LoRe-LCA

Low Resource consumption buildings and constructions by use of LCA in design and decision making

Deliverable D3.2
Guidelines for LCA

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1 Introduction

The use of LCA is emerging in the building and construction sector, however the methodology is applied in different ways, more depending on the tools that are used than the purpose of the study.

This work within the LoRe-LCA research coordination action aims in giving guidelines for the actors involved in LCA for building and construction, meaning the practioners as well as the tool developers.

2 Purpose and scope

The main objective of WP3 is to establish a consensus on how to use LCA for a whole building, combining the LCA for the products in the building and the environmental impacts of the buildings operation phase.

An LCA can be performed for different purposes in the building sector, for instance:

- Help in the design of a new building (or road) with low environmental impacts,
- Help in the design of a renovation project, lowering the impacts of an existing building,
- Choose a building site to minimize environmental impacts,
- Contribute in a certification or labelling process,
- Study the design of an environmentally friendly building material or component.

The LCA methodology may be applied in a different way according to the purpose of the study, e.g. the choice of a building site may influence transport needs and the related impacts, so that this aspect will be integrated in the system boundaries whereas transport may be excluded if the purpose of the LCA is to compare various architectural designs for a fixed building site.

Buildings are complex systems, and simplifying their description is needed if LCA is to be used by building professionals, having a limited time to perform a study. Another difficulty is the lack of data, particularly at early design phase, during which the decisions have the largest influence on the environmental performance, making LCA even more useful.

It is therefore needed to advise tool developers and users about good practice, particularly regarding the following issues:

- Definition of a building as a system with functional unit and system boundaries,
- Definition of simplified building description with default values for the early phase of a project (e.g. architecture sketch),
- Identification of good practice regarding LCI (Life cycle inventories),
- Recommendations regarding specific methodological aspects.

Deliverable D3.1 *Building LCA good practice report*, starting from an analysis of the state of the art made in WP2, presents a comparison of different approaches and when possible identification of good practice. For instance, different indicators are proposed for resource depletion, different methods exist to account for recycling, etc. May be one alternative has more advantages, and can be proposed as good practice. In some cases, no conclusions can be drawn during this project and further research needs may be identified. General LCA guidelines like in documents from ILCD[1] or CALCAS[2] are studied but some recommendations may differ due to the specificity of the building sector. Finally, this analysis of good practice and knowledge gaps leads to propose some possibilities for further research.

Deliverable D3.2 *Guidelines for designers* is an operational summary providing the main conclusions of the work package, structured in 2 parts a) for tool developers and b) for users.

3 Recommendations for tool developers

The first recommendation is to integrate existing knowledge, about LCA in general, and about the specific application of this approach in the building sector. Corresponding literature is suggested in this document. But as LoRe-LCA is a research coordination action, the document also shows limits in the present knowledge, possible contradiction between the different documents analysed, and proposes some research activities that tool developers may anticipate in order to plan some adaptation of the tools according to the progress of knowledge.

This document is structured in two mains parts: general knowledge about LCA, and specific application in the building sector. The analysed literature, and particularly the ILCD handbook – International Reference Life Cycle Data System-, published by the Institute for Environment and Sustainability (Joint Research Centre of the European Commission in Ispra), is very detailed and integrates complex topics like comprehensive impact indicators systems, iterative process for setting cut off rules, consequential versus attributional LCA etc. Such approach requires that tool developers spend a lot of time for acquiring this knowledge, and implementing it in their tool.

Some building practitioners have developed simple excel files allowing e.g. CO_2 emissions or energy use to be evaluated by adding the contributions of building materials and processes. Such “do it yourself” LCA may be useful in a first step to have an idea about the method, but as knowledge is progressing, the limits of such tools become clearer as well as the need for more sophisticated tools. A specificity of the construction sector is that each building is generally unique, unlike industrial products which are manufactured in large series. There is therefore a more limited time for studies, and particularly for LCA. For this reason, specific tools are developed and these tools are used by building professionals, architects and consultants, who are no LCA experts. As a

[1] See European platform on life cycle assessment : http://lct.jrc.ec.europa.eu/eplca

[2] European Coordination Action for innovation in Life Cycle Analysis for Sustainability, http://www.calcasproject.net/

consequence, the respect of good practice in applying LCA is primarily the responsibility of tool developers, particularly ensuring consistency among the different data and methods combined in the tools. We hope that this document will contribute to facilitate the improvement of tools, and also prepares further useful research activities in this field.

3.1 Integrating the existing knowledge about LCA

The ISO 14040 and 14044 standards[3] constitute a first basis and provide a definition of the LCA methodology. These documents correspond to an internationally agreed framework, and remain rather vague. Much more detail is provided by the set of documents published by ILCD. This is why we use here this handbook as a basis. It is structured in several documents, and we have analysed the following:

- General guide for LCA detail,
- General guide for LCA provisions,
- Specific guide for LCI,
- LCIA Background analysis,
- LCIA Framework requirements,
- Review schemes.

It would not make any sense to reproduce or simply summarise here these documents: it is strongly recommended to read them. The comments hereunder concern possible questions regarding the application of this handbook in the building sector, due to its specific characteristics, and possible gaps in the knowledge that may require further research activities.

General-guide-for-LCA-detail

This guide addresses the different steps of the LCA method, as they are described in the ISO 14040 standard:

- goal definition,
- scope definition,
- life cycle inventory,
- life cycle impact assessment,
- interpretation,
- reporting,
- critical review.

[3] ISO 14040:2006, Environmental management, Life cycle assessment, Principle and framework

ISO 14044:2006, Environmental management, Life cycle assessment, Requirements and guidelines

Some complementary aspects are introduced, like the suggestion of an iterative process to perform an LCA, and methodological choices (particularly attributional versus consequential LCA) according to 3 main situations. Important annexes are included on specific topics like: data quality concept, calculation of CO_2 emissions from land transformation, modelling reuse, recycling and energy recovery, avoiding misleading goal, scope and interpretation, addressing uncertainties.

An iterative process is suggested, because more information is available during the inventory and impact assessment phases, which may induce the need to refine the initial scope (e.g. key processes may be identified, leading to refine the corresponding data collection and/or cut off rules). Such iterative process is already implemented in the building sector: the architect may adapt the design according to some calculation results, which in return leads to new calculations. Generic data may be used at an early design stage (e.g. average values for building materials) and may be replaced by specific producer data when a contractor compares several products. This illustrates the possibility of a parallel evolution of both building design and LCA.

The handbook defines two main approaches: attributional and consequential LCA. Attributional modelling inventories input and output flows as they occur, whereas the consequential approach accounts for the consequences of the studied system ("foreground system") on the background system (e.g. electricity and fuel production, raw materials, waste treatment etc.). Three main situations are identified, and the choice between attributional and consequential LCA is advised for each situation:

- a decision at a "micro-level", e.g. the design of one building, is supposed having negligible consequences on the background system, so that attributional LCA is advised;
- on the other hand, a decision at a "macro-level" (e.g. building sector policy making) may have large scale structural effects on the background system so that consequential approach is recommended;
- use of LCA for accounting, with or without system-external interactions.

A specificity of the building sector may be noted here: each building has limited environmental impacts and consequences on the background system, but this is no more the case for the whole sector. For instance in France, 70% of new constructions are heated using electricity. This induces a very high peak demand in winter, and consequently the implementation of new thermal plants with high CO_2 emissions, even if the contribution of each building is small. Some experts recommend therefore to account for these supplementary CO_2 emissions when performing an LCA, which corresponds to a consequential approach. Applying the ILCD recommendation in the building sector is thus not completely obvious, and some further investigation may be suggested on this issue.

A matrix numerical resolution is sometimes proposed to solve the interactions between the different industrial processes[4]. For instance, producing concrete requires energy, producing energy requires steel, which in turn requires energy and concrete, etc. A matrix system allows the impact of each process to be evaluated, accounting for these interactions. Surprisingly, this possibility is not mentioned in the ILCD handbook.

Another specificity of buildings is the complexity of their function, particularly regarding indoor conditions (thermal, visual and acoustic comfort, air quality etc.) so that a very strict definition of the functional unit is hardly possible: e.g. with no air-conditioning, even a small change in the design of a project may induce a small change of summer temperatures; if such temperature level is strictly précised, alternative designs could be compared anymore because the functional units are different. Therefore some flexibility is needed to some extent. Indoor conditions could be addressed at the interpretation phase: e.g. one alternative may lead to lower environmental impacts but slightly higher overheating risk in summer.

Defining the system boundaries is also a difficult task in the building sector, due to the complexity of the studied system. Research is still needed regarding the application of cut off rules. At the moment, tools allow the users to select included components in the building description. The iterative process described in the ILCD handbook is difficult to implement in practice, above all for non LCA experts. Tool developers may provide recommendations according to their own experience, so that users are guided about the appropriate level of detail when describing a building. Heat produced by the building heat losses or equipment contributes to the heat island effect, influencing the energy load of other buildings in the city (the concept of "context system" is proposed in the handbook). Extension of the system would be needed to account for such effects, but modelling micro-climates is still a difficult research topic.

According to previous studies[5], each design alternative (e.g. replacing double glazing by triple glazing, changing the insulation material, etc.) has a limited effect on the global impacts. Only a combination of measures has a significant influence (e.g. comparing a passive building to a standard building). If the cut off rule is determined according to the very small variation of each individual measure, collecting data with a sufficient precision is hardly possible. The cut off process suggested in the handbook certainly has to be adapted to the building sector.

The database including life cycle inventories (LCI) of materials and processes is a key element of any LCA tool. A list of requirements is included in the ILCD handbook, e.g.:

- compatibility of the data with the goal and scope of the assessment, as well as further steps (impact assessment, interpretation),

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[4] Olivier Jolliet, Myriam Saadé et Pierre Crettaz, Analyse du cycle de vie, comprendre et réaliser un écobilan, Presses Polytechniques et Universitaires Romandes, Lausanne, 2005

[5] PRESCO thematic network (Practical recommendations for sustainable construction), see http://www.etn-presco.net/generalinfo/index.html

- representativeness regarding technology, location and time, particularly for generic data, and data corresponding to the background system,
- precision, check by a third party (use of pre-verified data sets),
- consistency, essential particularly if several materials are to be compared.

It is not sure if existing data bases in the building sector respect these requirements.

Elementary flows in LCI should preferably be inventoried as individual substances rather than flow groups like e.g. “VOCs” (volatile organic compounds). Such groups are in general not suitable for subsequent impact assessment and can cause large bias in the results. According to the handbook, “it is not permissible to hide highly impacting (e.g. toxic) substances in common sum indicators”. This rule is not always respected in the present EPDs for building products.

In the case of long life-time products like buildings, the use of future-related foreground scenarios is recommended, which suggests another research topic to identify such scenarios. The handbook proposes some ideas like considering a mix of best available technologies, and requires that sensitivity studies are performed in order to check that future-related uncertainties do not affect the results and interpretation, or otherwise that limits of the study are clearly stated.

It is recommended to use specific data for the foreground system and generic data for the background system. One possible goal of applying LCA is to contribute in the eco-design of a building. In this case, using LCA in the early design phases is essential because the decisions influencing the most the environmental quality are made at these phases. But in general the producers of building materials and components are still unknown at that time so that using specific data is not possible. The use of generic data seems therefore more relevant in early design.

How to deal with missing data is another difficult question. Some processes judged negligible may be excluded, but this requires some justification. In a consequential approach, the identification of processes to be included is more complex: new production plants or services implied by the foreground system, market displacement, consumers behaviour changes etc. Primary consequences may have in their turn secondary consequences with related processes. Marginal processes may be different from the average processes considered in the background system attributional model. The ILCD handbook provides a methodology to identify these processes (e.g. mix of more likely marginal processes), primary and secondary consequences (e.g. rebound effect). Applying this methodology in the case of a building typology could constitute a useful applied research activity.

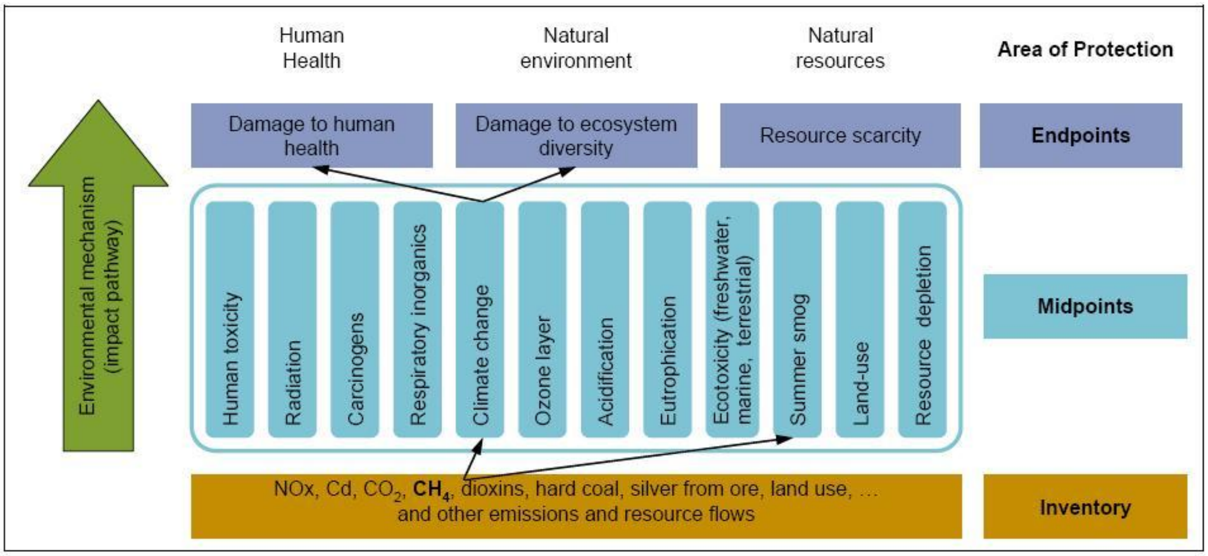
The handbook proposes to express the energy content of fuels in the Lower calorific value of the water free resource, measured in MJ. In the building sector, condensing boilers are used so that the upper heating value could be more appropriate. According to ILCD, all renewable energies have to be inventoried. But consuming solar electricity produced in the building itself or solar electricity from the grid may have different consequences on e.g. peak demand and grid management. The efforts for integrating PV modules in a building could be rewarded by discounting impacts related to the corresponding electricity production. This aspect has therefore to be clarified. May be the right split is not between renewables and non renewables, but between limited and non limited energy flows. For instance wood, hydro-power and geothermal energy is limited: consuming wood reduces the resource for others. On the other hand installing a solar collector on a roof does not reduce the resource for others, so that adding solar and biomass energy consumption does not seem relevant.

In the case of co-products or "co-functions" (e.g. a domestic waste incinerator with heat recovery has two functions: waste treatment, and heat production), some allocation methods are proposed in order to evaluate the impacts of each product/function. For instance the impacts of incineration are known. Using the substitution method, the impacts of waste treatment would be obtained by substracting the average impacts of heat production. This method is suggested also for recycling, taking the example of recycling waste wood to produce particle boards (page 84). The impacts of chipping waste wood are known. The waste wood treatment impacts are derived by sustracting the impacts of average wood chips production. This method is also called "avoided burden method". Concerning recycling, the ILCD proposal leads to possible double counting: in order to avoid this risk, the avoided burden may be rather counted 50% only at each end of the life cycle. The ILCD recommendations provide new perspectives (but also research activities) regarding the application of consequential LCA in allocation: e.g. recycling more wood from buildings may influence the average wood chips production.

A method is proposed to account for carbon storage in timber. The biological uptake and release of CO_2 cancel each other out, but a correction flow for delayed emission of biogenic CO_2 is considered. An example of a house with 4 tons of carbon stored in 10 tons of wooden beams is given. The biological uptake of CO_2 is 4 x 44/12 = 14.7 tons of CO_2-eq., and the release is the same amount. Assuming a 80 years life span for this house, the corrective flow is -14.7*80/100 ton CO_2-eq. i.e. -11.7 ton CO_2-eq. In this approach, emissions beyond 100 years are considered separately.

The handbook also clarifies how to model waste. Waste flows are no elementary flows, but are flows inside the "technosphere", and therefore their further management and treatment needs to be modelled, with the exception of radioactive waste and mine filling because no agreed model is available. A method is proposed to deal with recycling, reuse and energy recovery. In the case of attributional modelling, it consists in considering that a primary production creates co-products: the primary product, the secondary product (the same product that can be recycled after use), and possible subsequent products in case of multiple recycling. Another approach is proposed for consequential modelling, which is similar to the avoided burden approach, accounting for a possible lower life span for the recycled product. These approaches could be tested in the case of building products, in order to have a clearer idea on how they compare to other approaches (e.g. CEN method, 50% avoided burden…).

Regarding life cycle impact assessment (LCIA), the handbook states that "selection of impact categories must be comprehensive and cover all relevant environmental issues related to the analysed system". The figure below gives an example of such impact categories, making a distinction between mid-points and end-points.



From life cycle inventory to midpoint and endpoint indicators, source : ILCD Handbook

Different methods are proposed to assess Resource scarcity, e.g. the abiotic depletion potential (CML methodology[6]), or the surplus energy to extract minerals and fossil fuels (Ecoindicator 99 methodology[7]). One common gap in both methods concerns uranium. No characterisation factor is given for the second indicator[Van Caneghem, 2010]. In the first indicator, ultimate reserves are considered and the corresponding value is very large for Uranium: 62.5 billion tons, to be compared with 13 million tonnes probable reserves given by the U.S bureau of Mines. As a result, the use of Uranium has a negligible influence on the indicator value. In fact, a large part of these ultimate reserves is very much diluted so that more energy would be needed to extract usable uranium than the energy this uranium could provide. Therefore considering ultimate reserves does not seem relevant in this case. If probable reserves would be used instead, the indicator value would be much more sensitive to uranium consumption. This aspect is important in the building sector, which consumes around 65% of the electricity produced in Europe, with around 40% average contribution of nuclear plants. Specific research would therefore be needed to improve or complement the existing resource indicators.

A CEN standard has been elaborated regarding the application of LCA for buildings (see the next §), and another set of indicators has been selected, so that the recommendation here would be to anticipate a further evolution of impact assessment methods.

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[6] Guinée J. B., (final editor), Gorrée M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H. A., de Bruijn H., van Duin R., Huijbregts M. A. J., Lindeijer E., Roorda A. A. H., Weidema B. P. : Life cycle assessment; An operational guide to the ISO standards; Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands, 2001, 704 p.

[7] GOEDKOOP M. and SPRIENSMA R. (2000) "The Eco-indicator 99 : A damage oriented method for life cycle impact assessment", PRé Consultants, Amersfoort, The Netherlands, 142 p.

Normalisation is based upon a reference value, generally per capita. This reference value could correspond to a regional, national, European or world average, according to the purpose of the study. Weighting factors are always normative/subjective, and reflect value assumptions: they are not necessary in LCA but may be required by a client or political authority. In any case, LCIA methods, possible normalisation and weighting, should be precisely documented so that the users have a clear knowledge of the performed evaluation.

Interpretation is probably one of the steps requiring the most expertise. The tools should help the users identifying the processes/materials and life cycle stages having a highest contribution in the global impacts, e.g. using bar or pie charts, and contribution analysis techniques. Sensitivity studies are also needed to check the robustness of the results in terms of assumptions (e.g. life span, modelling choices etc.). Scenario analysis techniques can be used for this purpose. Uncertainty analysis (e.g. using Monte Carlo simulation for stochastic uncertainty) would be also helpful, which could constitute another research topic. Identifying limitations in the conclusions may be addressed by presenting example case studies, showing that recommendations (e.g. design advice) can be accompanied with statements limiting their scope (e.g. this recommendation is valid if the building life span is longer than 50 years). The risk of misinterpretation could also be illustrated by examples (e.g. over-interpreted comparison based upon insignificant impact differences).

Reporting could be shared between the description of the tool made by the developer (methodology, main assumptions, possible exclusion of neglected processes, LCI data, impact assessment methods, possible normalisation and weighting…), and the study report written by the user (building description, specific assumptions in the project like considered life span, transport distances etc., interpretation of the results…). According to the handbook and ISO standards, if the study includes some comparison of techniques and is made public, no value based weighting of indicators is permitted.

As mentioned previously, LCA cannot be performed in the building sector with the same level of detail as in the industry. In practice, a critical review process cannot be organised e.g. for the design of one building. May be one solution is that such a review is organised once (or once a year) for each tool. Organising a users club with the possibility to cross review some studies, internet forums etc. could be relevant.

General-guide-for-LCA-provisions

This document is an operational summary of the previous one, including only the provisions (requirements) but not the details.

Specific guide for LCI

This document is included in the first one.

LCIA-Background-analysis

This document analyses existing impact assessment methods: CML 2002, Eco-indicator 99, EDIP97 and 2003, EPS2000, Impact 2002+, LIME, LUCAS, ReCiPe, Ecological scarcity (Ecopoints 2006), TRACI, MEEuP and other methods (USEtox, EcoSense, Ecological footprint…). This analysis addresses the purpose of each method, its set of indicators (mid-points and end-points), its geographical and temporal validity, the consistency in the treatment of different impacts, the number of substances covered, possible normalisation and weighting.

LCIA-Framework-requirements

This document is intended to support a robust and consistent framework and methods for life cycle impact assessment, considering three main areas of protection (AoP): human health, natural environment, and natural resources. Characterisation models are evaluated in terms of completeness of scope, environmental relevance, scientific robustness and certainty, documentation, transparency and reproducibility, applicability, as well as a supplementary stakeholder acceptance criteria related to the suitability for communication in a business and policy context. Regarding human health, a focus is put on the DALY indicator (Disability-adjusted life years), which does not account e.g. for carbon monoxide emissions. Such limit may be problematic in the building sector. The document recommends using the Potentially Disappeared Fraction of species (PDF) as end-point indicator for the AoP Natural Environment, but no recommendation is made regarding Natural resources. Dealing with mid-point indicators is easier, so that recommendations are provided for e.g. climate change, ozone depletion, acidification, eutrophication etc. Some mid-point indicators have similarities with end-point (human toxicity, eco-toxicity, resource depletion), showing that impact assessment is still a research topic.

Review-schemes

The necessary level of review in different application contexts is illustrated through a set of review schemes for 12 cases. Two review types, “independent external review” and “independent panel review” are defined. The reviewer’s skills and expertise are also addressed, a separate document being dedicated to the reviewer qualification.

3.2 Specific LCA application in the building sector

Since the first European project addressing the use of LCA in the building sector (REGENER, 1995-96), several projects have been dedicated to this topic. The more recent project ENSLIC Building provides a state of the art document and guidelines regarding the application of LCA in the building sector, see www.enslic.eu.

A CEN standard defines a way to apply LCA for buildings[8]. The approach seems sometimes in contradiction with the ILCD approach, regarding for instance:

- completeness of the indicators set (no indicator on human toxicity and biodiversity),
- system boundaries (no modelling of waste treatment),
- methodological aspects (modelling recycling, CO_2 storage in timber).

[8] prEN 15643-2:2008 Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance

This shows that more research is needed to progress towards more a comprehensive and robust methodology. Nevertheless, the CEN standard provides a first basis, allowing environmental quality to be accounted now by practicioners. One suggestion could be to apply the CEN method if the tool is intended for certification, whereas eco-design tools could be more research-oriented and include supplementary elements.

In any case, it is suggested to perform the benchmark study elaborated in the frame of the European thematic network PRESCO (Practical Recommendations for Sustainable Construction, see http://www.etn-presco.net/generalinfo/index.html). Two case studies are described. The first one is a simple concrete cube allowing a first verification of the life cycle calculation in a very simple case. The second is a wooden house, also not too complex so that the risk of erroneous input is minimised. Several environmental indicators have been calculated using 8 tools developed in different countries. The results can be used to compare new tools and identify possible errors.

As explained previously, the LoRe-LCA project is a research coordination action. The main goal is to refine the state of the art, and identify gaps in the present knowledge and corresponding research activities that would be useful. All Building LCA tool developers are welcome to provide some input and ideas in order to contribute in the progress of this new field of expertise.

4 Recommendations for users

The recommendations should include:

- Functional unit
- System boundaries and process tree
- Simplification and cut off rules
- Use of default values

When relevant, specific aspects will also be addressed: dynamic LCA, attributional versus consequential, minimal list of substances, contextualisation

4.1 Programme and architectural competition

4.1.1 Background

Architectural competitions offer an excellent way to find the best solutions concerning design, economy, functionality, energy efficiency and sustainability. The European Commission considers architectural competitions to be a driving force for architectural quality, providing benefits in terms of financial aspects, quality, functionality and efficiency with relevance throughout the life of buildings [(COM 2007) 501]. Furthermore EU Directives on public tenders oblige public authorities to conduct architectural competitions for their buildings.

The most important phases for implementing sustainability-relevant aspects in the building planning are the programming stage and the architectural competition. In those phases of the planning stage all decisions that have to be made are of upmost importance to create sustainable buildings. For example in the preliminary design phase (which is the scope of work in almost all architectural competitions) decisions on aspects like orientation, compactness and openings of windows determine the future energy performance and the operation costs of buildings.

Consideration of LCA aspects (or at least Life Cycle Thinking) in architectural competitions is difficult to introduce due to the lack of knowledge and suitable tools, in terms of objectivity, consistency and simplicity.

4.1.2 Recommendations

LCA related issues have to be implemented already within the tendering of the competition. The main focus of the following recommendations is on “classical” architectural competitions, as this type is the most common competition type all over Europe. Classical architectural competitions are competitive tendering to select the architect to carry out design work for his winning project. It is not tendering for a building itself with detailed information about construction, materials, HVAC systems and guarantees for construction costs. A practicable implementation of LCA-related aspects has to be done along the typical stages of architectural competitions, considering content and scope of these stages.

4.1.2.1 Structure of classical architectural competitions

Architectural competitions can be divided into following stages:

- Programming stage (Project development)
- Tendering
- Design work of participants
- Design approval through experts
- Jury meeting

4.1.2.2 Content and scope of architectural competitions

Beyond doubt the most important stage to implement sustainability aspects is the programming stage. In this stage clients have to set clear targets concerning the energy performance (like the energy standard) and sustainability aspects (like CO_2- equivalents of building materials) of the projected building. Benchmarks set always have to be seen in relation to their costs (favoured life cycle costs). As qualitative target values hinder comprehensive LCA, quantitative target values are highly recommended. To enable a comparable assessment of environmental aspects in the design approval stage, content, scope and methodology of the LCA to be conducted have to be defined. In such way the definition of the functional unit (area, use, assumed building life span etc.) is a must to get comparable results.

In the competition stage (preliminary design stage) information on the building are limited to design-related aspects like definition of heated and cooled areas, shape to volume ratio, area and disposition of windows, building position and orientation. Detailed information on construction system, building materials and HVAC systems are not available. This circumstance has to be kept in mind when integration of LCA in architectural competitions is planned. Because of these limited information about the building a comprehensive LCA study (following the methodology stated in ISO 14040 and 14044) for competition projects in most cases is not feasible and however, a partial integration of Life Cycle Thinking (Life Cycle Aspects) is possible. Another approach to bypass these information gaps could be the use of default values for unknown parameters (e.g. defaults for u-values).

4.1.2.3 LCA specifications and their implementation

General requirements

Competitive tendering (especially for public clients) has to follow certain rules for the set of technical specifications (here LCA-aspects). Therefore LCA specifications should also meet the following requirements:

- Verifiable
- Transparent
- Comparable
- Quantitative (as far as possible)

Weighting of LCA-aspects

LCA specification and their weighting should be seen in relation to other specifications (architectural quality, function, costs, etc.). Therefore tendering institutions/clients have to provide clear and transparent weighting criteria for the participants of competitions. Also a weighting within different LCA-specifications (e.g. higher weighting of indicators with higher environmental impacts) in most cases makes sense.

Design approval stage

For the proof of LCA-data provided by the participants tendering authorities have to create clear rules. Provision of a standardised, simplified LCA-tool by the tendering authority, which has to be used mandatory by all participants, is the only way to get comparable LCA results. Participants should have the possibility to use this LCA-tool for the optimisation of their projects. Evaluation of results should be done by experts in the design approval stage. Besides other results LCA results should be summed up in a report for the jury, which is the basis for the jury decision.

Jury meeting

Especially for architectural competitions with strong focus on environmental aspects the inclusion of LCA experts with voting power in the jury meeting is essential. Decisions of the jury should be based on quantitative results provided by a report from the design approval stage.

System boundaries

As there is only limited information about the building in the competition stage and, additionally, the winner project often takes changes until its realisation in most cases only few LCA aspects can be taken into account. If calculations for LCA are done on spreadsheets (without simulation tool linked to CAD), which is currently the most common way in architectural competitions, the system boundaries should be restricted to product and use stage, with the product stage limited to the manufacture of building structure and building envelope materials. To reduce operating expenses of all actors in architectural competitions the assessment of construction and building materials should be limited to the thermal building shell and suspended ceilings. On one hand experiences from different LCA studies show that these building elements have the biggest environmental impacts and on the other hand information on these elements are available in almost all architectural competitions.

Stage	Module
I. Product stage	Raw materials supply
	Transport
	Manufacturing
II. Construction process stage	Transport
	Construction-installation on-site process
III. Use stage	Maintenance (transport included)
	Repair & replacement (transport included)
	Refurbishment (transport included)
	Operational energy use: heating, cooling, ventilation, hot water and lighting
	Operational water use
IV. End-of-life stage	Deconstruction
	Transport
	Recycling/re-use
	Final disposal in landfill/incinerator

Table 1 Life cycle stages of a building based on the CEN/TC 350 and stages recommended for assessment in architectural competitions using no simulation tool linked to CAD (red)

For competitions using simulation tools linked with CAD, more comprehensive assessments are possible, as on one hand more input data are available and on the other hand environmental impacts along all life cycle stages can be calculated automatically.

Functional equivalents

Preferably the functional equivalent should be the total building based on the requirements of the tendering body (e.g. a wooden residential building with 20 flats a`100m^2, in passive house standard, etc.).

Energy for the use stage – Heating and Cooling

Throughout the life cycle of almost all conditioned (heating, cooling, ventilation, DHW, lighting) buildings the energy demand during the use stage outweighs energy consumption during other stages (exception: plus energy buildings). The assessment of the energetic performance of competition projects should be on calculation of useful energy, which is determined by design-related aspects. A quantitative energetic assessment gives rise to only marginal additional effort as the data base (mainly geometrical data) is ready available of each competition project.

Default values/presumptions have to be provided by the tendering authority for **all** participants of the competition:

- Definition of the thermal standard by determination of default values for U-values and g-values (transparent building parts)
- Determinations concerning the kind of ventilation (natural ventilation or mechanical ventilation with/without heat recovery)

Recommendations for indicators and functional units:

- Useful energy demand for heating in kWh/building (functional equivalent)/year(s)
- Useful cooling energy demand (without internal gains) in kWh/building (functional equivalent)/year(s)

Functional units (based on kWh/m2 conditioned area) showing the energetic standard (e.g. passive house standard) should be used only for information - the annual energy performance depends on the total amount of m^2 of conditioned area/competition project.

Assessment on final energy or primary energy need much more detailed information on the building and the HVAC system. If assessments on final or primary energy are to be prescribed default values for HVAC-systems and energy sources should be used. If assessment is on primary energy, primary energy should be split up into primary energy non renewable and primary energy renewable, where primary energy non renewable is the more important indicator. Another approach might be the split into limited and non limited energy flows. In this logic, imported biomass, hydropower, geothermal and wind energy would be accounted for but solar electricity or heat produced on site would not be considered limited.

Active use of solar energy

Against other HVAC-systems active use of solar energy (thermal and photovoltaic solar collectors) on one hand has strong input on the design of the building and on the other hand the use of solar energy also has strong influence on the environmental performance of the building. Therefore the gains from solar panels should be part of the LCA. It is recommended to subtract the gains from the final and primary energy demand (which also leads to a reduction of CO_2-Equivalents).

CO_2 -Equivalents

Based on the results for the calculation of the final energy demand (with standardised default values for the HVAC-systems for all participants) and the application of predefined CO_2-factors CO_2-equivalents can be used as LCA indicator:

- CO_2-equivalents for heating in to of CO_2/ building (functional equivalent)/year(s)
- CO_2-equivalents for cooling in to of CO_2/ building (functional equivalent)/year(s)

Required input data for the assessment of energy related LCA aspects

To enable comparability of competition projects a minimum standard of information (plans, calculations) has to be provided compulsory by all participants:

- Conditioned gross floor area
- Conditioned gross volume
- Transparent areas (windows) separated by orientation
- Opaque areas of the thermal surface divided into roof, façade and ground slabs
- Area and orientation of solar panels (if required by tendering)

Compulsory use of one assessment tool by all participants is the only way to get reliable and comparable results. The use of alternative tools has to be excluded.

Energy for the use stage – Artificial Lighting

Besides heating and cooling the energy demand for artificial lighting is of importance for the environmental performance of buildings. Buildings with huge overall width, like office buildings, tend to have substantial energy demand for artificial lighting. Because of the level of detail and the enormous effort, quantitative assessment of lighting demand is difficult in the competition stage. Qualitative assessment can be facilitated by sectional drawings and floor plans showing the daylight concept of the building as shown in the example below. For competitions using simulation tools linked with CAD, more comprehensive assessments of the energy demand for lighting are possible, as on one hand more input data are available and on the other hand the energy demand for lighting can be calculated automatically.

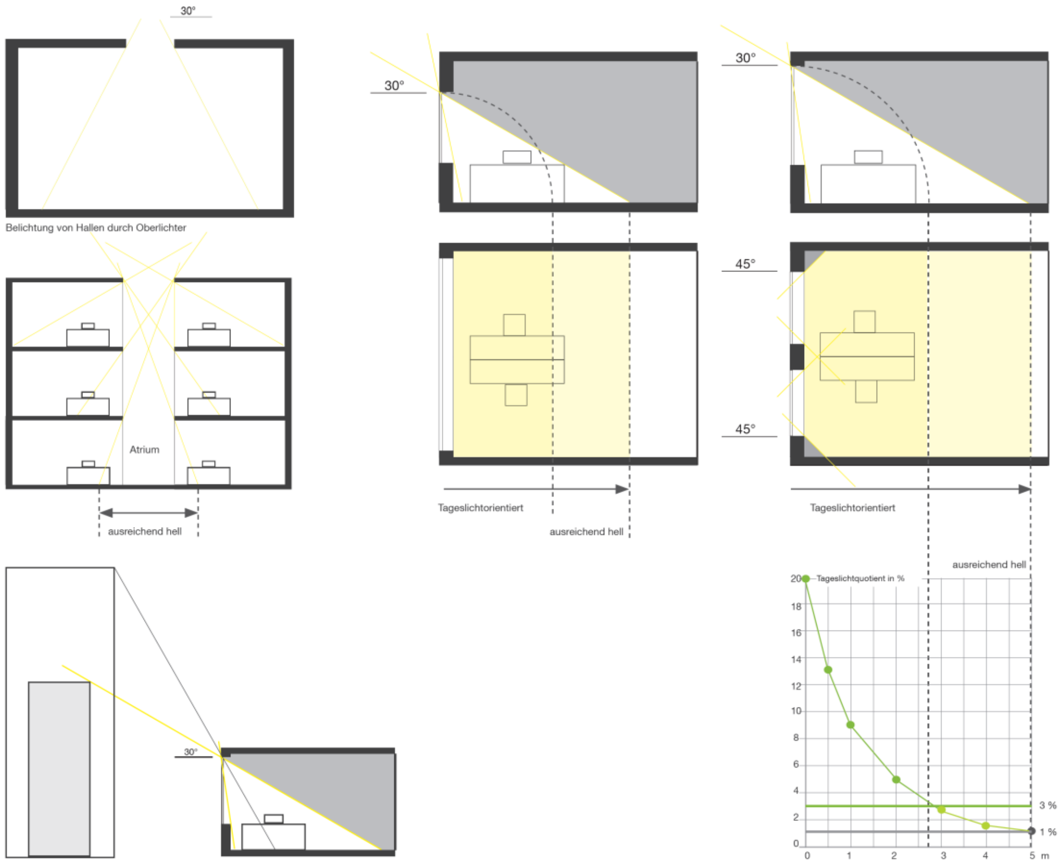


Fig. 1 Sectional drawings and floor plans for the assessment of daylight concepts [1]

Building materials and construction

Besides environmental impacts caused by operational energy use in the use stage, impacts from the product stage are of interest for the assessment of buildings in architectural competitions. In most of the architectural competitions a detailed description of the building elements (layout of walls, roofs, slabs, etc.) is not common, only the main construction system (wood, concrete, etc) is decided on at this stage. So unlike the above mentioned assessment of energy related LCA aspects the assessment of building materials and constructions requires higher efforts by all persons involved in architectural competitions. To reduce the effort of the assessment, system boundaries should be limited to the product stage and the focus, following the approach concerning energy aspects, should be on thermal building shell and on suspended ceilings. In general two approaches are possible:

Preset of the construction system and building materials

If clients have strong preferences for a construction system and building materials (e.g. a wooden building with wooden walls, wooden windows, wooden slabs, etc.), a detailed predefinition of all building elements makes sense. Participants of the competition are obliged to use this pre defined elements in a simplified LCA tool (with data base) provided by the client. In this case LCA results are only determined by design relevant aspects like area of walls, slabs and windows.

Free set of the construction system and building materials

To enable a wider range of scope participants are free in the choice of the construction and materials. Clients have to provide a simplified LCA tool (with data base) for all participants. In this case LCA results are determined both by design relevant aspects and the choice of different building materials. This approach means high efforts for all involved persons (architects, experts of the design approval stage), which certainly hinders a broader application in architectural competitions.

LCA Indicators

Following indicators are recommended:

- CO_2-equivalents in to of CO_2/building (functional equivalent)/year(s)
- Primary energy demand renewable in MJ/building (functional equivalent)/year(s)
- Primary energy demand non renewable in MJ/building (functional equivalent)/year(s)
- Indicator for radioactive waste

On one hand these are the most important indicators for building materials and on the other hand they are the same indicators as chosen for energy in the use stage, which enables a demonstrative comparison of impacts from the product stage and the use stage.

Required input data for the assessment of LCA related aspects

The assessment of building materials involves no change of system boundaries, so the same input data as stated for energy related aspects have to be provided by the participants (see above).

Land use

Especially for architectural competitions dealing with urbanistic issues, land use is of strong relevance. Sealing of natural ground through buildings and outside facilities has large environmental impacts (damage of soil fauna and flora, hindrance of ground water recreation, negative microclimatic impacts). Calculations for sealing degrees can be done with discharge coefficients of different surfaces (asphalt, green roofs, paving stones, etc.). To get reliable results, consistent discharge coefficients have to be provided by the tendering authority for all participants.

LCA land use indicators are proposed, e.g. the naturalness degradation potential (NDP) based upon the Hemeroby concept [Brenntrup, 2002]. Land occupation and Land transformation indicators can be derived [van der Voet, 2001]. Corresponding inventory data are available in e.g. Ecoinvent. To assess these aspects the following indicators are often used by practicioners, but they do not correspond to an LCA approach:

Degree of building density

The degree of building density is the ratio of the built area to the unbuilt area in percent. It is a common indicator in spatial and urban planning.

Degree of sealing

The degree of sealing is the ratio of sealed area (built area and sealed outside facilities) to the total plot area in percent.

Degree of sealing of the unbuilt area

The degree of sealing of the unbuilt area is the ratio of the sealed outside facilities to the total plot area in percent.

Life Cycle Cost Assessment (LCCA)

As there is only limited information about the building in the competition stage, a comprehensive assessment of life cycle costs hardly can be done. Stated below are recommendations for simplified assessments:

Costs for energy in the use stage – Heating and Cooling

Based on default values for different (predefined for all participants) heating and cooling systems and calculation results on final energy, rough estimations for the costs of the operational energy use per year(s) can be done.

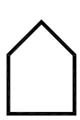
Costs for building materials and construction

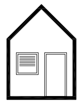
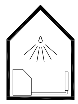
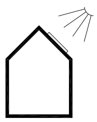
Based on default values for different (predefined for all participants) building elements (walls, windows, slabs, etc.), rough estimations for the costs of the product stage and costs of the use stage (maintenance, repair and replacement) can be done.

4.1.3 Tool for the assessment of energy related LCA aspects

As a practical example for the integration of energy related aspects in architectural competitions an Austrian assessment tool is given below. The so called IEAA-assessment tool was developed in the Austrian research project: “Integration of energy relevant aspects in architectural competitions”, powered by the Austrian “Klima- und Energiefonds” (Download under: http://www.ifz.tugraz.at/index.php/ieaa-tool).

To fulfil the requirements of architectural competitions the tool provides a modular structure: The assessment is going into details step-by-step, as far as required by the client. E.g. the assessment levels for energy are on useful, final and primary energy. Three basic modules for the building envelope and the building’s HVAC-systems are supplemented with a module for active use of solar energy. Table 2 gives a short description and the resulting values of the four modules of the assessment-tool.

	Modules	Description	resulting values
	module 1 building basics	energetic assessment of “immanent-design” aspects such as compactness, orientation, window area as well as horizon- and self-shading	HWB*, KB* EEB PEB, CO2

	module 2 building advanced	energetic assessment of “non immanent-design” aspects with consideration of construction elements, flexible shading elements, building’s thermal capacity, etc.	HWB, KB EEB PEB, CO2
	module 3 building services	simplified energetic assessment of the HVAC-system (space heating, domestic hot water, cooling, ventilation, lighting) based on the chosen energy source	EEB PEB, CO2
	module 4 active solar energy use	consideration of the use of active solar energy by thermal and photovoltaic solar collectors	EEB PEB, CO_2

HWB*…useful energy for heating (utilization profile residential building; regulatory requirements); KB*…useful energy for cooling (without internal gains; regulatory requirements); HWB…useful energy for heating; KB…useful energy for cooling; EEB…final energy; PEB…primary energy; CO_2…CO_2-emissions

Table 2 Overview of the modular concept of the IEAA-assessment-tool [2].

The tool is working with different default values (U-values, reference equipment for HVAC-systems, shading system, etc.). On one hand this strategy helps to minimise the efforts for participants and on the other hand it provides comparable results. Figure 1 shows input parameters and the interdependences of the modules.

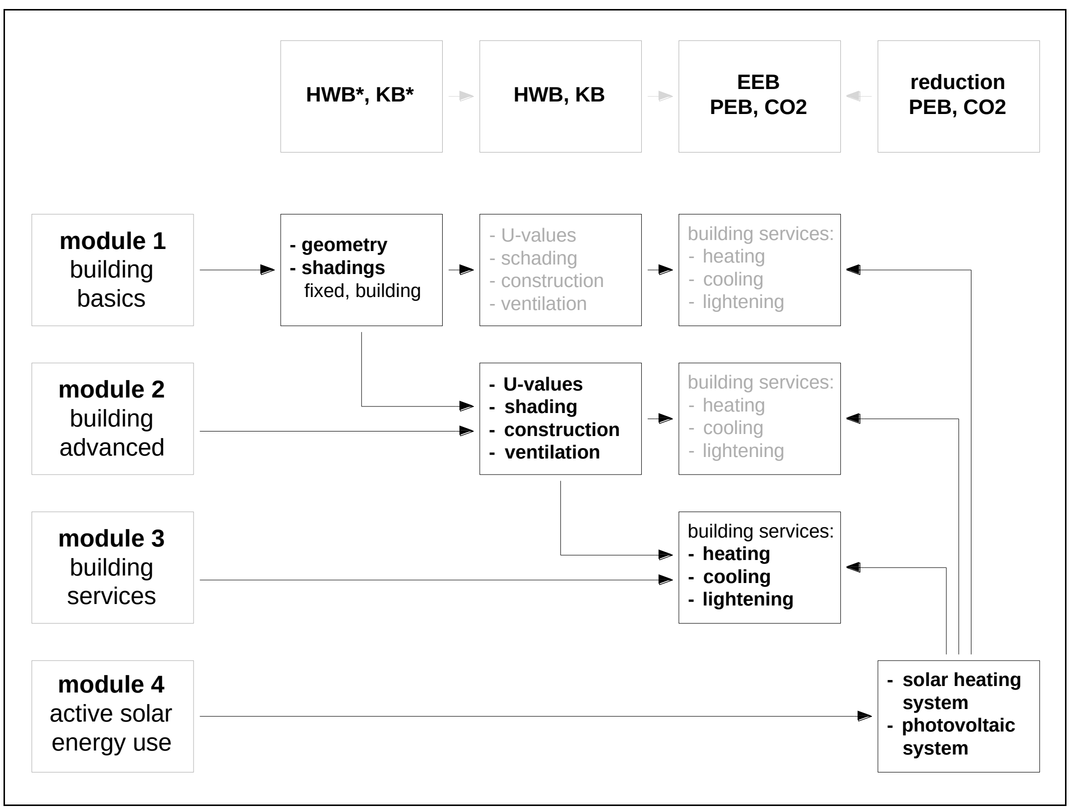


Fig.2 Required input-parameters (black) and default-assumptions (grey) of the individual modules plus their result-values [2].

Figure 2 shows “Module 1 – building basics” with geometric input data to be filled in by participants (green cells) and calculation results (yellow respectively red) cells. Geometrical input data are conditioned gross floor area, conditioned gross volume, exterior walls, walls and slabs to unheated areas, walls and slabs to ground and windows (separated by orientation). In the middle of the figure predefined default values (defined by the tendering authority) like U-values for the different building elements, information about the ventilation system and the kind of construction (heavy to lightweight) can be seen. In the last section of the figure results for heating and cooling on useful energy level, total final and primary energy demand and CO_2-equivalents of module 1 are cited.

M1 Modul 1: GEBÄUDE - BASIS

M1.1 Angaben

Grundflächen

Bezugsfläche (BF; 80% von BGF_{kond})	800	m²
konditionierte Bruttogrundfläche (BGF_{kond})	1.000	m²

Gebäudevolumen

konditioniertes Bruttovolumen	3.488	m³

Gebäudehüllflächen

	thermische Gebäudehülle (Bruttoflächen)		*davon Fensterflächen*		*Eigenverschattung*
Dach (Decke außen)	802	m²	20	m²	*Verschattung default*
Außenwand	553	m²	163	m²	
Nord	116	m²	10	m²	*Verschattung default*
Nord-Ost		m²		m²	*Verschattung default*
Ost	157	m²	59	m²	*Verschattung default*
Süd-Ost		m²		m²	*Verschattung default*
Süd	123	m²	46	m²	*Verschattung default*
Süd-West		m²		m²	*Verschattung default*
West	157	m²	48	m²	*Verschattung default*
Nord-West		m²		m²	*Verschattung default*
erdberührte Wand		m²			
erdberührter Boden	802	m²			+ Horizontverschattung
Wand zu unbeheizt		m²			– anzeigen
Decke zu unbeheizt		m²			

sonstige Vorgabewerte

	U-Wert			*U-Wert*	*g-Wert*
Dach	0,12	W/m²K	Fenster in Wänden	0,85	0,50
Außenwand	0,15	W/m²K	Fenster in Dächern	0,85	0,50
erdberührte Wand	0,17	W/m²K	Verschattung	Außenjalousie	
erdberührter Boden	0,17	W/m²K			
Wand zu unbeheizt	0,20	W/m²K	Gebäudeschwere	mittelschwer	
Decke zu unbeheizt	0,15	W/m²K	Rückwärmzahl	70%	

M1.2 Ergebnis

Ergebnis Modul 1

l_c -- $1/l_c$	Kompaktheit -- A/V-Verhältnis	1,62	m	0,62	1/m
HWB*	Heizwärmebedarf (Wohngeb.)	16.548	kWh/a	4,7	kWh/m³a
KB*	Kühlbedarf (außeninduziert)	2.352	kWh/a	0,7	kWh/m³a
EEB	Endenergiebedarf	77.328	kWh/a	77,3	kWh/m²a
PEB	Primärenergiebedarf	213.258	kWh/a	213,3	kWh/m²a
CO_2	CO_2-Emissionen	36.177	kg/a	36,2	kg/m²a

- Seite 2

Fig.3 IEAA-assessment-tool “Module 1 – building basics”

Figure 3 shows “Module E – Presentation of results” giving a numeral and graphical overview of the results in form of an energy balance on useful energy level, final and primary energy demand and CO_2-equivalents.

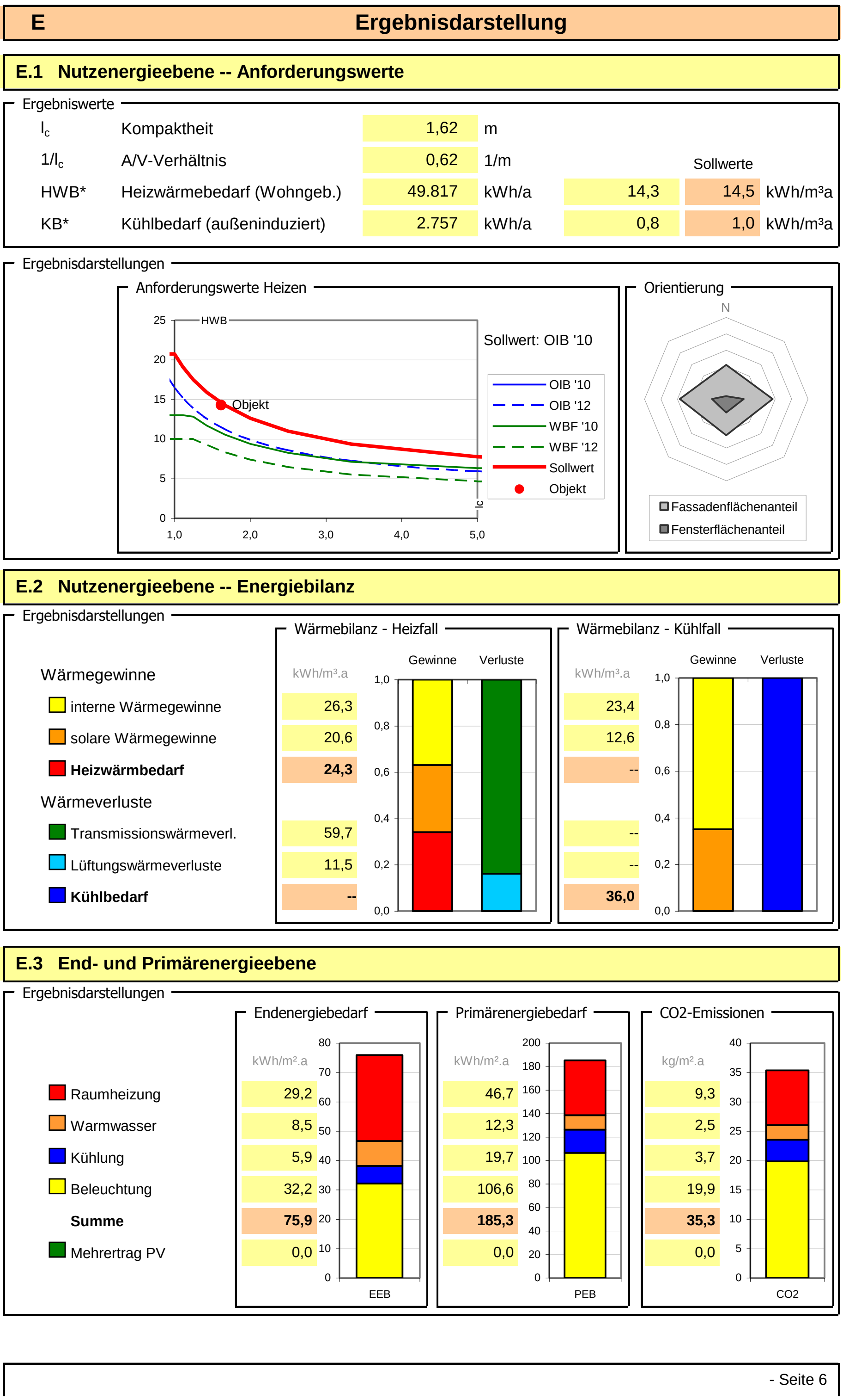


Fig. 4 “Module E – Presentation of results”

References

[1] Beispiele von Systemschnitten zur Beurteilung von Tageslichtkonzepten. Quelle: Technische Universität München, Lehrstuhl für Bauklimatik und Haustechnik, Prof. Dr.-Ing. Gerhard Hausladen: ClimaDesignCompetition, Entwicklung eines energetischen und raumklimatischen Planungswerkzeugs für Architekten und Ingenieure in der Konzeptphase bei der Planung von Nichtwohngebäuden sowie Erstellung eines Anforderungs- und Bewertungskatalogs für Architekturwettbewerbe. Forschungsbericht im Auftrag des BBR im Rahmen der Forschungsinitiative Zukunft Bau, 2009, page 80

[2] Gratzl-Michlmair, M.; Staller, H.; Djalili, M. (2009): Integration energierelevanter Aspekte in Architekturwettbewerben (IEAA). In: Null Emissions Gebäude, page 9 – 16. 13. Internationaler Kongress e-nova

4.2 Urban design

Traditional tasks for urban designers which relate to sustainability involve notions like urban structure and form, mainly covering urban typologies and urban density. To discuss how LCA could be a tool for increased urban sustainability thus mainly encompass to use LCA for studying environmental impacts of different densities and different building typologies as decision support in planning processes. Concerning decisions regarding density and building typology, the resulting environmental impact will mainly relate to personal transports and the buildings in a life cycle perspective. Indirectly, the choice of energy system will play an important role but depending on the contextual situation, the energy system might already be set. In practice, LCA has hardly or to a very limited extent been used as decision support for these planning purposes. However, if broadening the scope of the urban designer and planner to actually playing a role in managing and planning a sustainable urban environment, to adopt a life cycle perspective is definitely favourable.

Apart from the already mentioned questions about density and building typology, a number of other potential application areas can be identified. At a general level, LCA can be used as an analytical tool concerning development of the city district level. At a more detailed level, for local authorities it can serve as a procurement and evaluation tool in architectural competitions, to relate target-setting to giving land permits and for governance strategies such as to negotiate environmental targets in different types of building developments. An important argument for to actually pose targets and demands for building developments within local governments is that it encompasses an important action when working locally with implementing global and national environmental targets. Climate strategies and climate goals are increasingly developed at local authority level and analytical tools are then necessary for identifying coping strategies and for evaluating the implementation and fulfillment of similar policies.

However, how system boundaries are set will play an important role when developing relevant decision support. For example, when monitoring environmental impact at community level, such as emissions contributing to climate change, emissions are in general calculated based on sources within the geographical boundary of the local government. Then, the emissions do not cover the impact caused by goods and services consumed within the geographical boundary but produced outside the boundary. Figure xx shows this difference [9] which can be transferred to local city or city district level.

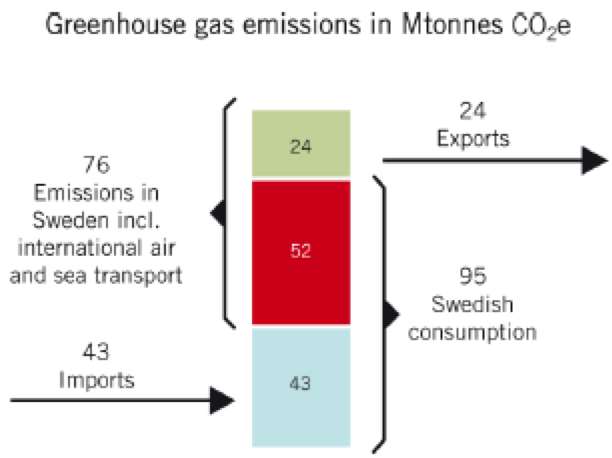


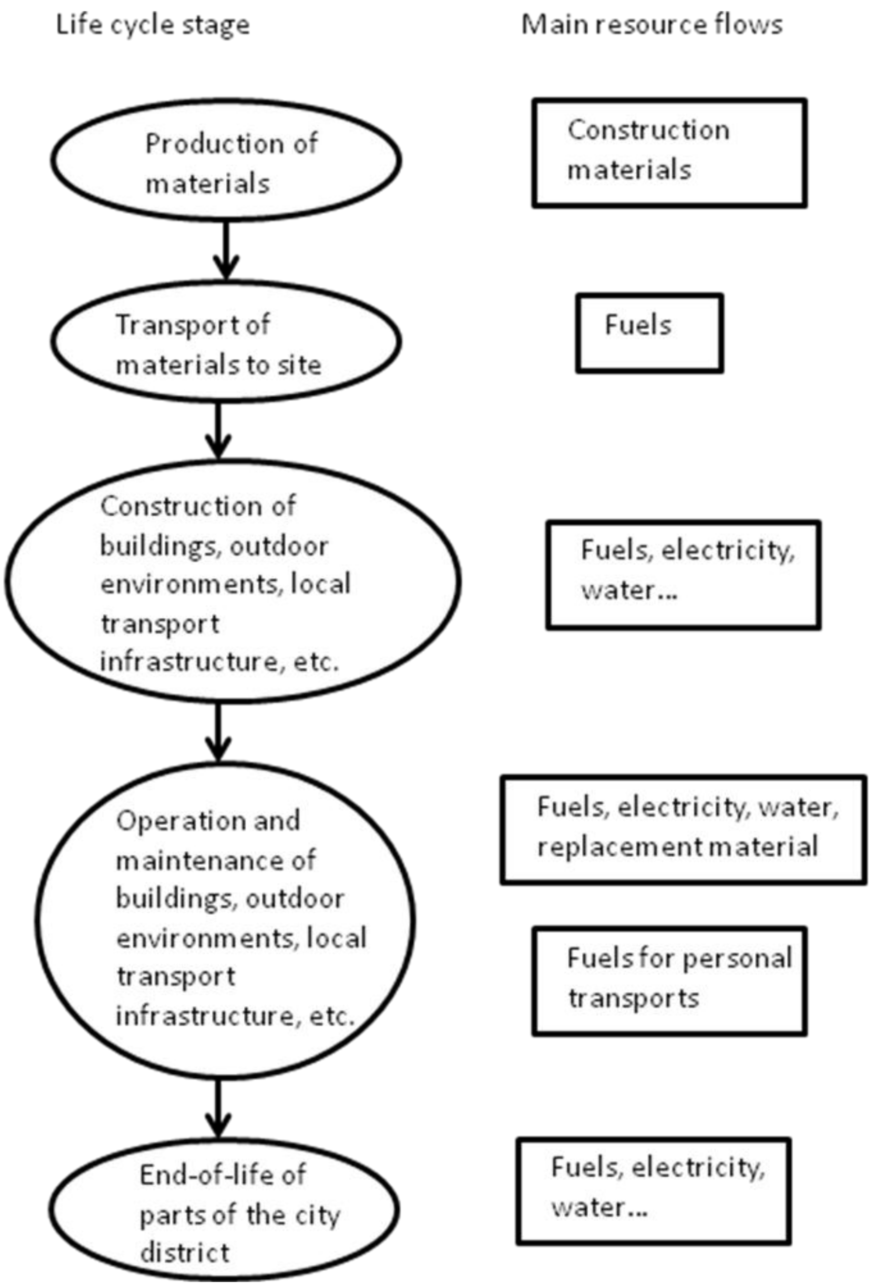
Figure 0: Greenhouse gas emissions in 2003: 76 Mtonnes CO_2e in Sweden including international transport, 24 Mtonnes CO_2e in Sweden to produce exports to other countries, 43 Mtonnes CO_2e in other countries to produce imports to Sweden, and finally 95 Mtonnes CO_2e both in Sweden and in other countries to meet the needs of Swedish consumption.

[9]

An illustrating example if using only a production perspective is that it could imply that currently used brownfield land should be used for new housing developments instead. Such a decision may lead to reduced emissions within the geographical boundary due to local industries moving. However, the industries may then move to a neighbouring municipality and increase the emissions there instead. In addition, it may lead to higher emissions due to increased commuting transports when industries tend to move farther away from where people live. To base similar decisions on an inventory which does not involve a consumption perspective will in such situations lead to sub optimization and priorities in the wrong direction. A life cycle perspective will therefore be a more serious approach.

Regarding potential applications in urban sustainability management and development, LCA can also play a role in environmental impact assessment of plans and infrastructure development. A number of LCA studies deal with providing decision support on infrastructural systems at municipal level such as the evaluation of different options for new waste management systems, energy systems and systems for collective transports, etc. This application will however be dealt with further in section 4.2.7 . Related to environmental impact assessment, location of different activities is an important issue for urban planners and designers, which will be discussed more below.

A few potential applications in which LCA can provide strategic decision support for urban planners and designers will here be discussed a bit more in detail. As a start, if studying the urban level with LCA, an initial, simplified process tree could look like this for, e.g a new city district:



The general processes described above indicate a system boundary that connects to the geographical border of the city district. However, during the operation stage the citizens of the city district will consume amounts of other consumables which will be brought into the geographical boundary. If taking the perspective of understanding the life cycle impact of the city district citizens, it could also be argued that citizens' leisure time transports such as flights etc. also should be included in LCA calculations. Using a consumption rather than a production perspective would incorporate these processes into the system boundary. However, a first recommendation regarding system boundaries when using LCA in the urban design context, is to only include processes which level of impact have a direct relation to decisions taken by the urban designer. For this context, the rough process tree above can be seen as including the main processes to consider. Nevertheless, the choice of system boundaries is dependent on the specific purpose and application of LCA in the urban design context and this “default process tree” can then be reduced or expanded depending on the particular application, which will be more discussed below.

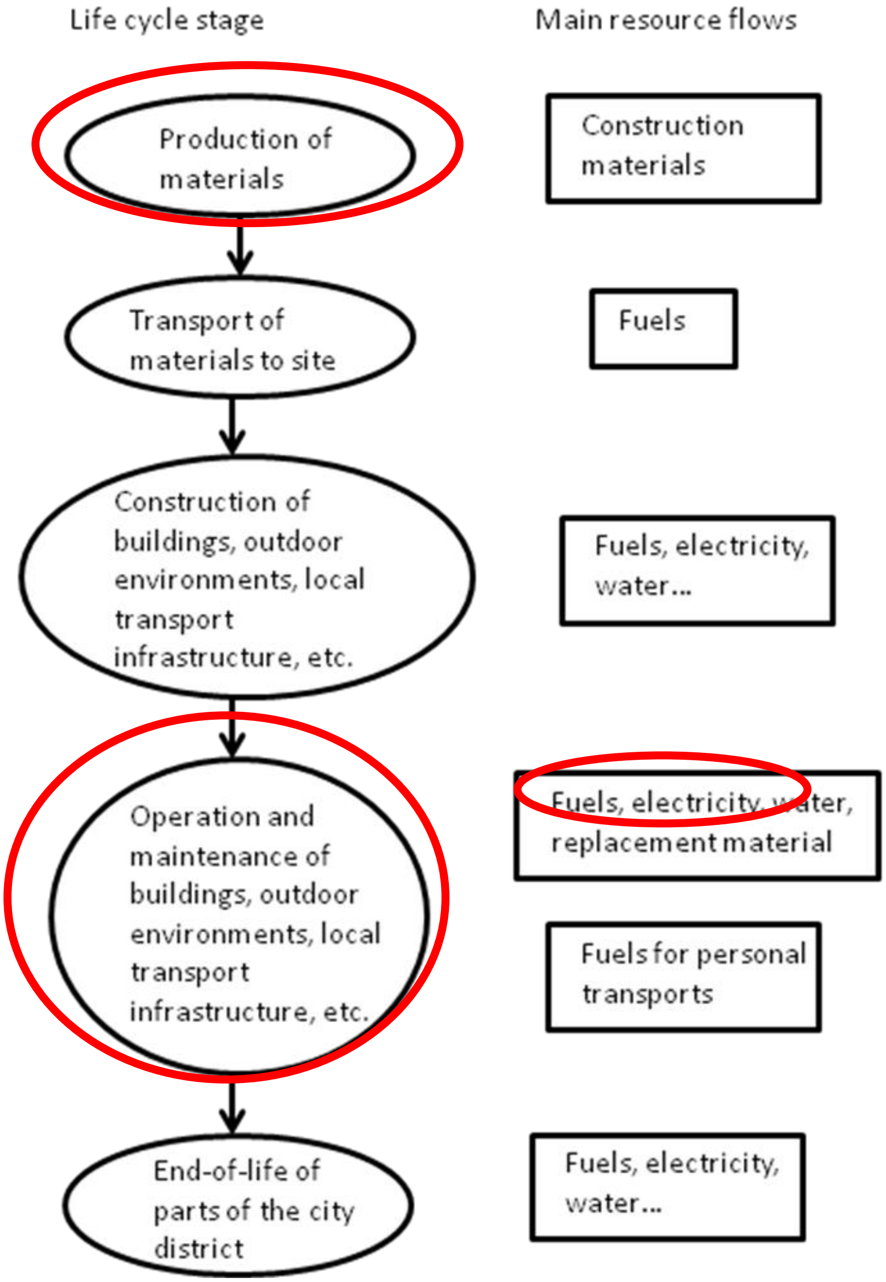
Two main application areas will be discussed: 1) for governance strategies: to receive land permits, etc, 2) for decision-making of development strategies, including decisions related to density, urban typologies, location of new settlements and evaluation of the environmental impact at city district level.

4.2.1 Target-setting and evaluation of environmental impact in governance strategies

Depending on real-estate ownership and current legislation in individual countries, a number of options exist for urban planners to pose or negotiate environmental targets for new urban developments, whether it be smaller developments or entire new city districts. The architectural competition is one possibility which has been discussed in section 4.2.1. If the municipality owns the land to be developed, to pose targets when giving the land permits is another one. In addition, the municipality usually has an opportunity to negotiate targets with developers also under other circumstances. Such a more governing role for local authorities is currently, increasingly discussed due to the intensified focus on energy-saving and climate goals in general. Policy documents such as the European union targets on energy-saving (a reduction with 20% to 2020 and a reduction with 50% to 2050), and similar local targets and climate strategy documents in municipalities put pressure on local authorities to find new ways to implement similar targets in new urban development projects. In addition, more and more developing companies work with internal environmental management systems and policies which means that they have internal policies and targets they aim to follow. Local authorities could thus appeal to developing companies to take extra measures by claiming their own internal environmental management systems. To adopt a life cycle perspective is then the most serious approach when posing targets.

In this situation it is assumed that the site of the new development is already set. A simplification may in this context be to not include personal transports in the life cycle calculations/target-setting since the magnitude of these mainly will relate to the location in relation to public transport, distance to different service functions, etc.. The functional unit should equal the requirements put on the new development, such as number of dwellings, floor height, indoor environmental quality requirements, etc. Since this implies very early design, many simplifications must be made if using LCA calculations. The most simplified approach concerning system boundaries and included processes is indicated in the process tree below. These recommendations would also apply for if the purpose of the study is to evaluate choices regarding different building typologies in a new development. However in such a case, it would then be possible to simplify the data inventory even further.

On the other hand, such simplification is needed when performing LCA on excel tools or using general LCA tools requiring all material quantities and processes to be input manually. It not necessary anymore using building LCA tools linked to a graphical interface, because materials quantities are automatically calculated and the process tree is generated by the tool. End of life processes like incineration of wood and plastics may have non negligible impacts, so that the simplification proposed hereunder may not be valid.



- Only include two life cycle stages in the calculations: production of construction materials and operation stage.
- Only include buildings (and perhaps also the close outdoor environment to the buildings).
- Only include construction materials for main building elements, such as roof, slabs, external walls, parking lots, etc.
- Only include the operation of the buildings in terms of energy use during their life-time.

In a case study of a the use of LCA in urban design of a new housing development in Sollentuna municipality (Sweden), in the European ENSLIC project these simplifications are illustrated (www.enslic.eu).

Naturally, the inclusion of more life cycle stages and processes would give a more detailed study. If the purpose is to study different alternatives which for instance have large differences concerning construction techniques, it should be recommended to include the construction stage. If the studied alternatives imply large differences concerning measures taken to promote personal transport in form of public transport, walking and cycling (e.g limited amount of parking places, high quality of cycle rooms, cycle paths, etc.) it is recommended to try to incorporate personal transports in the calculation of the operation stage.

However, most important, to make use of LCA as a tool for urban designers, the tool to use for calculations including all specifications regarding which processes to include or not must be the same for evaluation of all alternatives. Important background data that needs to be provided for the participants of an architectural competition or developers interested in land permits include: LCI-data for energy and materials, specification of what building elements to include, anticipated life time for buildings, system boundaries such as whether to include the construction of parking space or not, etc. That is, to designate the calculation tool to be used.

4.2.2 Use of LCA for environmental assessment of city districts/city level

Apart from the more detailed purposes for using LCA in urban design described in the previous section, the use of LCA for understanding the environmental impact of a city district or city can also be discussed more in general. The intensified focus on the notion sustainable cities has resulted in an increased demand for analytical tools to understand whether a city is "sustainable or not". Nevertheless, so far there are few tools that make use of LCA calculations for this purpose.

The well-known LEED and BREEAM tools today also cover sub-tools that target the city district level[9]. However, neither of these makes use of LCA calculations in their

[9] LEED 2009 for Neighbourhood Development (www.usgbc.org), and BREEAM Communities (www.breeam.org)

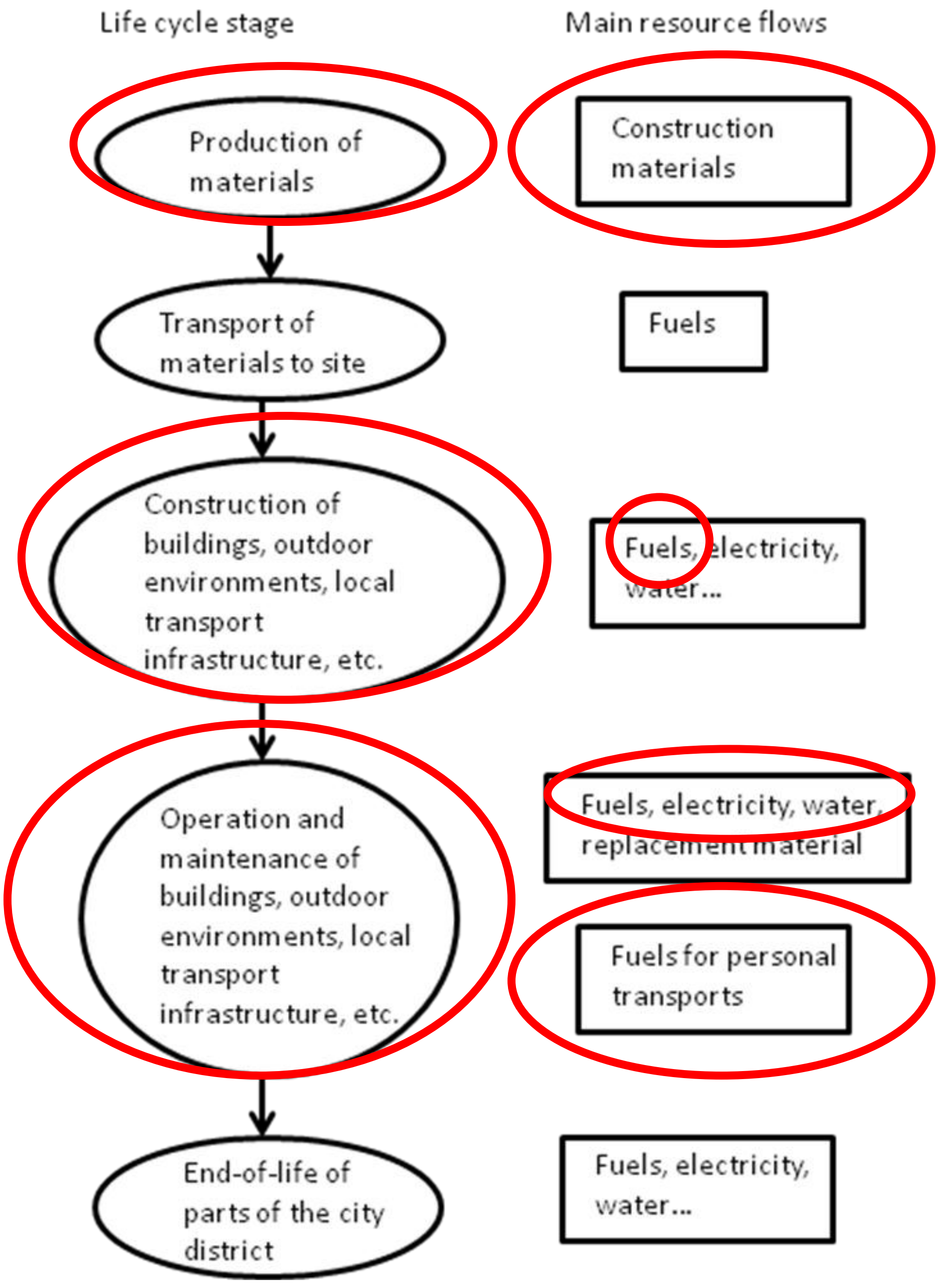
assessments. Instead they are indicator systems with more simplified indicators, such as a direct measure on density instead of calculating environmental impacts related to a certain density.

Another group of tools include the ones which were mentioned in the beginning of section 4.2.3, that is tools which mainly aim to monitor and evaluate for instance a municipality's contributions to climate change. One of the currently most important similar guideline documents includes ICLEI [10], which is also used in different eco-cities concepts such as the Clinton initiative, etc. These guidelines aim to quantify the impacts of implemented and proposed measures relevant in the local authority planning realm. The document only gives guidance regarding the estimation of greenhouse gas emissions in the local area, divided in two parts: the emissions related to the internal local government operations and the emissions related to the community. The guidelines aim to provide specifications regarding how to collect an adequate inventory of the emissions within the local area contributing to climate change in *one* year. It is therefore not directly designed to be used for evaluating different alternative developments in a life cycle perspective. However, it can be of interest for local planners regarding how to connect these types of inventories (which usually form the basis for the municipal target setting) with the task of taking relevant decisions in more concrete implementation of urban planning.

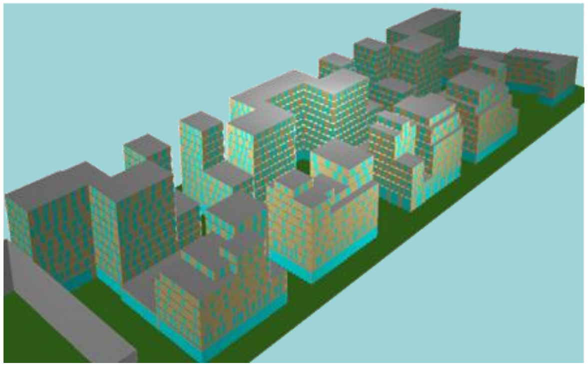
One tool that claims to address the city district level and makes use of LCA for making environmental assessments is the Swedish Environmental load profile [11, 12]. It has mainly been used for evaluation of environmental targets set by Stockholm municipality in new development Hammarby sjöstad planned for around 20 000 residents. In this tool, the following LCA methodology is used:

The overarching functional unit used is a city district planned for a certain number of residents, that is all impacts are calculated per planned resident in the city district. However the tool is structured in parts: Individual, Household, Building, Estate and Area level whose impact can be added for calculating impacts at Area level. The most common use has been to calculate the impacts generated at building-, estate- and area level and then add these to calculate the total impact at Area level [12]. This implies that the input data varies depending on which level the tool assesses. For building and estate level the dominant input data relates to the flows of energy and material. For the area level, additional input data mainly relates to an estimation of personal transports of the residents in the area. The input data then has to build on transport modeling related to for example distance to public transport, work places, service, etc. Thus, the tool claims to cover all processes and life cycle stages in the process tree below. However, it is unclear how other input data than the dominant flows are acquired for the calculations and also which simplifications have been made.

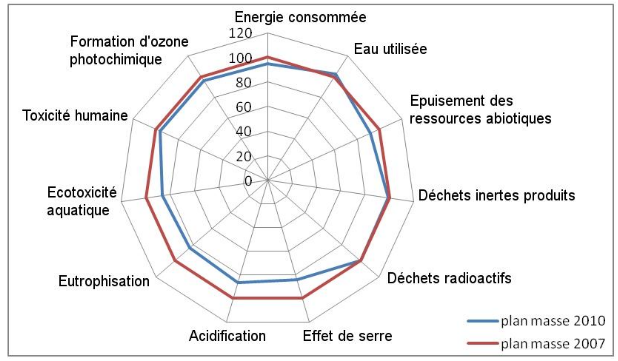
The tool has been looked upon as being too complex and therefore an attempt was made to simplify it by reducing the covered processes (see the remarks above regarding the possibility of performing a more complete LCA thanks to a user friendly interface). Based on a case study on a part of the city district Hammarby Sjöstad in Stockholm, it was concluded that the life cycle stages and processes indicated in the process tree below were the most significant (cover the majority of the total environmental impact of the city district). Some of these processes contribute much to only one of the impact categories, for example water and sewage to eutrophication potential. This is however just one case study and general conclusions are difficult to draw. It gives a hint on which the most significant processes are but more work is necessary to come up with more specific recommendations regarding this.



LCA has also been performed to study an urban development in Paris. The link between a graphical interface and the LCA tool (see figure hereunder) allowed the whole process tree to be integrated : transport of materials to site has been accounted for using default values; End of life processes have also been included, considering the same processes as they are implemented today (e.g. incineration for wood and plastic elements).



Graphical interface ALCYONE



LCA tool EQUER, comparison of alternatives

Example of using LCA to study an urban development in Paris

Finally, assessing the environmental impact of a city district involves high complexity. Setting system boundaries is therefore a problematic task since the citizens of people will be dependent on services provided outside the city district, such as consumer goods, employment and ecosystem services such as waste water treatment. It is advisable that system boundaries, simplifications, use of default values, etc. must be decided for the particular purpose of an urban design task. For example if evaluating different building typologies, personal transports may be excluded. On the contrary, if studying different density alternatives or questions like where to locate different services, personal transports is the most important input data in the inventory. In addition, impact categories like resource and land use are then also important to include in LCA calculations. If studying more long-term alternatives for the urban development in a municipality or region, consequential LCA should be used in most cases. Since the future energy system then will play an important role for the results, it might also be advisable to study different scenarios regarding energy mix with some kind of dynamic LCA.

4.3 Policy making

4.3.1 Introduction

The ecological performance of a product gains gradually greater attention. The LCA, as a tool which helps to identify the environmental quality of products, is more frequently used by decision makers with the intent to prevent the negative outcomes or to provide the positive environmental effects. But relating to different level of decisions (Micro-level, Meso-/macro-level or Accounting [ILCD Handbook 6.5.4]), the intents and applications of LCAs differ also widely. Subsequently there are different types of LCAs – the attributional LCA (ALCA) and the consequential LCA (CLCA), which are not always clearly distinguished by LCA-Tool users. Therefore, in order to provide the user an effective decision support, a policy of compiling LCA must be established.

Figure 1 shows the procedure of an LCA and illustrates the relationship between goal definition and the choice of LCA models.

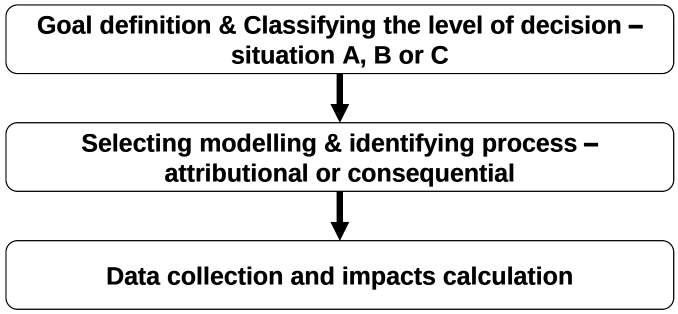


Figure 1: LCA procedure

4.3.2 Goal and Level of decision

The goal and level of decision addressed by an LCA should be clearly expressed. For instance the question raised by the user may be of the type "What are the consequences if I choose product A instead of product B?", or "What are the environmental impacts of product A compared to product B?".

In the case of decision making support, the scope of the effects through decisions must also be distinguished into different levels in accordance with the consequences and affected time spans. In the ILCD Handbook, the decision context is classified in three situations A, B and, C which regard both, the ranging and the influence of decisions. Figure 2 gives an overview of the difference between the situations A, B and C.

<table>
<tr><td rowspan="4">Decision support?</td><td rowspan="3">Yes</td><td colspan="2">Kind of process-changes in background system / other systems</td></tr>
<tr><td>None or small-scale</td><td>Large-scale</td></tr>
<tr><td>Situation A
"Micro-level decision support"</td><td>Situation B
"Meso/macro-level decision support"</td></tr>
<tr><td>No</td><td colspan="2">Situation C
"Accounting"
(with C1: including interactions with other systems, C2: excluding interactions with other systems)</td></tr>
</table>

Figure 2: Kinds of process-changes [From Goal definition – identifying purpose and target audience, source: ILCD Handbook]

In the situation A, the change due to the decision is confined typically within a small-scale and within a short term time span at product level. Most often for situation A, the LCA is done to differentiate the environmental quality by choosing preselected material (or process) for a product, in order to find out the environmental burden of the product. What means, that the decision only refer to particular product or process. The typical LCA in situation A is a traditional product EPD for comparing products, without studying the consequences of choosing a product. In this case even the alternative techniques and materials are known as a rule, and the change cannot influence the market or the state of technology noticeably. So, the situation A is generally only product-related and is also called micro-level according to its restricted effectiveness of it sector.

Compared with situation A the implication of decision in the situation B is much more substantial and more powerful. Because, in situation B the decision support focuses on developing strategies with large scale consequences and in long time span to enhance the high whole life cycle environmental quality of products. Therefore the Situation B is also depicted as the meso-/macro-level of decision support, e.g. raw material strategy. In this case new materials, equipments and technologies could also be used for analysing the process of a product, in order to identify environmental characters of materials, plants etc. over their whole life cycle. Changes in succession of the decisions may hence overcome thresholds and shift the market situation. To ensure the fundamental advance of the environmental quality, policy making, strategy development and concept development are the key task of situation B.

The feature of situation C is not necessarily for the purpose of measurement. The aim in situation C is generally the pursuit of the flows or interaction between various systems, e.g. energy price changes or new technology of energy production. In fact, this sort of LCA is rather a monitoring or accounting than an evaluation system. Due to the complexity of the material flows between various systems and the uncertainty through the poor information about the interdependency between the sub-systems, the LCA can only try to act as if this complex system can be quantitatively measured. In that case the clear description of the relationship of product involved systems and qualified treatment of data is much more important than the judgement of the ecological quality of a product.

This recommendation aims at supporting LCA-Tool users for policy making. Most of the users try to analyse some new materials or technologies, or want to identify the product group with largest environmental burdens or potentials within a time span of five to ten years with the help of LCAs. These aims involve the middle-ranging decisions and changes of technologies, market, etc. that are not limited by the product level, rather than with the goal to conceive policies for the development alike situation B. So the goal in this document is defined as the meso-/macro-level decision support.

4.3.3 Selecting modelling - ALCA vs CLCA

The complexity of an LCA with a meso-/macro-level goal situation is the modelling of an adequate LCA system. That means various alternatives shall be compared with the help of LCAs over a long period. That causes a lot of uncertainty and lack of information, which can only be replenished with assumption scenarios. So this situation allows a choice of modelling the system between attributional and consequential LCA, as a result of that these both modelling systems are sometimes mixed up by the user. As these two modelling methods consider the environmental impacts and benefits of a product within different system boundaries, the confusion of ALCA and CLCA may conclude unfair comparison. If the assessment is even applied in an inadvertent mixture form these two models, the results will be totally corrupt.

Currently, the most often applied LCA in the practice is the Environmental Product Declaration (EPD) which comprises a series of measurable information about a product’s environmental impacts over a defined life span (e.g. global warming potential, energy consumption, Acidification Potential, etc.). EPD ascertains the life cycle inventory of a product from the cradle to the gate, and estimates its impacts on the environment in direct relation to the inputs according to the DIN EN ISO 14040 standards. This kind of LCA allocates the environmental impacts directly into the raw materials, transports and production processes and is called attributional LCA (ALCA) if the influence of the studied system on the background system is not accounted for.

On the other hand, consequential LCA (CLCA) aims to integrate the effects of the studied system on background processes. For instance a new construction with electric heating may increase the winter peak demand, which requires the implementation of peak production systems, therefore modifying the electricity production mix and related impacts.

ALCA, the attributional LCA is concentrated on accounting the relevant material flows of a product and providing the information about the environmental impacts of a product through its whole life span, according to the production, use and disposal. ALCA describes the cause-and-effect-relationship between the inputs and the outputs, i.e. the direct impacts of a product. Usually, current average data of process and material flows are used for ALCA. The attributional model is most qualified for consumption-based accounting, therefore it is especially well applicable in identifying the impacts in separate parts of the life cycle. It can also be used for enhancing the environmental quality of a product though the reform of process or row materials. However ALCA is not appropriate for evaluating the total impacts apropos of changes in other life cycle stages.

Actually, the assessment methods for both types of LCAs are similar. The constitutive difference between the ALCA and CLCA is the modelling of systems, because the aims of the assessments are divergent. As an ALCA aims to find out the environmental properties of a product through its life cycle within a defined system boundary; a CLCA considers the interactions between the subsystems and the background system. ALCA and CLCA correspond to different goals..

The consequential model brings the consequences of changes in the ensuing phase, e.g. use, end of life, etc., into focus, both inside and outside the “actual” life cycle of a product. Also the market effects as a result of the changes should be taken into account of the assessment. The calculation of CLCA is dependent upon assumptions and forecast of effects on account of the changes in different phases in the life cycle. CLCA trends to expand the system boundaries and uses often marginal data to allocate co-products, so as to quantify the indirect effects of a product as well as direct ones. Therefore, marginal data are often required for the assessment. This sort of LCA is due to its dependency on the predefined assumption almost always uncertain.

CLCA is convenient for quantifying the total effects of a change in the expanded system of product life cycle, and it can therefore help decision makers more easily than ALCA. But the advance that emerges through the changes in outcome, are not directly relevant to the production and consumption, and so the effects may be less interesting for some decision makers. And it must be explained that the results are depending on the assumptions with interpretations and prognosis and it reflects merely an interrelationship different systems.

There are still several opinions wheter ALCA or CLCA should be preferred according to the objectives of the study (e.g. consequences of a choice, or comparison of products).

This leads to other questions, like “Can we compare products without studying the consequences on the background system of choosing each product ?”. This research field is obviously still open.

4.3.4 Data collection

The strategies of data collection and impacts allocation are depending upon the choice of the LCA modelling system. The key factors of this phase are the system boundaries and treatment of co-products/processes. And these must be defined in line with the goal of the LCA and the requirements of the chosen modelling system, ALCA or CLCA.

As aforementioned, in an ALCA the system boundaries of a product (e.g. a particular building material or an individual building) can be clearly delimited within a closed system, e.g. the production of particular building material, construction of an individual building and/or the energy and resources consumption. As opposed to this, the system boundaries of CLCA must almost always be expanded and is contingent upon the marginal change in the use or end of life phase.

Whereas ALCA only considers processes and material flows directly used in the production or consumption of the product, CLCA takes also account of all processes and material flows, both directly or indirectly (market effect, change of the state of the art), affected by marginal changes in the use or end of life phase of a product. Furthermore, CLCA is much more intricate than ALCA. Because CLCA attempts to convey not only ecological but also additional economical relationship between various stages and parts of life cycle of a product with expanded system boundaries. Which means the structure of the modelling is more complex. Even the data base of CLCA is much more complicated than the data base of ALCA. Due to the assumption of future information and shift of uncertain relationships, CLCA use often instead of average data marginal data which requires nearly always the statistical interpretation of trends.

For the tool user it is therefore very important to keep in mind that the data collection must be conformed to the chosen LCA modelling. And the inaccuracy of a CLCA must be taken into account and warned by comparison.

4.3.5 Conclusion

Both the ALCA and CLCA are applicable for the assessment of a building project. In order to avoid unfair comparisons and false conclusions a certain modelling system must be chosen according to the objectives of the LCA study, with the help of following check points:

1. Defining the scope and purpose of the LCA,
2. Qualifying and quantifying the possible environmental consequences which are relevant to the decision.
3. Identifying the suitable LCA model.
4. Describing and defining the studied system, e.g. system boundaries, allocation principle of co-production, etc.
5. Describing and defining the background system potentially influenced by the studied system.

CLCA may provide the decision maker with additional measurements of environmental impacts of a building project, but assumptions are needed regarding the interaction with the background system. Therefore this approach requires a large expertise and still constitutes a research field. Due to the current data bases on construction materials and processes coupled with the variety in design and construction of buildings, we recommend to prefer using ALCAs to support the regular selection process, except if a new material or process which could cause changes in background systems is involved, e.g. a passive house which spares a conventional heating system. And the limit scope of ALCA as well as the uncertainties of CLCA shall always be considered in the policy to ensure that all the outcomes are comparable and comprehensible.

4.4 Providing EPDs

An ISO-type III environmental declaration is based on a life cycle assessment study carried out in accordance with the ISO 14040 series and following the rules established for each product category. Consequently an Environmental Product Declaration (EPD), also called type III Eco-label, provide quantitative information of the environmental impact of a product during its whole life cycle.

This is ensured in an Environmental Declaration Program, which provides both general and product category specific prescriptions for data collection, handling and calculation rules. The latter are contained in the Product Category Rules (PCR), which set the specific goal and scope of the LCA and the guidelines for developing EPDs for one or more product categories.

At present there are some EPD programs/systems, as presented in the next table.

EPD program/system	**Administrator**	**Country**	**Sector**	**Web**
Déclaration sur les caractéristiques écologiques de produits utilisés dans la construction	SIA (Schweizerischer Ingenieur- und Architektenverein)	Switzerland	Building & Construction	sia www.sia.ch
The International EPD® System	The International EPD Consortium (IEC)	Sweden (origin)	Several	EPD® www.environdec.com
BRE	BRE Environmental Profiles Certification	United Kingdom	Building & Construction	bre www.bre.co.uk
MRPI® (Milieu Relevante Product Informatie)	NVTB (Nederlands Verbond Toelevering Bouw))	The Netherlands	Building & Construction	MRPI® www.mrpi.nl
Umwelt-Deklarationen (EPD)	IBU (Institut Bauen und Umwelt e.V.)	Germany	Building & Construction	Institut Bauen und Umwelt e.V. bau-umwelt.de

Programme de Déclaration Environnementale et Sanitaire pour les produïts de construction (FDE&S)	AFNOR Groupe	France	Building & Construction	www.inies.fr
RT Environmental Declaration	The Building Information Foundation RTS	Finland	Building & Construction	www.rts.fi

EDP Environmental Declaration of Products	Ministry of the Environment	South Korea	Several	www.koeco.or.kr
EPD- Norge	Næringslivets Stiftelse for Miljødeklarasjoner	Norway	Several, Building & Construction	www.epd-norge.no
EcoLeaf	JEMAI (Japan Environmental Management Association For Industry)	Japan	Several	www.jemai.or.jp
DAPc – Declaración Ambiental de Productos en el sector de la Construcción	CAATEEB (Col·legi d'Aparelladors, Arquitectes Tècnics i Enginyers d'Edificació de Barcelona)	Spain	Building & Construction	http://es.csostenible.net/dapc/

Overview of existing EPD Programs worldwide

The EPD Program Administrator[10] must define in the General EPD-Rules[11] the scope of the EPD Program (i.e. if it is limited to a particular geographic area, or for a certain industrial sector, products or product groups, etc).

In addition, the EPDs must be checked and verified by an accredited entity following the verification procedure established in the EPD Program. The verifying entities must determine if the product declaration meets international normative and the EPD-Rules:

- ISO 14020, ISO 21930 and ISO 14025.
- General EPD-rules.

[10] **EPD Program Administrator:** Entity that carry out a type III environmental declarations program or system.

[11] **General EPD-Rules**: Set of rules that guide the management and use of an EDP system or program. They are created and managed by each EPD Program Administrator for each system or program and they are, based on ISO 14025 specifications.

- Product Category Rules (PCR).

The verifying entity shall prepare a verification report following the general standard format specified by the ISO 14025, but also considering the EPD System format specifications. Although the data should be verified, either internally or externally, a third party audit is not always necessary. The need for third party verification is a decision of the EPD Program Administrator.

The EPD Program Administrator establishes the minimum requirements for verifying entities, including at least:

- Knowledge of the sector, the product and the environmental aspects.
- Experience in life cycle assessment and knowledge of the processes analyzed.
- Knowledge of the rules and normative framework of EPDs and LCA.

At present, EPDs are mainly oriented for business to business (B2B) communication, although they could be used in the future in a business to consumer (B2C) communication. Nowadays, the information currently reported in most EPD is still too difficult to be understood by the majority of people. Results are often reported in terms of tables and absolute values of mid-term life cycle indicators, which are not understandable for non-experts. In this sense, to develop sector-specific “average” EPDs would serve as benchmark value for each specific product group.

4.4.1 System boundaries

The EPD should include at least the manufacture of the building products. Optionally, the manufacturer may include the stages of construction, use, maintenance, and end-of-life according to the modules listed in prEN 15804. If the whole life cycle is considered, this should be subdivided into the following stages and modules:

- Production, including all processes from the cradle to the gate (raw materials extraction and processing, transport, energy demand, etc.). It includes the modules A1, A2 and A3 of prEN 15804.
- Construction: transport processes from the gate to the building and the on-site construction processes (modules A4 and A5 of prEN 15804).
- Use: it includes the operation, maintenance, repair, replacement and renovation of the installed product, including transport (modules B1, B2, B3, B4 and B5 of the prEN 15804), and the energy and water demand inside the building during the use of the product (modules B6 and B7of the prEN 15804).
- End-of-life: it includes all the processes associated to the deconstruction, demolition, transport, reuse and recycling, and final disposal (modules C1, C2, C3, C4 of the prEN 15804).

The environmental burdens and benefits associated to the expansion of the system boundaries including product reuse, recycling and/or energy recovery (i.e., materials and secondary fuels[12].) should be declared as additional information, in a separate module.

4.4.2 Reference service life

If the use stage processes are included, the manufacturer should provide information on the reference service life. This information should be verifiable. In order to estimate the reference service life, the general rules in ISO 15686-1 and ISO 15686-8 can be applied, as well as other specific rules established in other regulations of construction products.

4.4.3 Cut-off rules

If the information available is not enough, the mass and energy inflows and outflows that represent less than 1% of total mass and energy could be excluded (but only if they do not cause significant environmental impacts). According to ISO 21930, the total sum of inputs and outputs not included in a process will be less than 5% of the total mass and energy used. However, these cut-off rules do not apply in the case of hazardous or toxic substances.

4.4.4 Data quality

All the data sources used should be documented, specifying clearly their uncertainty, integrity, representativeness, coherence and reproducibility.

The data used to develop the environmental declaration must meet the following requirements:

- They must be representative and properly justified. As far as possible they should be as recent as possible and not be older than 10 years (or 5 years for manufacturer’s specific data).
- All the data collected should refer to a time period of 1 year.
- The technological coverage should reflect the reality of the product declared.
- The geographical coverage should reflect the average or general data in the region/country where the manufacturing company is located.
- The variance for the specific data should not exceed 10%.

The data included in the inventory should be collected for each unit process within the system boundaries. The data sources used (including the reference year) should be documented. Data can be classified into the following sections:

- Inputs: energy, raw materials, ancillary materials, etc.
- Products, co-products and waste.

[12] Secondary fuels: Fuels based on any material, which is already used in any way. Mostly are waste materials from natural or artificial production processes converted to gaseous or liquid fuels (e.g. biogases from anaerobic digestion, gasification of used organic material, etc.)

- Emissions to air, water and soil.

In order to achieve data consistency, the data should come from the next sources:

- European Life Cycle Database (ELCD). This database is promoted by the European Commission and it is public and free. It includes data on basic materials and processes, supplied or approved by the industrial sector.
- Official database of the EPD Program. Some EPD Programs include an official database with environmental information on basic materials and construction processes, energy use, transport and packaging. This database is checked and maintained by the EPD Program Administrator.
- Other sources. Any other data used must be consistent with the ELCD and the Official database respect to the format, method of data collection and system boundaries. If a company uses own data, it shall describe these aspects.

The use of specific data or general average data should be documented. Usually, the following rule applies:

- Raw materials production: specific data and/or general average data (European or worldwide level) shall be used.
- Product manufacture: specific data shall be used.
- Electricity mix: if there is no regional data available, national data will be used. If the electricity consumption is relevant, the influence on the results when using regional or national data should be assessed.

4.4.5 Environmental indicators

Impact assessment should be carried out according to several environmental indicators, using the characterization factors defined in prEN 15804. The main indicators are:

- Use of renewable and non-renewable primary energy, expressed in MJ (net calorific value) per functional unit.
- Use of renewable and non-renewable secondary fuels, expressed in MJ per functional unit.
- Use of fresh water, expressed in m^3 per functional unit.
- Amount of hazardous, non-hazardous and radioactive wastes, expressed in kg per functional unit.
- Material outflows: components for reuse, materials for recycling or energy recovery, expressed in kg per functional unit.
- Global warming potential, expressed in kg CO_2 equivalent.
- Stratospheric ozone layer depletion potential, expressed in kg CFC11 equivalent.
- Acidification potential of soil and water resources, expressed in kg of SO_2 equivalent.
- Eutrophication potential, expressed in kg PO_4^{3-} equivalent.

- Photochemical ozone creation potential, expressed in kg ethane equivalent.

It is important to highlight that the standard prEN 15804 only includes consensual indicators, therefore damage indicators regarding health and biodiversity are missing.

4.4.6 Comparability of EPD

EPDs do not provide preference criteria for a product; as well they do not establish minimum standards to be met. Nevertheless, they can boost the demand and supply of products & services with lower environmental impact. Besides they allow a fair comparison between different products.

The objective is to allow a fair comparison between different products. But the comparison of EPDs is only possible if the same Product Category Rules and the following conditions have been followed:

Must be identical:	Must be equivalent:
- Definition and description of the product category (function and use). - Functional unit. - Cut-off rules. - Procedures and rules for calculation. - Selection of impact indicators.	- System boundaries. - Data description. - Data quality requirements (coverage, accuracy, completeness, representativeness, consistency, reproducibility, sources and uncertainty). - Methods of data collection. - Allocation of energy and matter flows. - Materials and substances declared. - Instructions on the content and format of the EPD. - Information on the stages not considered, if the EPD is not based on an LCA covering all life cycle stages. - Period of validity.

Comparability of EPDs

The comparison of the building products should be based on the same functional unit and including all the life cycle stages. Therefore, the EPDs that do not consider all life cycle stages have a limited-comparability.

4.4.7 Normative references

- ISO 14020:2000 Environmental labels and declarations – General principles.
- ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations – Principles and procedures.
- ISO 21930:2007 Sustainability in building construction – Environmental declaration of building products.

- prEN 15804:2009 Sustainability of construction Works – Environmental product declarations –Core rules for the Product Category of Construction Products.
- prEN 15942:2009 Sustainability of construction works - Environmental product declarations -Communication format – Business to Business.
- FprCEN/TR 15941:2009 Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data.
- ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.
- ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.
- ISO 15686-1:2000. Building and constructed assets – Service life planning – Part 1: General principles.
- ISO 15686-8:2008. Building and constructed assets – Service life planning – Part 8: Reference Service Life and Service-Life estimation.

4.5 Infrastructure design

Infrastructure includes a number of items, such as roads, water supply, power grids, sewage systems, telecommunication, waste handling. In general, it facilitates the production of goods and services.

All forms of infrastructure have an impact on the environment. This impact can be quantified with the help of life cycle assessment, but the underlying models are sometimes very complex. The objectives are usually the assessment of the infrastructural system to optimise the system or some parts of it, but sometimes the infrastructure is part of the “bigger picture”. In case of the road infrastructure, for example, the goal can be the optimisation of the road itself (what kind of materials to use, which construction technology to apply, etc.) (section 3.1.4.) or the optimisation of the transport of goods or passengers from A to B. The latter necessitates a much more comprehensive analysis (the road infrastructure, but also the choice of vehicles, route planning, etc.). In every case, the system boundaries depend on the goals of the study.

The optimisation of the infrastructure may consider different aspects. Considerable environmental benefits can be reached by using intelligent systems [Kuthi]. Intelligent Transport Systems (ITS), for example, provide real time traffic information. Based on the geographical coordinates and the speed of the vehicle, the intelligent navigation system is able to calculate the fastest route to avoid traffic jams. This way the consumption and emissions of the car can be reduced, assuming a constant use of road transport (which may not be the case).

There are many studies available in the literature on the environmental assessment of infrastructure design. As this is a very large area, here only a few examples are shown for the application of LCA in this field.

4.5.1 Transport infrastructure

Four main types of transport infrastructure are usually distinguished: road, rail, air and water transport infrastructure, all having very different infrastructural needs. All of these are used by both freight and passenger transport. Depending on the goal of the study, only the infrastructure itself or also the emissions and consumption of the vehicles and their manufacturing is taken into account. The reference flow for the infrastructure itself is, for example, one meter of road over a one year period (m*a). For the whole transport system, the reference can be, for example, the transport of one tonne of goods by a certain transport system over one kilometre (t*km) in case of freight transport, or the transport of one passenger over one kilometre (passenger*km) for passenger transport. Land use and land transformation are in most cases relevant issues. Life cycle inventories are available for various transport system, for example by Frischknecht and Maibach and the ecoinvent database [ecoinvent 2007]. There are a large number of LCA studies available in the literature, especially on specific components of the transport infrastructure, for example the optimisation of a bridge with special materials.

- *Road infrastructure* includes the construction, renewal, operation and disposal of the road. There are various types of roads, for example motorways and roads of different classes. The infrastructure includes not only the road structure itself, but also the necessary tunnels, bridges, highway stops, etc. The construction stage involves the material and energy use, as well as the transport of materials and the emissions due to the construction of the road. The impacts during operation are due to the energy and material use and also for safety measures, such as lighting, de-icing, marking of lines and weed control. The reference flow of the analysis may be, for example, one meter road over one year (m*a).
- *Rail infrastructure*: the construction involves the actual construction of the rail track, the points, tunnels, bridges, signalling system, train overtaking stations, sound insulation walls and the buildings, such as stations or service garages. The operation includes for example de-icing, lubrication and the application of herbicides. The reference flow may be one meter rail track over one year (m*a).
- *Airport infrastructure*: the construction involves the building halls and the sealed area of the airport. Operation is, for example, clearing of the aircraft, de-icing, heat and electricity for the buildings and aircraft maintenance.
- *Water infrastructure* includes the port infrastructure and the canal infrastructure (artificial waterways). Port infrastructure consists of the sealed area of the port and the buildings. The operation includes the energy consumption, but also the impact of oil spills to water, for example.

4.5.2 Energy systems

Different energy systems are very different in their infrastructural needs, but LCA is a useful tool for their optimisation and comparison. A study on district heating, for example, analysed which components of the district heating grid the main environmental contributors are [Oliver-Sola et al. 2009]. The functional unit was a neighbourhood infrastructure that provided heat for space heating and domestic hot water for a standard family in a district heating system for 240 dwellings within a local urban neighbourhood for 50 years. The system included the power plant, main grid, auxiliary components of the main grid, trench works, service pipes, components in the buildings and the dwellings. The study found that the main impacts were not due to the main grid, as expected, but in the power plant and the dwelling components.

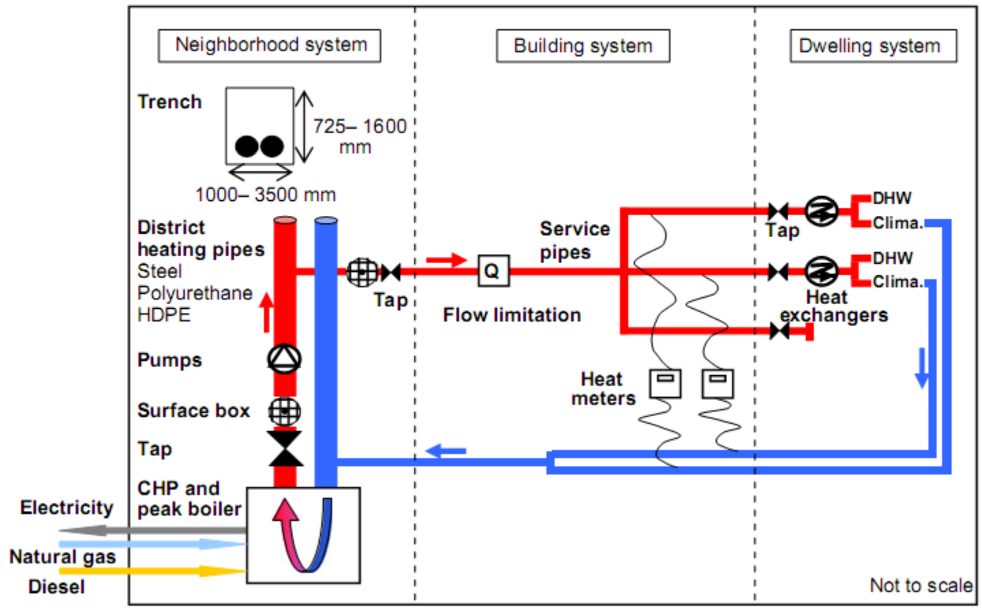


Figure: Schematic diagram of the systems and components that compose a district heating infrastructure [Oliver-Sola et al. 2009]

4.5.3 Wastewater treatment

Wastewater treatment infrastructure includes the canalisation and the treatment plants. LCA studies have shown that the infrastructure has a relevant impact even when the whole treatment process is considered [ecoinvent 2007]. The increasingly stringent environmental regulations on the nutrient removal, for example, have a positive impact on the quality of the local waterways, but have a negative impact elsewhere: the infrastructure resources, operational energy, direct greenhouse gas emissions and chemical consumption generally increase with increasing nitrogen removal [Foley et al. 2010]. Infrastructure resources and chemical consumption also increase significantly with increasing phosphorus removal. But this increased phosphorus removal offers an opportunity for resource recovery and reuse. Complex LCA studies are needed to evaluate the environmentally most suitable options.

4.5.4 Solid waste management systems

There are numerous LCA studies on municipial solid waste management systems and a substantial number of LCA computer models [Cleary 2009]. These compare, for example, different end-of-life scenarios. In most of the reviewed LCAs recycling generates greater net environmental benefits than landfilling and thermal treatment, and thermal treatment scenarios have a better performance than landfilling. The construction and maintenance of the infrastructure, the collection routes and the plants are very relevant in this regard.

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