems, etc.
- participate in LCA standards development for products, particularly PCR creation;
- collaborate with industry organizations in developing industry-average LCI data

d) Expansion of services in the life cycle

- offer maintenance/servicing contracts
- offer take-back guarantees;

More information about the assessment of embodied impacts by Construction Product Manufacturers is given in the special guideline document developed by Annex 57.

5.3. Actions for policy makers

Federal, state and local governments being the main law- and policy-makers have a crucial role in promoting and ensuring the consideration of embodied impacts in the built environment. This can be achieved by integrating requirements, targets and benchmarks for embodied impacts into the current national or regional policies and laws related to energy and resource efficiency (Balouktsi et al., 2016). In most countries, present legislation and building regulations do not address embodied energy and embodied GHG emissions based on a survey realized by the ST4 group of Annex 57. In this sense, the following actions for this group of actors are recommended/ advisable, among others:

a) Further development of laws, regulations and funding programmes

- consider the embodied impacts in national building regulations translated into clear and mandatory performance requirements (e.g. in Europe, an embodied energy requirement and target can included in the Energy Performance of Buildings Directive (EPBD) and subsequent recasts focused currently on operational impacts).
- mandate the declaration of environmental impacts of products
- promote the use of low-impact materials in the design of specific types of buildings through funding

b) Provision of research funds for the development of design and assessment tools, as well as databases

- develop national building sustainability and certification systems including requirements for embodied impacts
- develop national LCA databases

c) Publication of freely accessible databases, tools and information

- Provision of freely available data and tools (e.g., www.nachhaltigesbauen.de in Germany)

d) Role as a leading example

- Consideration of embodied impacts in public building projects
- Consideration of embodied impacts in GPP

More information about the consideration of embodied impacts by policy makers is given in the special guideline document developed by Annex 57.

5.4. Actions for procurers

Procurer is responsible for developing a project procurement strategy to support the achievement of project objectives like sustainability. Procurer helps the client or owner (if he is not the client himself) set the right requirements to ensure that the building is constructed to fit the intended purpose, functions and meet the sustainability related requirements. In this sense, the following actions for this group of actors are recommended/ advisable, among others:

a) Qualification and enhancement of competence

b) Integration of embodied impacts into the tendering and contracting
- integrate clear embodied impacts requirements and benchmarks in the project brief, invitation to tenders and other contracts and documents;
- consideration of embodied impacts in the assessment of offers

c) Development and publication of reference values for embodied impacts

More information about the consideration of embodied impacts by procurers is given in the special guideline document developed by Annex 57.

5.5. Research needs

Current research needs can be fulfilled to a great extent either through efforts from professional associations to develop a sufficient knowledge base to keep pace with current industry-related demands or through attempts from individual scientists, experts, or tool developers to limit the uncertainty and variability in LCA, as it is a still evolving science.

5.5.1. Contribution of professional associations

Professional associations and organizations have a key duty to play in ensuring that their members are prepared and informed on the importance of embodied impacts in buildings and their products. (Balouktsi et al. 2016). Such efforts go a long way in providing useful information to building-industry stakeholders through, for instance, the publication of various guidelines providing essential technical guidance on the identification, calculation and reduction of such impacts (as described in Part 1, chapter 2). However, the existing guideline documents cannot fit together as one system, (based on different definitions, system boundaries, data sources, etc) and their use has implications the information flow along the entire building supply chain. In this sense, the following actions for this group of actors are recommended/ advisable, among others:
- provide improved guidelines for practical implementation respecting the flow of information along the entire supply chain.
- develop average values and benchmarks (or databases providing free and publicly available information on completed projects) to support designers in the really early stages of the design and decision-making process, when the quantities of materials are still not known.

- integrate the task of the assessment of embodied impacts into the rules of practice (as an addition to the scope of services and an update of the fees incurred) so as to contribute to the increase in the number of the professionals providing such services.

5.5.2. Contribution of scientists, experts and tool developers

Scientists and experts play a leading role in the further development of LCA methodologies and benchmarks through their research activities and application of their knowledge into case studies (Balouktsi et al. 2016). In this sense, the following actions for this group of actors are recommended/ advisable, among others:

- develop solutions to deal with the place and time dependency in LCA and especially with far-off scenarios for processes such as deconstruction and disposal.
- develop solutions to tackle uncertainties concerning the consideration and handling of the recycling, reuse and recovery potential (module D in CEN TC 350 and ISO TC 59 SC 17 standards) in building LCA, as well as clear allocation rules.
- develop solutions to address the methodological issues concerning the future changes in the energy mix and product development and to assess the sensitivity of results to different assumptions applied to the model.

5.5.3. Recommendations for additional actor- and target groups

Standardization bodies

- provide clear definitions and system boundaries adapted to the needs of the construction industry

Developers of sustainability rating systems

- integrate LCA based methods and appropriate benchmarks into the systems – embodied impacts is a good starting point. Granting credit points for simply providing environmental information is discouraged.

Facility managers

- use a building file that will include all the information coming from the determination and listing of the type and quantity of materials needed for the building construction and repair/replacement, done within the context of an assessment of embodied impacts
- systemize the servicing and maintenance to support a longer useful life

Recycling companies

- optimise the component recycling and material recycling
- Build “building component stock exchanges”

6. Concluding remarks, open questions and outlook

The significant reduction of energy-related operational impacts, the growing interest in life cycle analysis and sustainability assessment of buildings, as well as the increased availability of data, have resulted in a growing interest in the description, assessment and targeted influencing of embodied impacts. At the same time, the willingness to take into account such aspects in the actual decision-making becomes stronger. Thus, the question arises as to what the state of the practical applicability is and to what extent suitable bases and guidelines exist.

So far, unclear definitions and system boundaries have hindered the wide spread introduction and integration of embodied impacts aspects into the decision-making processes in the construction sector. Therefore, in this report, to improve the transparency and comparability, a typology of system boundaries was developed and definitions for embodied energy (EE) and embodied GHG emissions (EG) were proposed. EG was clearly distinguished from stored carbon.

It is now important for selected actors to use the recommendations of the IEA EBC Annex 57 to improve the transparency and comparability and hence the credibility and reliability of their embodied impacts results. Yet it is also clear that new questions arise.

Open Questions

During the course of the IEA EBC Annex 57 project, a number of issues/questions that should be addressed in future projects came out. Examples are:

a) How can average values of EE and EG used in early stages of the design process to be replaced in the later design stages (detailed technical design, object documentation) by manufacturer-specific and product-specific values (comparable to a cost planning process)? What are the required conditions for this to be achieved (requirement for related information in the invitation to tender, provision of such data on offer, EPD's for all construction products)?

b) Worldwide the electricity mix is constantly changing (either due to an increase in renewable energy or an increase in coal-fired power plants to replace the nuclear power plants). What consequences does this have for the information related to EE and EG of the construction products manufactured at present or in future? What are the consequences for the documentation of the calculation and assessment results? What values should be used for a replacement of components taking place in future? From what sources can electricity mix related predictions be obtained?

Outlook

Operational and embodied impacts work hand in hand. Acquiring a complete understanding of both aspects allows design teams to create the best possible design solutions and specifications for a low energy and emissions building.

It is proposed to analyze the relationships and interdependencies between operational and embodied impacts in a future project.

7. List of references

Alcorn, A. (2003). *Embodied energy and CO_2 coefficients for NZ building materials*, Centre for Building Performance Research, Victoria University of Wellington, March 2003

Alcorn, J. A., & Baird, G. (1996). Use of a hybrid energy analysis method for evaluating the embodied energy of building materials. *Renewable energy*, *8*(1), 319-322.

Anderson, J. (2012). *CIRIA Carbon leader briefings - Materials, products and carbon*, Construction Industry Research and Information Association - CIRIA, pdf available at: http://www.ciria.com/lowcarbonbuiltenvironment/PDF/Materials,%20products%20and%20carbon.pdf

Anderson, J., & Thornback, J. (2012). *A guide to understanding the embodied impacts of construction products*, Constructions Products Association, UK.

Ariyaratne, C. I., & Moncaster, A. M. (2014). Stand-alone calculation tools are not the answer to embodied carbon assessment. *Energy Procedia*, *62*, 150-159.

Balouktsi, M., Lützkendorf, T., Frischknecht, R., Chae, C., Seo, S. (2014). *Assessment of embodied impacts – incorporation of the approaches of IEA Annex 57 into the overall context of environmental performance assessment*. in World SB14, Barcelona, 2014.

Balouktsi, M., Luetzkendorf, T., & Foliente, G. (2015). *Making a Difference: incorporating embodied impacts into the decision-making processes of key actors in the construction and property industry*. The SETAC 25th Annual Meeting Barcelona, Spain

Balouktsi, M., & Lützkendorf, T. (2016). Energy Efficiency of Buildings: The Aspect of Embodied Energy. *Energy Technology*, *4*(1), 31–43

Balouktsi, M., Lützkendorf, T., & Foliente, G. (2016). *Embodied impacts in stakeholder decision-making in the construction sector.* SBE16 Hamburg. Germany. 8-11 March.

Basbagill, J., Flager, F., Lepech, M., Fischer, M. (2013) Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts, *Building and Environment*, *60*, 81–92.

Bayer, C., Gamble, M., Gentry, R., & Joshi, S. (2010). *AIA guide to building life cycle assessment in practice*. The American Institute of Architect, Washington.

Brighton and Hove City Council (2011), *Brighton and Hove City Council Climate Change Strategy*, Brighton and Hove City Council, 2011

Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E., & Fernández, A. I. (2013). Low carbon and low embodied energy materials in buildings: A review. *Renewable and Sustainable Energy Reviews*, *23*, 536-542.

Zamagni, A., Buttol, P., Porta, P. L., Buonamici, R., Masoni, P., Guinee, J., ... & Pretato, U. (2008). *Critical review of the current research needs and limitations related to ISO-LCA practice*. Deliverable D7 of work package 5, Report of the EU 6th framework project CALCAS.

Clark, D. H. (2013). *What colour is your building? Measuring and reducing the carbon footprint of buildings* – Appendix A: Energy, CO_2 and Climate Change. RIBA Publishing, Document available at: www.whatcolourisyourbuilding.com.

Crowther, P. (1999). *Design for disassembly to recover embodied energy*, in: The 16th Annual Conference on Passive and Low Energy Architecture, Melbourne/ Brisbane/Cairns, Australia

Cullen, J., Carruth, M.A., Moynihan, M., Allwood, J.M., & Epstein D. (2011). *Learning legacy Lessons learned from the London 2012 Games construction project*. Cambridge University, Olympic Delivery Authority, 031.

De Wolf, C. (2012). *Material quantities in building structures and their environmental impact*. MSc thesis, Massachusetts Institute of Technology.

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), *Official Journal of the European Union*, L 153/13

Dixit, M. K., Fernandez-Solis, J. L., Lavy, S., & Culp, C. H. (2010). Identification of parameters for embodied energy measurement: a literature review. *Energy and Buildings*, 42 (8), pp.1238-1247.

Dixit, M. K., Fernández-Solís, J. L., Lavy, S., & Culp, C. H. (2012). Need for an embodied energy measurement protocol for buildings: A review paper. *Renewable and Sustainable Energy Reviews*, *16*(6), 3730-3743.

Dixit, M. K., Culp, C. H., & Fernández-Solís, J. L. (2013). System boundary for embodied energy in buildings: A conceptual model for definition. *Renewable and Sustainable Energy Reviews*, *21*, 153-164.

Eaton, K. J., & Amato, A. (1998). *A comparative environmental life cycle assessment of modern office buildings*. Ascot: Steel Construction Institute.

Engin, A., & Frances, Y. (2010). Zero Carbon Isn’t Really Zero: Why Embodied Carbon in Materials Can’t Be Ignored. Available at: http://www.di.net/articles/archive/zero_carbon/

EN 15643-1:2010 – *Sustainability of construction works. Sustainability assessment of buildings. General framework.* CEN. Brussels.

EN 15643-2:2011 – *Sustainability of construction works – Assessment of buildings – Part 2: Framework for the assessment of environmental performance.* CEN. Brussels

EN 15978:2011 – *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method.* CEN. Brussels

EN 15942:2011 – *Sustainability of construction works – Environmental product declarations – Communication format business-to-business*. CEN. Brussels

EN 15804:2012 – *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.* CEN. Brussels

European Commission (2012). *Roadmap: Communication on Sustainable Buildings*. DG ENV C1, Available at: http://ec.europa.eu

European Commission, JRC, & IES. European Platform on LCA. Available at: http://eplca.jrc.ec.europa.eu/ResourceDirectory/

European Union (2013). Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organization, *Official Journal of the European Union*, 2013/179/EU

Fay, R., Treloar, G., & Iyer-Raniga, U. (2000). Life-cycle energy analysis of buildings: a case study. *Building Research & Information*, *28*(1), 31-41.

Frey P. (2008) *Building reuse: finding a place on American climate policy agendas*. National Trust for Historic Preservation. Washington, DC

Friedrich, E. G., Baurat, G., & Müller, G. (1992). *Die Bauwirtschaft im Kleinwohnungsbau. Kritische Betrachtung der neuzeitlichen Bauweisen und Mitteilung von Erfahrungen mit Baustoffe*. Verlag von Wilhelm Ernst & Sohn, Berlin

Frischknecht, R. (2010). LCI modelling approaches applied on recycling of materials in view of environmental sustainability, risk perception and eco-efficiency. *The International Journal of Life Cycle Assessment*, *15*(7), 666-671.

Frischknecht, R., Wyss, F., Knöpfel, S. B., Lützkendorf, T., & Balouktsi, M. (2015). Cumulative energy demand in LCA: the energy harvested approach. *The International Journal of Life Cycle Assessment*, *20*(7), 957-969.

GEFMA–German Facility Management Association. (2004). Richtlinie GEFMA 100-1, Facility Management–Grundlagen. *Bonn (Entwurf 2004-07).*

Gething, B. (Ed.). (2011). *Green Overlay to the RIBA Outline Plan of Work*. RIBA Publishing.

Greenhouse Gas Protocol (2011). *Product life cycle accounting and reporting standard*. World Business Council for Sustainable Development and World Resource Institute.

Greenhouse Gas Protocol (2012). Third Party Databases. http://www.ghgprotocol.org/Third-Party-Databases

Häkkinen, T., Kuittinen, M., Ruuska, A., & Jung, N. (2015). Reducing embodied carbon during the design process of buildings. *Journal of Building Engineering*, *4*, 1-13.

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. *Proceedings of the Institution of Civil Engineers-Energy*, *161*(2), 87-98.

Hammond, G. P., & Jones, C. I. (2010). Embodied carbon: the concealed impact of residential construction. In *Global Warming* (pp. 367-384). Springer US.

Hammond, G., & Jones, C. (2011). *Embodied carbon. The inventory of carbon and energy (ICE), BSRIA*. ISBN 978-0-86022-703-8.

Haseltine, B. A. (1975). Comparison of energy requirements for building materials and structures. *The Structural Engineer*, *53*(9), 357.

Haynes, R. (2010). *Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings*, Available at: http://etool.net.au/wp-content/uploads/2012/10/Embodied-Energy-Paper-Richard-Haynes.pdf

Herzog, T. (2009). *World greenhouse gas emissions in 2005*. Washington–DC, États-Unis, WRI Working Paper, World Resources Institute. Available at: http://www.wri.org/publication/navigating-the-numbers.

Hill, R. K. (1983). Energy requirements for thermal insulations. *Journal of Building Physics*, *7*(2), 101-110.

Huberman, N., & Pearlmutter, D. (2008). A life-cycle energy analysis of building materials in the Negev desert. *Energy and Buildings*, *40*(5), 837-848.

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye, A. (2013). Operational vs. embodied emissions in buildings—A review of current trends. *Energy and Buildings*, *66*, 232-245.

IEA (International Energy Agency) (2011). WORLD ENERGY OUTLOOK 2011. Available at: http://www.worldenergyoutlook.org/weo2011/

IPCC (2007). *Climate change 2007. The physical science basis: Working group I contribution to the fourth assessment report of the IPCC* (Vol. 4). [Solomon, S. (eds.)]. Section 2.10.2. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA,

IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Vol. 5) [Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., & Minx, J. C. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

ISO 14025:2006. *Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures*. International Organization for Standardization. Geneva, Switzerland.

ISO 21930:2007. *Sustainability in building construction -- Environmental declaration of building products.* International Organization for Standardization. Geneva, Switzerland.

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*. International Organization for Standardization. Geneva, Switzerland.

ISO/TS 14067:2013. *Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification and communication*. International Organization for Standardization. Geneva, Switzerland.

ISO 16745:2015. *Environmental performance of buildings -- Carbon metric of a building -- Use stage*. International Organization for Standardization. Geneva, Switzerland.

Jensen, A. A., Elkington, J., Christiansen, K., Hoffmann, L., Moller, B. T., Schmidt, A., & van Dijk, F. (1997). *Life cycle assessment: a guide to approaches, experiences and information sources*, Report to European Environment Agency, Copenhagen.

Jones, C. I. (2011). *Life cycle energy consumption and environmental burdens associated with energy technologies and buildings*, PhD Thesis, University of Bath

KBOB, eco-bau, & IPB (2014). KBOB-Empfehlung 2009/1:2014: Ökobilanzdaten im Baubereich, Stand April 2014. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik

Knight, D., & Addis, B. (2011). Embodied carbon dioxide as a design tool–a case study. In *Proceedings of the Institution of Civil Engineers-Civil Engineering* (Vol. 164, No. 4, pp. 171-176). Thomas Telford Ltd.

Langston, Y. L., & Langston, C. A. (2008). Reliability of building embodied energy modelling: an analysis of 30 Melbourne case studies. *Construction Management and Economics*, *26*(2), 147-160.

Levine, M., Urge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., … & Yoshino, H. (2007). *Residential and commercial buildings. Climate change 2007; mitigation. Contribution of working group III to the fourth assessment report of the IPCC*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ligthart, T. N., & Ansems, A. A. M. (2012). *Modelling of Recycling in LCA*. InTech. Available at: http://www.intechopen.com/

Lucon O., Urge-Vorsatz, D., Zain Ahmed, A., Akbari, H., Bertoldi, P., Cabeza, L. F., … & Vilarino, M. V. (2014). *Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Manfredi, S., Allacker, K., Chomkhamsri, K., Pelletier, N., & Maia de Souza, D. (2012). *Product Environmental Footprint (PEF) Guide*. European Commission (EC), Joint Research Centre (JRC)

& Institute for Environment and Sustainability (IES). Available at: http://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf

Marchal, V., Dellink, R., Van Vuuren, D., Clapp, C., Chateau, J., Magné, B., & van Vliet, J. (2011). OECD environmental outlook to 2050. *Organization for Economic Co-operation and Development*

Mayer, H., & Flachmann, C. (2011). *Environmental-Economic Accounting: Extended Input-Output Model for Energy and Greenhouse Gases*. Federal Statistical Office of Germany. Wiesbaden

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things*; North Point Press: New York.

Menzies, G. F. (2011). *Embodied energy considerations for existing buildings*. Historic Scotland Technical Paper 13. Available at: www.historic-scotland.gov.uk/technicalpapers

Monahan, J., & Powell, J. C. (2011). An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings*, *43*(1), 179-188.

Müller, B., & Schebek, L. (2013). Input-Output-based Life Cycle Inventory. *Journal of Industrial Ecology*, *17*(4), 504-516.

Nebel, B., Alcorn, A., & Wittstock, B. (2008). *Life cycle assessment: adopting and adapting overseas LCA data and methodologies for building materials in New Zealand*, Ministry of Agriculture and Forestry, New Zealand

Nibel, S. et al. (2012). *Description and explanation of the selected indicators and related measurement and assessment methods with special focus on reliability, comparability and compatibility*. SuPerBuildings. Deliverable 4.2. Available at: http://cic.vtt.fi/superbuildings/

Oka, T., Yokoyama, K., Sawachi, T., Yokoo, N., & Yamamoto, M. (2014). *Introduction of Annex 57 – Evaluation of Embodied Energy and Carbon Dioxide Emissions for Construction Worldwide*, World SB14, Barcelona, October 2014

Pacheco-Torgal, F., Faria, J., & Jalali, S. (2013). Embodied energy versus operational energy. Showing the shortcomings of the energy performance building directive (EPBD). In *Materials Science Forum*, Vol. 730, pp. 587-591.

PAS 2060:2010 – *Specification for the demonstration of carbon neutrality*. British Standards Institution. UK, London.

PAS 2050:2011 – *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*. British Standards Institution. UK, London.

Passer, A., Kreiner, H., & Maydl, P. (2012). Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. *The International Journal of Life Cycle Assessment*, *17*(9), 1116-1130.

Plank, R. (2008). The principles of sustainable construction. *The IES Journal Part A: Civil & Structural Engineering*, *1*(4), 301-307.

Pullen, S., & Bennetts, H. (2011). *Valuing embodied energy in the conservation of historic residential buildings*, 45th Annual Conference of the Architectural Science Association, ANZAScA 2011, The University of Sydney

Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, *42*(10), 1592-1600.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W. P., Suh, S., Weidema, B. P., & Pennington, D. W. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment international*, *30*(5), 701-720.

Rhys, J. (2011). *Cumulative carbon emissions and climate change: has the economics of climate policies lost contact with the physics?*, Oxford Institute for energy studies. Available at: http://www.oxfordenergy.org/wpcms/wp-content/uploads/2011/07/EV-571.pdf

RIBA (2013). *RIBA Plan of Work 2013 Overview*, Royal Institute of British Architects, London.

RICS (2012). *Methodology to calculate embodied carbon of materials*. Royal Institution of Chartered Surveyors, London.

RICS (2014). *Methodology to calculate embodied carbon in a building's construction life cycle*. Royal Institution of Chartered Surveyors, London.

Sansom, M., & Pope, R. J. (2012). A comparative embodied carbon assessment of commercial buildings. *The Structural Engineer*, 38-49.

Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and buildings*, *39*(3), 249-257.

Sathre, R., & Gustavsson, L. (2009). Using wood products to mitigate climate change: External costs and structural change. *Applied Energy*, *86*(2), 251-257.

Selincourt, K. D. (2012a). *Embodied energy - a ticking time bomb? Part 1*, Green Building Press 44, Spring 2012. Available at: http://www.katedeselincourt.co.uk/

Selincourt, K. D. (2012b). *Embodied energy - a ticking time bomb? Part 2*, Green Building Press 44, Spring 2012. Available at: http://www.katedeselincourt.co.uk/

SETAC (1993). *Guidelines for Life Cycle Assessment: A Code of Practice*. Edition 1 [Ed.: F. Consoli], Society of Environmental Toxicology and Chemistry, Pensacola.

Sharrard, A. L., Matthews, H. S., & Roth, M. (2007). Environmental implications of construction site energy use and electricity generation 1. *Journal of Construction Engineering and Management*, *133*(11), 846-854.

Shi, X., & Yang, W. (2013). Performance-driven architectural design and optimization technique from a perspective of architects. *Automation in Construction*, *32*, 125-135.

SIA (2004). *Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten im Bereich Umwelt (SNARC)*. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich

SIA (2010). *Merkblatt 2032: Graue Energie von Gebäuden*. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich

SIA (2011a), *Merkblatt 2040: SIA-Effizienzpfad Energie*. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich, p. 28.

SIA (2011b) *Dokumentation D 0236: SIA-Effizienzpfad Energie, Ergänzungen und Fallbeispiele zum Merkblatt SIA 2040*. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich, p. 49.

Sustainable Homes (1999). *Embodied energy in residential property development - A Guide for Registered Social Landlords*. Available at: http://www.sustainablehomes.co.uk/

Tennenbaum, S. E. (1988). *Network Energy Expenditures for Subsystem Production*, MS Thesis. Gainesville, FL: University of FL, pp. 131

Thormark, C. (2002). A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential. *Building and environment*, *37*(4), 429-435.

Treloar, G.J. (1998). *A Comprehensive Embodied Energy Analysis Framework.* PhD Thesis, Deakin University

Treloar, G. J., Love, P. E., & Holt, G. D. (2001). Using national input/output data for embodied energy analysis of individual residential buildings.*Construction Management and Economics*, *19*(1), 49-61.

UK GBC (2015). *Tackling Embodied Carbon in Buildings*. UK Green Building Council. Available at: http://www.ukgbc.org/

UNEP (2009). *Buildings and climate change: a summary for decision-makers*. United Nations Environmental Programme, Sustainable Buildings and Climate Initiative, Paris, 1-62.

UNEP (2014). *Ozone Action Special Issue 2014*. United Nations Environmental Programme. Available at: http://www.unep.org/ozonaction/

UNFCCC (2011). Greenhouse Gas Inventory Data United Framework Convention on Climate Change. Available at: http://unfccc.int/ghg_data/items/3800.phpm

Upton, B., Miner, R., Spinney, M., & Heath, L. S. (2008). The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States. *Biomass and Bioenergy*, *32*(1), 1-10.

VanGeem, M. G., & Marceau, M. L. (2008). Energy Performance of concrete buildings in five climates in First International Conference on Building Energy and Environment. *Proceedings vols*, 1-3

Vukotic, L., Fenner, R. A., & Symons, K. (2010). Assessing embodied energy of building structural elements. In *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* (Vol. 163, No. 3, pp. 147-158). Thomas Telford Ltd.

Webster, M. D. (2004). Relevance of structural engineers to sustainable design of buildings. *Structural engineering international*, *14*(3), 181-185.

Weidema, B. P., Thrane, M., Christensen, P., Schmidt, J., & Løkke, S. (2008). Carbon footprint. *Journal of Industrial Ecology*, *12*(1), 3-6.

WRAP (2011)**.** *Procurement requirements for carbon efficiency***.** Waste and Resources Action Programme, UK. Available at: www.wrap.org.uk

WRAP (2016). *Embodied Carbon Database*. Waste and Resources Action Programme, UK. Available at: http://ecdb.wrap.org.uk/

Xing, S., Xu, Z., & Jun, G. (2008). Inventory analysis of LCA on steel-and concrete-construction office buildings. *Energy and Buildings*, *40*(7), 1188-1193.

Yohanis, Y. G., & Norton, B. (2002). Life-cycle operational and embodied energy for a generic single-storey office building in the UK. *Energy*, *27*(1), 77-92.

Appendix 1.A: Energy unit conversion factors

Today embodied energy is often expressed in mega joules (MJ) rather than kWh (commonly used for operational energy consumption), sometimes with the addition MJ oil-equivalents in order to highlight the nature of characterisation when aggregating different energy resources (such as oil, natural gas, coal, etc.). Below the conversion factors for four units commonly used for energy consumption (kWh, MJ, Btu and toe) are given.

	Kilowatt hours (kWh)	Megajoules (MJ)	British thermal units (kBtu)	Tonnes of oil equivalent (toe)
1 kWh =	1	3.6	3.409	8.5984×10^{-5}
1 MJ =	0.28	1	0.948	2.3884×10^{-5}
1 kBtu =	0.00029	0.0011	1	2.5199×10^{-5}
1 toe =	11.630	41.868	39.680	1

Note: 1kWh/m^2 is equivalent to 317 Btu/ft^2

Energy unit conversion factors

Appendix 1.B: Survey report – an analysis of the calculation of the indicators related to embodied energy and embodied GHG emissions in the different LCI databases

Prepared by:
Maria Balouktsi & Prof. Thomas Lützkendorf
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Rolf Frischknecht
Treeze.Ltd, Switzerland

The preparation of this report was part of the German contribution to the IEA EBC Annex 57, which is coordinated by the Project Management Jülich and financially supported by the Federal Ministry for Economic Affairs and Energy

(BMWi)

Bundesministerium
für Wirtschaft
und Technologie

November 2014

Citation:
Balouktsi, M., Lützkendorf, T. & Frischknecht, R. (2014) Survey Report: An analysis of the calculation of the indicators related to embodied energy and embodied GHG emissions in the different LCI databases. IEA EBC Annex 57. Subtask 1 (ST1). November 2014

Acknowledgements

The IEA EBC Annex 57 group would like to thank the people and organisations who gave of their time to participate in the survey. Particularly, special thanks go to the representatives of the different databases:

Survey Participant	Affiliation	Database
Tim Grant	Life Cycle Strategy	Australian National LCI Database
Ping Hou	IKE Environmental Technology Co. Ltd	Chinese Core Life Cycle Database
Prof. Atsushi Inaba	Kogakuin University	Japanese LCA Database
Uwe R. Fritsche	INIAS	GEMIS
Rolf Frischknecht	Treeze.ltd	Ecoinvent
Stephan Rössig	BBSR	Ökobau.dat

About the survey

Background and purpose

The IEA-EBC Annex 57 is devoted to the identification, assessment and targeted control of the “embodied energy” and “embodied greenhouse-gas emissions” due to building construction. The terms “embodied energy” and “embodied greenhouse-gas emissions” are understood from the project as the description of the use of energy resources and the emissions of greenhouse gases caused by the manufacturing, construction, maintenance and demolition of buildings. In this context, this is a great part of a life cycle analysis, an LCA or a carbon footprint of buildings, excluding all the parts that deal with the operational phase. The identification, assessment and management of the embodied energy and greenhouse-gas emissions is one aspect of the assessment of the environmental performance of buildings and contributes to the implementation of sustainable development principles in the construction sector.

One of the objectives of Annex 57 is to establish a synopsis of calculation procedures of the indicators “embodied energy” and “embodied greenhouse-gas emissions” (or embodied global warming potential) applied in the participating countries. In this sense, it was necessary for Annex 57 team to better understand what the differences are worldwide, when it comes to the calculation of these indicators. This was studied with the help of an electronic survey carried out by the Chair of Sustainable Management of Housing & Real Estate (Prof. Dr. Thomas Lützkendorf) of the Karlsruhe Institute of Technology (KIT) in Germany and treeze Ltd. (Dr. Rolf Frischknecht) in Switzerland as representatives of the Annex 57 group.

On this basis, information was acquired from different database specialists and administrators through an online survey in order to improve the possibilities of establishing a detailed comparison of calculation procedures of embodied energy consumption and embodied greenhouse-gas emissions. Specifically, the aim was to be investigated the following questions on the basis of different databases:

- When calculating embodied energy, which parts are considered (renewable/ non-renewable)?
- How is the embodied primary energy data to be used in the database of your country calculated (method)?
- When using the concept of energy resources extracted, which calorific value/ heating value is considered (gross/upper or net/lower)?
- How is the embodied energy of nuclear power quantified?
- How is the embodied energy of solar, hydro, wind and geothermal energy quantified?
- How the embodied energy of wood energy is quantified?
- When calculating embodied greenhouse-gas emissions, which gases are considered in the calculation of Global Warming Potential (kgCO_2eq.)?
- How are the embodied greenhouse-gas emissions from imported materials taken into account?

Methodology

Surveys were organized in electronic form. In the period from February to May 2014 a call for filling the online survey has been sent to several database specialists and administrators. There were 6 responses in total covering the following countries: Australia, China, Germany, Japan and Switzerland.

Results

The results of the survey in terms of the “embodied energy” related indicator are shown in table 1 and in terms of the “embodied greenhouse-gas emissions” indicator in table 2 (also analysed in Frischknecht et al., 2015). The overview shows that there are important differences from country to country in the approaches applied in the several databases for the quantification of these indicators.

Most approaches quantify both the renewable and non-renewable part of embodied energy consumption and differentiate between the two. In terms of the energy value of the chemical energy resources (fossil fuels and biomass), in many approaches this is derived from the lower heating value (net calorific value), some may switch between lower and higher heating values and finally a few approaches apply the higher heating value (gross calorific value).

Regarding the determination of the embodied energy of nuclear power, most of the approaches quantify the consumption of uranium resource (amount of uranium extracted) and apply an energy value (factor in MJ/kg). However, the level of this energy value varies significantly (from around 160'000 MJ/kg to 560'000 MJ/kg) depending on the enrichment grade and burn up rate of the nuclear fuel. A different approach is followed by the Japanese LCI database, where the nuclear energy indicator is derived by applying an efficiency factor (100%) to the amount of electricity produced by nuclear power. This means that 1kWh of nuclear electricity is equivalent to 1 kWh of primary nuclear fuel (uranium).

For the quantification of the input of the various renewable energy resources (solar, hydro, wind and geothermal) two main concepts are applied[47]:

- Renewable energy harvested – the renewable energy input into the manmade environment equals the amount of energy delivered by the energy collecting facility (AusLCI Database, GEMIS, Ecoinvent v2.2)
- Renewable energy harvestable – The renewable energy input into the manmade environment is the amount of renewable energy needed to produce the amount of energy delivered by the energy collecting facility. Here an efficiency factor is used (based on the efficiency of the energy collecting facility) to convert solar irradiation/ wind energy/ potential energy of water to electricity (Ökobau.dat, Japanese LCI Database).

In terms of the quantification of embodied energy of wood energy the most common approach followed by the databases is the application of heating value of wood to the amount of harvested wood.

[47] Frischknecht, R., Wyss, F., Knöpfel, S. B., Lützkendorf, T., & Balouktsi, M. (2015). Cumulative energy demand in LCA: the energy harvested approach. *The International Journal of Life Cycle Assessment*, *20*(7), 957-969.

As far as the “embodied greenhouse-gas emissions” indicator is concerned, in all of the examined databases the global warming potential (GWP) of GHG emissions is generally reported, expressed in units of carbon dioxide equivalent (CO2eq.), taking account of the different impact of GHGs on global warming. The GHG emissions considered in the calculation of the CO2eq vary from database to database. In most of cases GWP is calculated for the GHGs identified in the 4th IPCC Assessment Report, while the Australian database and the Swiss database have been updated to include the GHGs identified in the 5th IPCC Assessment Report. Freon gases (e.g. CFCs and HCFCs) as identified in Montreal protocol are only included in the Australian database.

In terms of the calculation of the embodied greenhouse-gas emissions from imported materials, there two prevalent approaches:

- the data of imported building products are taken from the Database of the exporting country and are adapted to the modelling requirements of the domestic Database (AusLCI, Ecoinvent, Japanese LCI DB)
- the data of imported building products are taken from the Database of the exporting country without any adaptations (Chinese Core LCA, in some cases also GEMIS)
- The emissions of imported materials are estimated assuming that they were produced in the imported country (in some cases GEMIS)

Table 1. Quantification of "embodied energy" related indicators

Database	AusLCI DB	GEMIS	Ökobau.dat	Ecoinvent data v2.2	Chinese Core LCA	Japanese LCA DB
Country	Australia	Germany	Germany	Switzerland	China	JAPAN
Calculation of embodied energy - grouping	Renewable/ non-renewable	Renewable/ non-renewable	Renewable/ non-renewable	Renewable/ non-renewable	Renewable/ non-renewable	non-renewable
Method of calculating embodied primary energy data	quantifying the amount of energy resources extracted from nature, multiplied by energy values [48]	quantifying the amount of energy resources extracted from nature, multiplied by energy values[49]	quantifying the amount of energy resources extracted from nature, multiplied by energy values[50]	quantifying the amount of energy resources extracted from nature, multiplied by energy values[51]	not specified	quantifying the amount of energy resources extracted from nature, multiplied by energy values
Chemical energy	LHV or HHV	LHV or HHV	LHV	HHV	LHV	HHV
Quantification of the embodied energy of nuclear power	consumption of uranium resource multiplied with an energy value (451'000 MJ/kg Uranium)	consumption of uranium resource multiplied with an energy value (depends on enrichment and tailings)	consumption of uranium resource multiplied with an energy value (451'000 MJ/kg Uranium)	consumption of uranium resource multiplied with an energy value (560'000 MJ/kg Uranium)	consumption of uranium resource multiplied with an energy value (159'200 MJ/kg Uranium)	amount of electricity produced by nuclear power divided by an efficiency factor (100%)
Quantification of embodied energy of solar, hydro, wind and geothermal energy	renewable energy harvested	renewable energy harvested except for biomass and geothermal energy (IEA statistical approach)	renewable energy harvestable (includes conversion efficiency from solar irradiation/wind energy/potential energy to electricity)	renewable energy harvested	not specified	renewable energy harvestable (includes conversion efficiency from solar irradiation/wind energy/potential energy to electricity)
Quantification of embodied energy of wood energy	wood harvested multiplied with heating value of wood	wood harvested multiplied with heating value of wood	wood harvested multiplied with heating value of wood	wood harvested multiplied with heating value of wood	not specified	wood harvested multiplied with heating value of wood

[48] Industry numbers from Energy Gas Australia and data from ABARES and National Greenhouse Gas Inventory

[49] GEMIS has explicit database for energy carriers ("fuels") with ultimate Analysis from whih heating values are calculated.

[50] http://www.gabi-software.com/uploads/media/GaBi_Modelling_Principles_2013.pdf

[51] Frischknecht R., Jungbluth N., Althaus H.-J., Bauer C., Doka G., Dones R., Hellweg S., Hischier R., Humbert S., Margni M. and Nemecek T. (2007) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH

Table 2. Quantification of "embodied GHG emissions" related indicators

Database	AusLCI database	GEMIS	Ökobau.dat	ecoinvent data v2.2	Chinese Core LCA	Japanese LCA Database
Country	Australia	Germany	Germany	Switzerland	China	JAPAN
Greenhouse-gas emissions considered in the calculation	GHGs identified in the 3rd IPCC Assessment Report/ 4th IPCC Assessment Report/ 5th IPCC Assessment Report/ freon gases (e.g. CFCs and HCFCs) as identified in Montreal protocol	GEMIS can use several metrics (GWPs and time horizons)	GWP for the GHGs identified in the 4th IPCC Assessment Report	GWP for the GHGs identified in the 4th IPCC Assessment Report/ 5th IPCC Assessment Report	GWP for the GHGs identified in the 4th IPCC Assessment Report	GWP only for the GHGs identified in Kyoto protocol
How do you take into account the embodied greenhouse-gas emissions from imported materials in your country?	the data of imported building products are taken from the DB of the exporting country and are adapted to the modelling requirements of the domestic DB	The emissions of imported materials are estimated assuming that they were produced in the imported country In some cases, the data of imported building products are taken from the DB of the exporting country	GHG emissions are calculated according to the actual supply chain (statistical import/consumption mix of respective region).	the data of imported building products are taken from the DB of the exporting country and are adapted to the modelling requirements of the domestic DB	the data of imported building products are taken from the DB of the exporting country	the data of imported building products are taken from the DB of the exporting country and are adapted to the modelling requirements of the domestic DB

Appendix 1.C: Survey report – an analysis of the state of knowledge on embodied impacts and its practical application for specific target groups and decision-making situations

Prepared by:
Maria Balouktsi & Prof. Thomas Lützkendorf
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The preparation of this report was part of the German contribution to the IEA EBC Annex 57, which is coordinated by the Project Management Jülich and financially supported by the Federal Ministry for Economic Affairs and Energy

(BMWi)

Bundesministerium
für Wirtschaft
und Technologie

September 2015

Citation:
Balouktsi, M. & Lützkendorf, T. (2015) Survey Report: An analysis of the state of knowledge on embodied impacts and its practical application for specific target groups and decision-making situations. IEA EBC Annex 57. Subtask 1 (ST1). September 2015

About the survey

Background and purpose

The IEA-EBC Annex 57 is devoted to the identification, assessment and targeted control of the "embodied energy" and "embodied greenhouse-gas emissions" due to building construction. The terms "embodied energy" and "embodied greenhouse-gas emissions" are understood from the project as the description of the use of energy resources and the emissions of greenhouse gases caused by the manufacturing, construction, maintenance and demolition of buildings. In this context, this is a great part of a life cycle analysis, an LCA or a carbon footprint of buildings, excluding all the parts that deal with the operational phase. The identification, assessment and management of the embodied energy and greenhouse-gas emissions is one aspect of the assessment of the environmental performance of buildings and contributes to the implementation of sustainable development principles in the construction sector.

One of the objectives of Annex 57 is to investigate and communicate the state of knowledge and its practical application for specific target groups and decision-making situations. In this sense, it was necessary for Annex 57 team to better understand what is the current state of the practice in relation to the integration of the determination and assessment of embodied energy consumption and embodied greenhouse-gas emissions into the decision making processes of different construction industry related stakeholders, as well as to be informed about already existing guidelines, practical instruments, assessment principles or examples of specific applications. This was studied with the help of an electronic survey carried out by the Chair of Sustainable Management of Housing & Real Estate (Prof. Dr. Thomas Lützkendorf) of the Karlsruhe Institute of Technology (KIT) in Germany as representatives of the Annex 57 group.

On this basis, information were acquired per individual stakeholder group in order to improve the possibilities of establishing even more into practice the determination, assessment and management of embodied energy consumption and embodied greenhouse-gas emissions. This was realized by distributing the online survey to important associations and organizations both acting locally and internationally, representing the most important stakeholder groups involved in the different stages of building design, construction and operation. Specifically, the aim was to be investigated:

- How long is the experience that the different stakeholder groups have regarding embodied energy and embodied greenhouse-gas emissions evaluation and management?
- What are the typical decision-making situations that usually occur in this field based on the experience of the different stakeholder groups?
- Are there any recommended, already used or own developed guidelines, databases, tools or even benchmarks by the different types of organizations/ stakeholder groups?
- Are there any case studies useful for the purposes of IEA EBC Annex 57?

Methodology

Surveys were organized in electronic form. In the period from February to May 2014 a call for filling the online survey has been sent to several national and international associations and organizations. All the project partners were asked to contact local stakeholders according to the instructions provided by KIT, so as to have an overview of the current practices in different countries. In addition, stakeholders acting at an international level were contacted by KIT, so as to gather important information influencing the global practice on the evaluation of embodied energy and embodied GHG emissions for building construction. There were 20 responses in total covering a large range of stakeholder groups and countries.

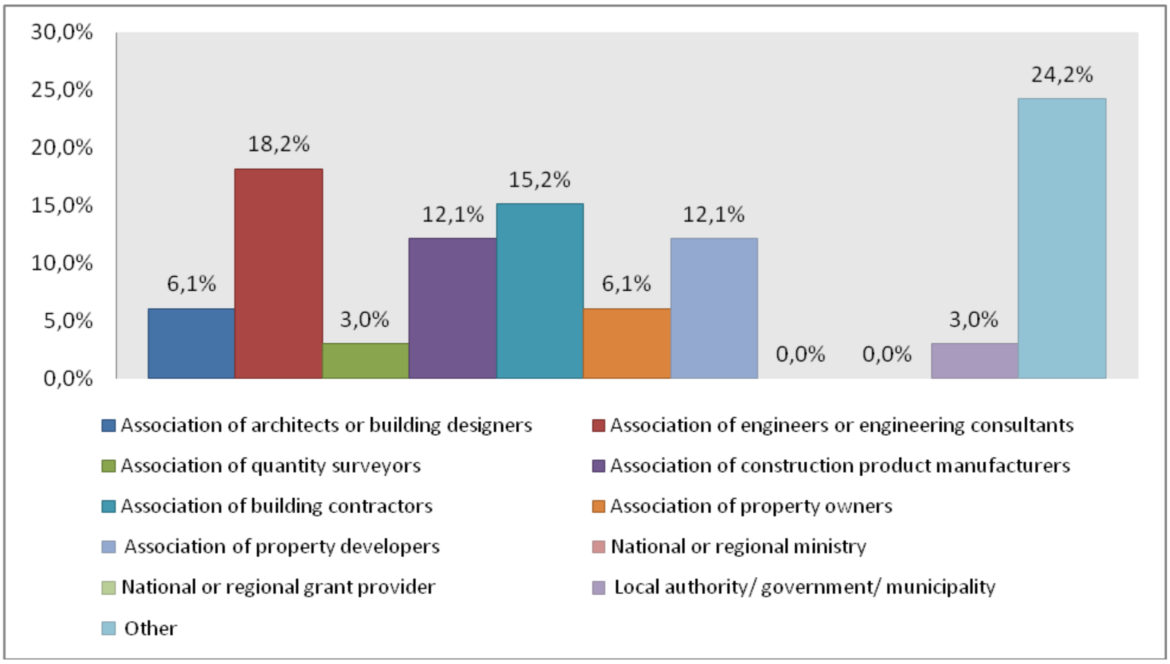
Participation/ Respondent Profile

Although broad participation was evident in the survey (stakeholders belonging to different types of groups and operating in different countries), a number of stakeholder groups were underrepresented or not represented at all. This included architects, quantity surveyors, property owners and clients, government & policy makers (including local authorities) and grant providers. A full overview of the response percent based on the type of organization is given in figure 1 and table 1.

Apart from the participation of organizations operating at an international level, also national organizations participated in the survey. Particularly, the following countries were represented:

- Denmark (engineers and building contractors)
- Norway (engineers, building contractors and construction product manufacturers),
- Sweden (engineers, building contractors, property owners, construction product manufacturers, local municipality and research institutes)
- Germany (engineers and research institute)
- Switzerland (LCA consulting company)
- Czech Republic (construction product manufacturers and the Czech Green Building Council)
- United Kingdom (carbon, engineering and sustainable building products consultants)
- United States (carbon consultants)

Figure 1 & Table 1. Response percent based on the type of organization/association represented by the participants of the survey



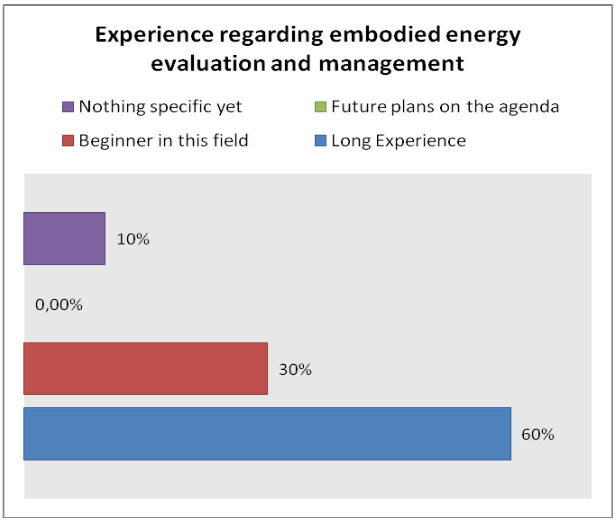
Type of Organization/ Stakeholder	Response Percent
Association of architects or building designers	6,1%
Association of engineers or engineering consultants	18,2%
Association of quantity surveyors	3,0%
Association of construction product manufacturers	12,1%
Association of building contractors	15,2%
Association of property owners	6,1%
Association of property developers	12,1%
National or regional ministry	0,0%
National or regional grant provider	0,0%
Local authority/ government/ municipality	3,0%
Other	24,2%

A detailed list of all the organisations participated in the survey can be found in Annex 1.

Key findings

1) The most organizations have already a long experience in evaluating and managing embodied energy and GHG emissions (Figure 2).

2) Long experience in the consideration of embodied energy and GHG emissions can be observed mostly in the following decision making situations: design process, optimization of products, sustainability assessment, development of policies and strategies, as well as development of laws and regulations (Figure 3).



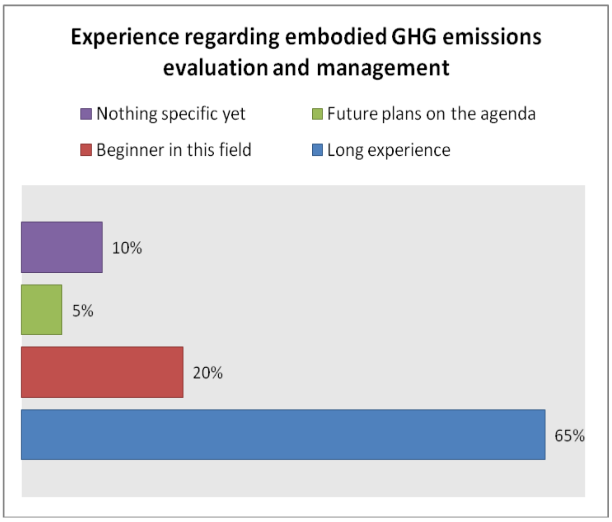


Figure 2.Diagrams, showing the experience (long experience, beginner in this field, etc.) of the organizations participating in the survey in terms of embodied energy and embodied GHG emissions evaluation and management.

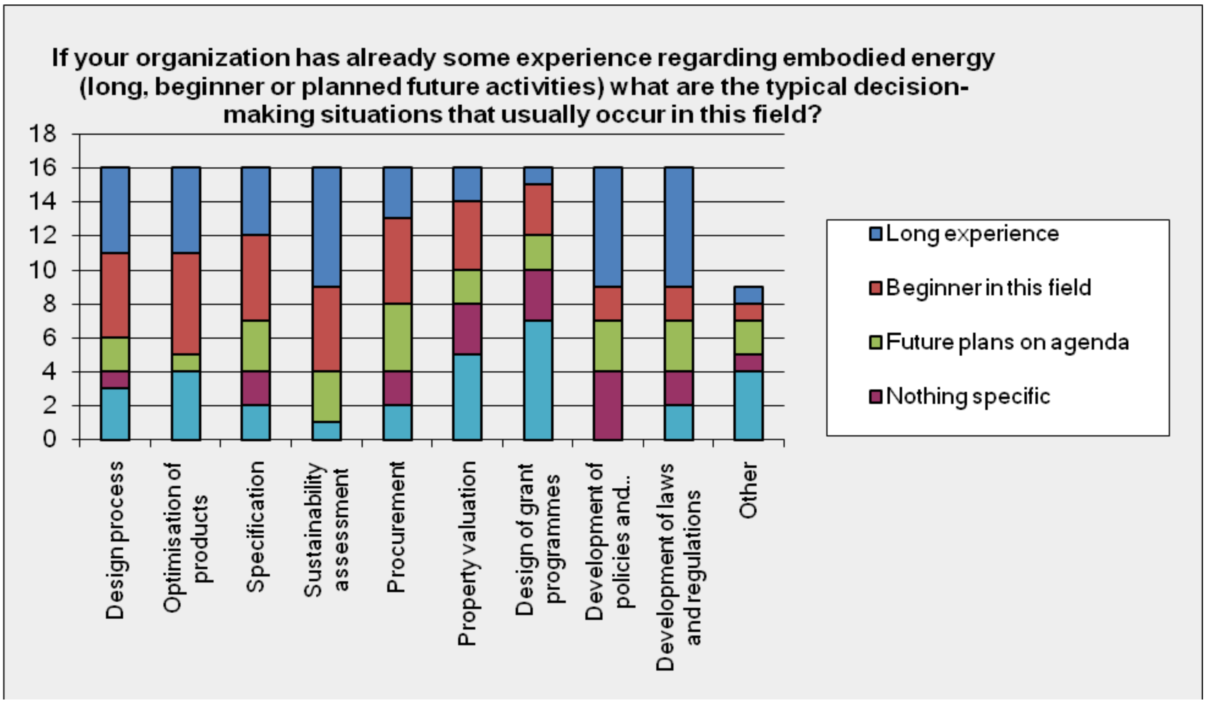


Figure 3. Decision making situations influenced the most by the consideration of embodied energy.

3) Different actor groups have different experience in the evaluation and management of embodied energy and GHG emissions, based on the decision making situations taking place. A detailed analysis is given in Table 2. Some more specific decision-making situations identified by the respondents representing different groups of actors are shown in table 3.

4) Specifically, the design professionals and consultants are interested in the (Table 3):
- integration of Eco-design principles (and consequently the issues of embodied energy and GHG emissions) into the design process
- Integration of carbon information into BIM models
- Use of LCA in certification systems, such as BREEAM and LEED.
- Comparison between different construction alternatives (wood, steel, concrete)
- Monitoring to reduce the environmental impact from the different projects

5) In the case of contractors, they are more interested in the (table 3):
- Monitoring to reduce the environmental impact from the different projects
- Setting energy and carbon target as part of the overall environmental goals
- Development of an internal road map for green improvements in buildings
- Integration of sustainability into property valuation

6) On the other hand, the construction product manufacturers are interested in the (Table 3):
- Development of EPDs
- Reduction of energy for production
- Use of EPDs as a basis for the sustainability assessment and other environmental improvements

7) Policy makers, as a governmental stakeholder group, are interested in the (table 3):
- Development of climate change strategy
- Development of legislation concerning reduced carbon footprint

8) On the other hand, public procurers are mainly interested in the (table 3):
- Requirements setting for the presentation of GHGs of materials built in by construction companies
- Implementation of sustainable public procurement

Table 2. Decision making situations per actor group

ACTORS / D. M. SITUATIONS	Architects and building designers	Engineers or engineering consultants	Construction product manufacturers	Building contractors	Property developers	Property owners	Government
Design process	**Long experience**	Future plans on the agenda	Not relevant	**Long experience**	Future plans on the agenda	Not relevant	Beginner
Optimisation of products	Not relevant	Not relevant	Beginner	**Long experience**	Not relevant	Not relevant	Beginner
Specification	Future plans on the agenda	**Long experience**	Beginner	Beginner	Nothing specific	Not relevant	Beginner
Sustainability assessment	**Long experience**	**Long experience**	**Long experience**	**Long experience**	**Long experience**	Not relevant	Beginner
Procurement	Future plans on the agenda	Not relevant	Beginner	Beginner	Future plans on the agenda	Not relevant	Beginner
Property valuation	Future plans on the agenda	Nothing specific yet	Not relevant	Nothing specific	Nothing specific	Not relevant	Beginner
Design of grant programmes	Nothing specific yet	Not relevant	Not relevant	Nothing specific	nothing specific	Not relevant	Beginner
Development of policies and strategies	Nothing specific yet	Nothing specific yet	Future plans on the agenda	Nothing specific	Nothing specific	**Long experience**	Beginner
Development of laws and regulations	Not relevant	Not relevant	Future plans on the agenda	Not relevant	Not relevant	**Long experience**	Beginner

Table 3. Decision making situations in detail

Actor Group	Decision making situations in detail
Designer	***Design process*** - integration of Eco-design principles to the design process - Integration of carbon information in BIM models ***Sustainability assessment*** - Use of LCA in certification systems as BREEAM, LEED - Comparison between different construction alternatives (wood, steel, concrete)
Contractor	***Development of policies and strategies*** - Monitoring to reduce the environmental impact from the different projects - Setting energy and carbon target as part of the overall environmental goals - Development of an internal road map for green improvements in buildings ***Property valuation*** - Integration of sustainability into property valuation

Construction product manufacturer	***Optimisation of products*** - Development of EPD's - Reduction of energy for production ***Sustainability assessment*** - Use of EPD's are used as basis for assessments and environmental improvements
Procurer (government)	***Sustainability assessment*** - Request presentation of GHGs of materials built in by construction companies ***Procurement*** - Implement sustainable public procurement
Policy maker (government)	***Development of policies and strategies*** - Development of climate strategy ***Development of laws and regulations*** - legislation concerning reduced carbon footprint

Table 4. Guidelines, databases and tools.

Tools	Examples	Countries
Guidelines	**ILCD Handbook**[52]	Internationally
	VDI Guideline for KEA[53]	Germany
	EeBGuide[54]	European research project
	Standards (e.g. EN 15978)	Europe
Databases	**National EPDs**	Germany, Norway, Czech Republic
	Ökobau.dat 2011	Germany
	ecoinvent data v2	Switzerland, internationally
	IVL database	Sweden
	Envimat CZ	Czech Republic
	USLCI	USA
	Natureplus	UK
Tools	**SimaPro v7.3.3**	
	ECOproduct	
	klimagassregnskap.no	Norway
	Anavitor / Skanska ECO2	Sweden
	Tally, Athena, etool,	USA
	build carbon neutral	
	Ecobilan TEAM	
	natureplus	
Benchmarks	**SIA 2040**	Switzerland

[52] An overview http://eplca.jrc.ec.europa.eu/?page_id=86

[53] An overview https://www.vdi.de/uploads/tx_vdirili/pdf/1807038.pdf

[54] An overview http://www.eebguide.eu/

Annex 1

Organisation (Weblink)	Countries/ Regions	No of members
WSP (www.wspgroup.com)	Global	15000
ARUP (www.arup.com)	Global	
World Federation of Engineering Organizations (WFEO) (www.wfeo.net)	Global	
SKANSKA (www.skanska.com)	North America, Latin America, Europe	55000
NCC (www.ncc.se)	Sweden, Norway, Denmark, Finland, Russia, Germany	10000
The Chartered Institute of Building (CIOB) (www.ciob.org)	Africa, Europe, Middle East, Americas, Australasia	45000
SKANSKA Sweden (www.skanska.se)	Sweden	10000
VEIDEKKE Group (www.veidekke.se)	Denmark, Norway, Sweden	6500
Construction Products Association (www.byggevareindustrien.no)	Norway	180
Czech Green Building Council (www.czgbc.org)	Czech Republic	100
Insulation Manufacturers Association (www.avmi.cz)	middle and east Europe	
Insulation Manufacturers Association (www.mineralniizolace.cz)	Czech Republic	
Swedish Association of Public Housing Companies (www.sabo.se)	Sweden	300
Sollentuna municipality (www.sollentuna.se)	Sweden	
SP Technical Research Institute (www.sp.se)	Sweden	
Treeze fair life cycle thinking (www.treeze.ch)	Switzerland	
Resource Efficiency Centre (www.ressource-deutschland.de)	Germany	
Carbon Leadership Forum (www.carbonleadershipforum.org)	United states	
Sturgis Carbon Profiling (www.sturgiscarbonprofiling.com)	USA, UK	
Alliance for Sustainable Building Products (www.asbp.org.uk)	UK	40

www.iea-ebc.org

Energy in Buildings and
Communities Programme

EBC is a programme of the International Energy Agency (IEA)