LoRe-LCA

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

Deliverable D3.1
Building LCA good practice report

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1 Introduction

The use of LCA is emerging in the building sector, but the methodology is applied in a different way depending on which tool is used. Around ten different tools have been reviewed in Europe. 8 tools have been compared in the frame of the European Thematic

Network PRESCO (Practical Recommendations for Sustainable Construction) allowing some good practice to be identified but further harmonization is still needed. Some choices have been made in a CEN standardization committee, but some of these choices are made in a limited time and a deeper analysis would be useful regarding some aspects, and particularly resources.

This work package within the LORE-LCA research coordination action aims at finding good practice among the existing tools, identifying possible gaps in the knowledge and need for further investigation. Recommendations are then derived towards tool developers and users. A first draft of this document has been cross-reviewed by the project partners and external experts. Feedback has been collected and the document has been adapted to produce this final version.

2 Purpose and scope

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

An LCA can be performed for different purposes in the building and construction 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 minimise 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 Deliverable D3.1 Building LCA good practice report

The guidance documents from ILCD[3] are used as starting point. But buildings are different from most other industrial products:

• They are generally designed in a single unit – not thousands of copies of the same product, so very detailed LCA is not possible within the economic framework of a building project;

• They have a very long lifetime – 80 years or more, so end of life scenarios are more difficult to decide.

Due to these characteristics, the LCA methodology has to be adapted.

LCA can be applied in the building sector for different objectives, for instance:

- manufacturers can study the eco-design of building materials and equipment,

- architects and building consultants can compare various alternatives during the design phase in order to reduce the environmental impacts of a project,

- facility managers can study the influence of the users' behaviour and advise appropriate measures during the operation phase of a building,

- building owners and local communities can require and check the environmental performance level of projects.

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[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/

[3] see http://lct.jrc.ec.europa.eu/eplca/deliverables/consultation-on-international-reference-life-cycle-data-system-ilcd-handbook

The way to apply LCA depends on the objective: for instance if the purpose is to select a building site for a new construction, this decision will have a large influence on transport needs and their related environmental impacts. In this case, transport (e.g. home-work commuting) has to be included in the studied system. On the other hand if the building site is already fixed and the purpose is to compare architectural designs, transport might be excluded.

LCA is still complex, therefore identifying good practice is essential, and further research is still needed concerning some topics. This report is structured in the following way:

- System description (functional unit, system boundaries, process tree, cut-off rules),
- Simplification of LCA and adaptation to buildings (default values, simplified description, dynamic and consequential LCA adapted to long lasting systems like buildings),
- Relevance and quality of data (inventories, including indoor emissions, regional contextualisation),
- Specific methodological aspects (biogenic CO2, co-products, end of life and particularly recycling, environmental indicators and particularly regarding resources).

3.1 Study of the system description (functional unit, system boundaries, and processes).

Good practice will be collected in order to harmonise the definition of functional units and system boundaries among the different LCA tools. The list of processes to be included (e.g. water consumption and treatment, domestic waste treatment…) will be elaborated as well as cut off rules. The task will use the work in CEN TC350 as a starting point.

3.1.1 Functional unit

The functional unit is essential in LCA. It is a measure of the performance of the functional outputs of the studied product system. The primary purpose of the functional unit is to provide a reference to which the inputs and outputs are related, which is necessary to ensure comparability of LCA results. The functional unit can also be specified with respect to time and place.

For building LCAs, the functional unit commonly includes information regarding a quantity, a function (e.g. providing space for living and/or working), the quality of this function (comfort level, quality of life), and a duration.

In the European standardisation process Sustainability in Construction (CEN 350), the term *functional equivalent* is introduced at building level in contrast to functional unit at the product (building material) level. The currently used definition of functional equivalent according to CEN (2011) is *"quantified functional requirements and/or* *technical requirements for a building or an assembled system (part of works) for use as a basis for comparison"*

Functional requirements here stands for "type and level of functionality of a building or assembled system which is required by the client and/or by users and/or by regulation" [CEN, 2011] . The functional and technical requirements according to FprEN 16843 can include for example structural safety, fire safety, indoor air quality, security, adaptability, energy efficiency, accessibility, de-constructability, recyclability, maintainability, durability and service life of a building or building component. If performing relevant comparisons between different buildings (for instance in an architectural competition) it is recommended by CEN that at least the major functional requirements, intended use and relevant specific technical requirements are well described, in order to enable transparent comparisons. CEN here recommends the following items to be described by the functional equivalent:

- type and use (required functions);
- area and/or volume;
- pattern of use (e.g. occupancy);
- design life and reference study period;
- location of the building; [CEN, 2011]

For a residential building, the functional equivalent may thus be described as: *A building designed for 90 residents at a specific location, which fulfil national regulations and requirements regarding comfort, health, safety, energy demand etc. over a presumed life time, e.g. 80 years*.

The precision of the functional unit or equivalent must be dependent on the specific application. The client specifications concerning type, use, area, volume, location and all other types of functional and technical requirements then serve as the functional unit + an anticipated life time. That is, the precision of the functional equivalent coincides with the precision of the client demands with regard to the functional and technical requirements of the building in use (after construction or retro-fit).

The reference service life or study period should be précised by the client in a programme or client's brief. In DGNB 50 years has been chosen as study period; this can be questioned because this value depends on the use (e.g. residential or tertiary), and possibly a local context. The terms service life and study period are often used in the same context. However, they do have a different meaning, and service life and study period may be different.

A special circumstance regarding functional units of buildings is that buildings may provide multiple functions such as dwellings, offices and a restaurant in the first floor. In such cases, the functional unit (or equivalent) must include a quantification of all such functions, e.g. 20 work places for offices to be occupied 40 hours per week.

The comfort level is an important part of the function of a building. Comfort levels should therefore be specified, for example as specified in national regulations. For instance, thermal comfort may be specified as maintaining a certain indoor air temperature (e.g. 22 ºC), indoor air quality can be specified as a certain indoor air exchange rate per hour (e.g. 0,5) and sound conditions can be specified as a certain sound classification (e.g. B).

If the LCA for some reason is comparative in which buildings of different size or constellation is compared (e.g. benchmark with reference and best practice values), a benchmark unit (functional unit) which relates impacts to e.g. numbers of building users, utility time or heated m^2 is necessary. The ILCD handbook introduces the concept of "reference flow", i.e. the flow (or flows in case of multifunctional processes) to which all other input and output flows quantitatively relate. In such a case the benchmark unit cannot be specified very precisely but needs to be formulated as the least common unit related to the buildings under comparison. For understanding and interpreting the results of such a comparative LCA, each building should be further described regarding more specific functional and technical properties like the ones that may be included in the functional equivalent. However, naturally it makes no sense to compare buildings that differ much.

Recommendations for further research

At the level of a neighbourhood, the functional unit is more complex to define due to the many services to be provided and requirements to be fulfilled. This covers the different types of buildings, open spaces, networks etc. Including the ecosystemic services, related to biodiversity, as part of the functional unit may be relevant, but this requires further research activities. Urban agriculture and transport related issues could also be integrated.

3.1.2 System boundaries and process tree

In an LCA study, the system is defined as the collection of individual processes or necessary subsystems that when materially and energetically connected result in the presence of the studied product in the market. The system is usually represented by means of a diagram of interconnected processes. Consequently the system boundaries define the individual processes which will be included in the system to be studied.

When performing an LCA study, one of the most important decision is to define adequate system boundaries, that involves deciding which individual processes will be considered and the level of detail in which they will be analysed. It should be noted that it is not necessary to spend resources on quantifying inputs and outputs which do not significantly influence the overall conclusions of the study. Obviously the more information that is gathered the more extensive will the LCA study be, the more time it will take to carry out, and the greater the cost will be.

For these reasons it is necessary to define boundaries in accordance with the objectives of the LCA study and the impacts assessed. For instance if the aim is to compare several possible building sites, home to work transportation has a large influence on the results and should be accounted for. On the other hand if the building site is already chosen and the objective of using LCA is to help in the design, transport issues may be of less importance. All decisions to omit a stage of a building life cycle, a process or any inputs/outputs must be clearly indicated and justified. The criteria, or cut-off rules, to fix the system boundaries must guarantee that the results are not compromised.

According to the recommendations made by the Technical Committee "Sustainability of construction works" CEN/TC 350, 4 stages are usually considered in the life cycle of a building: production, construction, use and end of life.

Table 3-1 Life cycle stages of a building based on the CEN/TC 350 standard, prEN 15804 Sustainability of construction works - Environmental product declarations – Product category rules

Stage	Module
I. Product stage	A1. Raw materials supply
	A2. Transport
	A3. Manufacturing
II. Construction process stage	A4. Transport
	A5. Construction-installation on-site processes
III. Use stage	B1. Use, installed product
	B2. Operational energy use: heating, cooling, ventilation, hot water, lighting, building automation and control
	B3. Maintenance (transport included)
	B4. Repair (transport included)
	B5. Replacement (transport included)
	B6. Refurbishment (transport included)
IV. End-of-life stage	C1. Deconstruction
	C2. Transport
	C3. Recycling/re-use
	C4. Final disposal in landfill/incinerator/etc.

The product stage includes the processes associated to the supply of raw materials, transport up to the production gate and internal transport needs and manufacturing processes at plant for the construction products, including the structure and the building envelope. The building structure is composed of basement retaining walls in the underground floors, pillars, and basement floor, usually built of reinforced concrete. The building envelope is composed of exterior and interior walls, roof, windows and doors. With the increasing numbers of Environmental Product Declarations (EPD) for different construction products, some inventory data can be obtained directly from existing EPD. Also they can be obtained from existing LCA databases.

Depending on the purpose of the LCA study, the production of the energy systems of the building could be also included at the product stage. In this case, the production of the boilers for heating and DHW, tanks for thermal storage, distribution pipes, heat pump or air conditioning systems, renewable systems (photovoltaic modules, solar thermal collectors, small wind turbines, etc.) and even lighting lamps could be inside the system boundaries.

The construction process stage comprises the transport of the construction products and energy systems from the manufacturing plant to the building site, including any transport, intermediate storage and distribution. It also includes the transport of the construction equipment, such as bulldozers, skid-steer loaders, hydraulic diggers, power saws, cranes, rock crushers, etc. from the supplier to the site, the energy demand for this equipment and the wastes of the construction process including transport and final disposal of these wastes. The inclusion and evaluation of this stage is relevant when comparing conventional on-site construction with prefabricated construction.

The use stage involves mainly the final energy demand for heating, cooling, ventilation, DHW and lighting, as well as the contribution of the renewable energy systems. The final energy demand is calculated according to the standards giving guidance for calculating the energy performance of buildings. In this sense, different software tools including dynamic thermal simulation on an hourly basis or other simpler procedures can be used. The thermal and electric production from renewable systems has to be estimated by different tools. The operation of the related equipment and services of the building (e.g. an escalator) are also part of the use stage and can be estimated based on an operation scenario.

Depending on the purpose of the LCA study, other aspects could be also included at the use stage: the water demand and the treatment of the wastewater at the municipal wastewater treatment facilities, the users' mobility, consumable products, solid waste, etc. When analysing residential buildings, the mobility of the building users is usually excluded of the use stage due to the lack of adequate data. Also, due to the complexity of obtaining reliable data, consumable products and solid waste generated (cardboard, glass, plastics, etc.) are normally excluded.

Building maintenance, repair, replacement and refurbishment processes are also considered at the use stage. This usually include the replacement of the building envelope (window, doors and other elements) and the energy generation equipment (boilers, heat pumps and air conditioning systems, lighting lamps, renewable energy systems, etc.). The cleaning operations, the repainting of walls and the repairs of the different energy systems and the building envelope will also be considered depending on the purpose of the study, although it could be difficult to obtain precise data. Necessary maintenance during a products service life should be included in the product EPD. The maintenance involves the production of the new products/systems, the transport from the manufacturing plant to the building site and the final disposal of the replaced products/systems.

Depending on the purpose of the LCA study, the changes in the future technical specifications (such as the energy efficiency, the heat losses, etc.) between the new and the replaced products or systems could be considered in the assessment. This is discussed in the paragraph 3.2.3.

The end-of-life stage involves the demolition of the building and the disposal of each building product. Three scenarios of disposal can be considered: direct final disposal without recycling, partial recycling via sorting plant and direct recycling at the building site. A special circumstance is that building product disposal will be usually performed 50 years after a building has been built. This implies a high uncertainty in the end-of-life stage (see also § 3.4.3 regarding end of life).

In the Ecoinvent data base, no bonus or burden compensation is given for recycled product within the data itself. No partial allocation of burdens from recycling processes to the old (primary) and the new (secondary) products is made. This approach allows the user to choose a model for recycling; in some models, the system boundary cuts off the recycling process itself, but includes sorting plants and the disposal of non-recyclable product. Wastes with high recyclable content are thus relieved of some of the burdens from disposal. This approach may not be relevant for building design, because the possibility to recycle a product at the end of life offered by a "design for dismantling" approach is not completely rewarded (the fact that recycling avoids a production process is not accounted for). This issue is discussed in more detail in § 3.4.4 regarding recycling.

The disposal without recycling involves the separation of the materials from the original construction, sorted into a MTC waste through and directly transported off to final disposal. In this case, the dismantling burdens (demolition energy and particle emissions), a transport to the final disposal site and the final disposal in a landfill or incinerator are inside the system boundaries.

The recycling after sorting is applied if the building material cannot be separated at the building site, but is mixed with other materials. The material is separated from the original construction, sorted into a MTC waste through and transported off to sorting. Different materials can partly be separated in a sorting plant. The fractions separated in a sorting plant are either recycled or disposed in landfills or incinerators. Consequently, sorting does not automatically mean recycling for all materials. Sorting plants merely separate a recyclable fraction (gravel, bricks etc.) from unwanted materials (plaster, wallpaper, etc.). In this case, the dismantling burdens (demolition energy and particle emissions), transport to a sorting plant, the waste sorting process, transport of the non-recycled fraction to the disposal facilities and final disposal in a landfill or incinerator are inside the system boundaries. The recycled fraction which will be further processed is outside the system boundaries.

The direct recycling is applied if the building material is separated at the building site and is recycled without prior sorting. The material is separated from the original construction, sorted into a single material through and transported off to recycling. Only dismantling burdens (demolition energy and particle emissions) are included. The transport of the used material to the point of recycling is therefore cut off and assigned to the recyclate consumer. The only burdens for direct recycling are dismantling energy consumption and

PM emissions during dismantling. There is no complete consensus with this allocation criterion, but most publications, including the ISO standard, would recommend system expansion. For example, the reduction of impacts associated with recycling can also be distributed equally between the primary and secondary products. This is discussed in paragraph 3.4.3.

Recommendations for further research

None

However, the influence of changing the system boundaries should be studied to give LCA performers a better basis for knowing what would be of high importance to include. Specifically it is a need for more information of the on-site activities and use of consumables, and their influences on the LCA results.

3.1.3 Cut off rules

In principle, when performing LCA calculations, all building components and their impacts that occur within the building or within the selected scope need to be taken into consideration and most applications claim to do so. However, in practice, it can be observed that not all the material flows of a building can be covered in an LCA. There is almost always insufficient time, incomplete data to accomplish such a precise study. On the contrary, there are some quantitatively irrelevant material flows, which only cause unnecessary complicated procedures in the LCA calculation. Not merely for a simplification of the system, but rather due to the unreliable data base, some of these dispensable building elements should be ignored – cut off in an LCA, to reduce the unnecessary complicity and enable comparative calculation.

In order to provide a regulated simplification of LCA, different rules were developed on how building components should be regarded in the calculations and at what stage cut-off rules should be applied (e.g. DIN EN ISO 14040, ISO 14041 and DGNB). Most of these norms or regulations, however, restrict both the inputs (building materials, packing, waste, etc.) of data as well as the outputs (impacts: GWP, EP, energy demand, etc.).

As an example on how to treat the problem of cut-off rules, the system of the German Sustainable Building Council can be regarded. All the building materials which have less than 1% of the total weight (inputs) of the building and the impact in the life cycle (outputs) due to the fact, that these materials make up less than 1% of the entire energy demand, GWP, or other impacts categories e.g. AP and EP can be neglected. An additional rule sets, that the sum of the neglected materials should not be larger (i.e. heavier) than 5% of the total weight and impacts of the building.

As an example of the simplified methodology the following data are given for an apartment building in Germany. (In order to make calculations easier, the German sustainability system also provides a simplified calculation methodology that finds widespread application. The only materials regarded are those, which are structured within the group of building materials and technical applications (corresponding to the costing categories 300 and 400 of the German national standard DIN 276-1 Building costs Part 1: Building construction.) Scaffolding, surroundings, furniture etc. are not regarded in the system.)

Building elements	**Weight**		**Primary energy**		**Global Warming Potential (GWP100)**	
	kg	%	MJ	%	kg-Eq	%
exterior walls, incl. windows and linings (insulation, paint, plaster, etc.)	28.381,3	0,5%	1.070.014	12,1%	146.986	9,8%
roof (roof-truss, insulation, roof cladding, dormer, etc.)	140.303,6	2,2%	300.251	3,4%	30.635	2,0%
slabs incl. linings (paint, plaster, drop ceilings) and coverings (sound insulation, carpet, tiles, raised floor etc.)	1.273.358	20,3%	1.698.901	19,2%	236.808	15,7%
foundation slab incl. Insulation and covering	276.150,8	4,4%	484.030,1	5,1%	57.509,3	3,8%
foundation	24.239,5	0,4%	576.788,1	6,1%	77.772,9	5,2%
Interior walls incl. linings (paint, plaster, etc.)	982.376,7	15,7%	765.309	8,7%	126.913	8,4%
Doors	7.384,5	0,1%	49.997	0,6%	-10.165	-0,7%
engin. heating plant excl. heating pipes and radiators	1.000	0,02%	24.653	0,3%	2.079	0,1%

Example of building materials which are above the cut-off rule in the system of the German Sustainability Council.

These cut-off rules seem to be very well elaborated as long as one is not checking the problem - how to find out the actual total (100%) environment impacts of a building. In almost every case it is virtually impossible to record all the building materials completely. Even though one can extrapolate the accurate weight of a building, it is still hardly possible to figure out the exact impacts of particular building elements without an exact evaluation. Otherwise, if the actual the magnitude of impacts is known, it should be unnecessary to diminish the quantity of the data inputs. And obviously, there isn’t any longer simplification in the LCA calculation.

In fact, an LCA inventory or calculation can always only approach an approximation. The aim of cut off rules is to regulate a systematic decrease of the calculation objects in an acceptable scope to enable unelaborate LCAs. Nevertheless, the reliability of the results must be ensured. Therefore, it is suggestive that, instead of limiting the both constituents in the LCA - inputs and outputs, only to bound the inputs, namely both quantitatively (the percentage of the total weight of building) and qualitatively (the sorts of material). Which means the neglected mass should not be too big: the minimum weight of cut off mass all at all should be appointed. And the building materials which cause high environment impacts in the selected impacts categories (in particular one or all) must be enclosed in the LCA.

One instance is the cut-off rules in the LEED LCA: At least 95 per cent by mass of inputs; and all energy sources within the production process are required to be recorded;

and all the material inputs that may have high environmental burden (toxic compound, high requirement of resources or energy, etc.) shall be identified and recorded. [Integrating LCA into LEED – Working Group B (LCA Methodology) – Interim Report #1: November 2006]

Similar to LEED, BREEAM requires also to identify and to record the high influence materials. The 98 per cent of total weight shall be recorded, which comprise of the building elements as well as the packing and waste through construction. Not only the materials which require high energy or environment relevant resources in their extraction, use or disposal but also the materials which are categorized as toxic or hazardous must be recorded.

In these cases the limits of cut offs and the qualitative requirements of the document are clearly defined, hence not only the simplification is obvious, but also the plausibility of the results can be ascertain. But in order to identify the “high impact” building materials, a clear classification of diverse building materials shall be pre-existent. Furthermore, the system boundaries must be consulted and the total building weight shall be reasonably assessed.

For these reasons, it is suggestive to add a sensibility analysis in the cut off rules in which the impact classes of building materials in different impact categories are outlined. In this way the influent and indispensable building materials can be quickly defined. The undesirable omission of the inputs and falsification of the results of LCA can also be avoided. An example of these kinds of schemes is the Green Guide, a material rating tool for material BREEAM. In this tool building materials for different usages (e.g. commercial buildings, retail, domestic, etc.) as building elements (e.g. external walls, roofs, insulation, etc.) are classified separately (from A+ to E) in all impacts categories (e.g. GWP, EP, water extraction, human toxicity, etc.) and accumulated into overall rankings.

Subsequently, the impact categories (system boundaries) should also be regarded combining with the main building structure (e.g. wood, solid, steelwork construction, etc.). Because, a low influent building material in a high energy demand design (solid construction) may take an adverse effect in a low energy demand design (wood construction). But should the importance of a material be evaluated according to its relative or the absolute effect? Ancillary materials can also be important according to the construction technique [Kellenberger, 2009].

Attention must also be taken that principles of cut of rules must be carried out:

- Reduction of data collection and simplification calculation

- Avoidance of unadulterated results

- Reliability and Comparability of LCAs

- Complete and verifiable documentation of building flows

Input-Output Analysis (IOA) can be used to gather missing inventory data, see [Guinée, 2002] and [Finnveden et al, 2009]. This could help to reduce the uncertainty related to cut off. The sum of several small contributions can be fairly large, as mentioned by [Nässén et al, 2007]: there is a difference between results from traditional process-based LCA and IOA where the latter give higher results for environmental impacts from building materials.

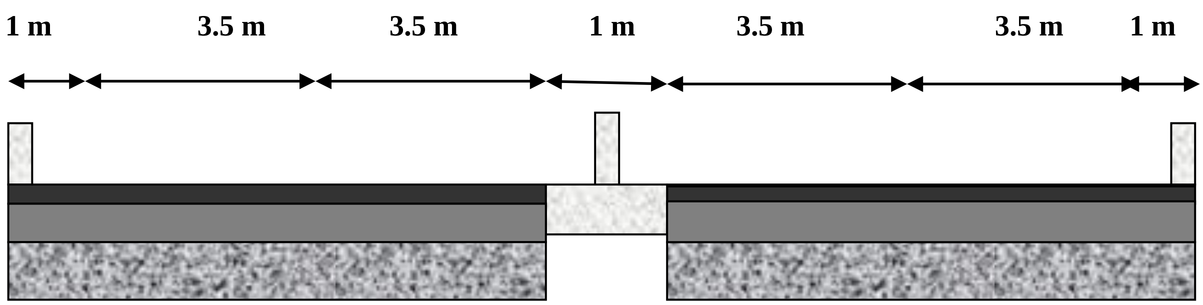
Recommendations for further research

Elaboration of a methodology to identify the influent material flows in a particular building, to complement missing data using IOA, and to derive adequate cut off rules.

3.1.4 System description for roads

The system definition depends on the objectives of the study. If the objective is to compare the impacts of road versus railway or to compare different routes, the impacts related to the use of vehicles have to be included because they are much larger than the impacts of the infrastructure. If the objective is to compare various materials and construction techniques for a given traffic, the use of vehicles can be excluded from the system as long as the choice of the materials do not influence the fuel consumption of the vehicles.

In any case, the functional unit should precise the geometry of the road (number and width of lanes, hard shoulder, see figure hereunder) including a length (e.g. 1 km), the function (related to the number of different types of vehicles –cars, trucks with different sizes…- per hour or per day), the quality of the function (e.g. noise protection, respect of biodiversity, security aspects…), and a duration (e.g. 100 years).



Example cross section of a road

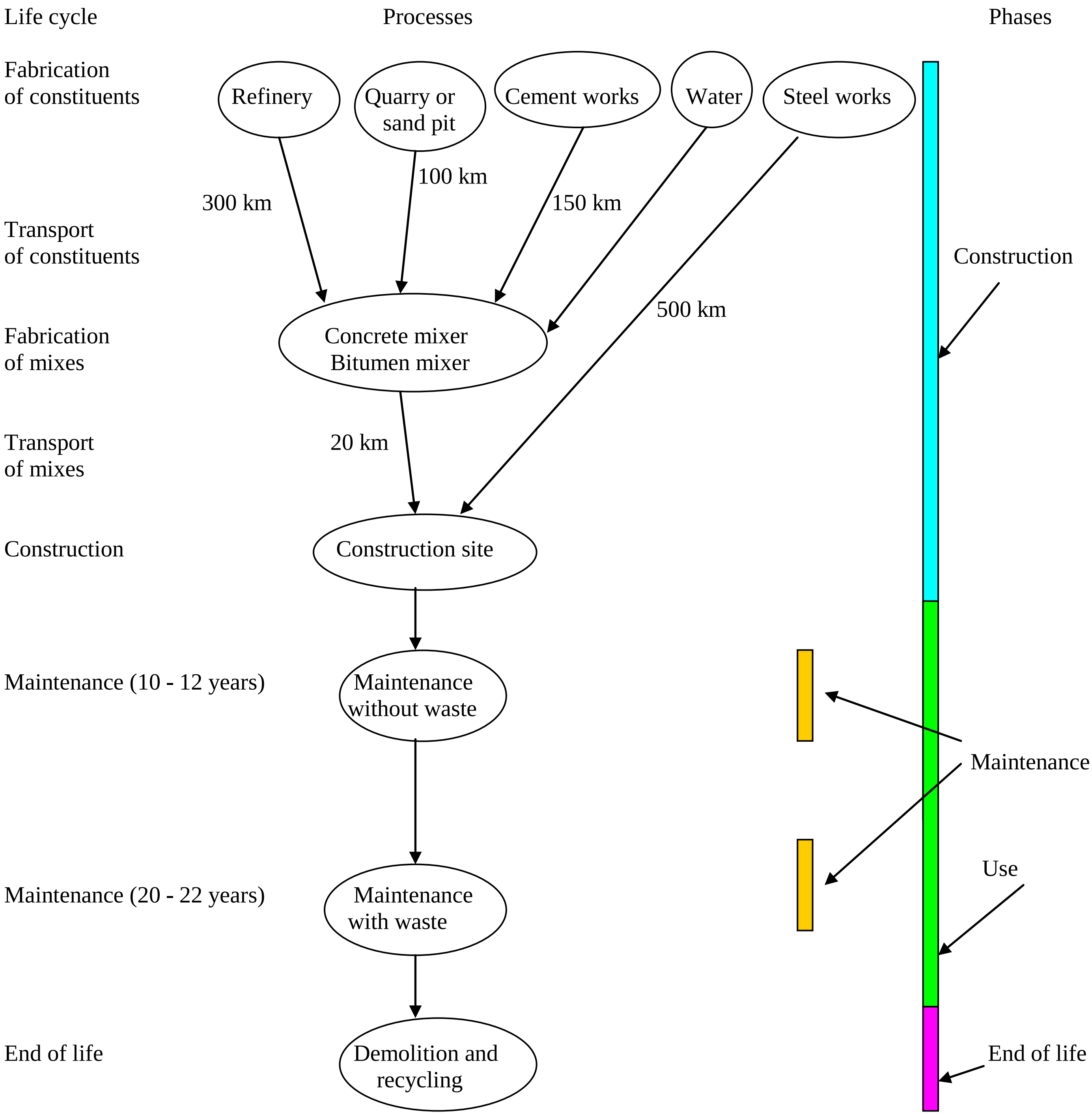
The life cycle stages are: fabrication and transport of materials, construction, use and maintenance (e.g. replacing the surface layer or adding some bitumen). One opinion is that there is no “end of life” for roads, unlike buildings that are demolished some time. Other actors propose to account for end of life processes in order to encourage e.g. recycling of steel components.

Different material layers and road compositions can be compared provided that the same function is fulfilled (e.g. concrete versus bitumen surface, use of excavation earth, steel versus concrete or wood crash barrier). Some precision has to be provided on the quality of materials, e.g. cement content of concrete 350 kg per m^3 and composition (12% cement, 82% gravel and 6% water), quality of steel (e.g. galvanized steel for crash barriers, construction steel for reinforced concrete…), quantity of steel used for reinforced concrete. The weight of each material per km road can be derived according to the road geometry, the thickness of each layer, and the density of each material.

Transport distances have to be assumed for the different materials (from refinery to construction site for bitumen, from cement production and from sand pit or quarry to concrete production site, from concrete and steel production to construction site, from road to landfill etc.). The transport mode is generally truck, which size has to be indicated (e.g. 40 t).

The fuel consumption of mixing equipment for concrete production or other materials is generally known per kg of final product. Consumption for other construction equipment may be expressed per day, and complemented with a productivity (area of road treated per day, or length of hard shoulder installed per day). Different machines are used on site and should be accounted for: excavator, compactor, mobile coffering, surface finisher, crash barrier installation. These machines may be used several times for the different layers (foundation, platform, upper layer, surface layer…).

Example life cycle description of a road



The use stage may include street lighting and electricity consumption for security devices (sometimes provided by photovoltaic systems), which clearly are part of the roads function, and traffic (impacts of the vehicles). PV systems can be used as sound barriers, and the environmental benefit of renewable electricity production may be accounted for.

PV system used as sound barrier

Traffic can be defined by a number of different vehicles per day or per year (e.g. 10,000 vehicles a day, 80% cars and 20% trucks with different sizes, e.g. one third 16t, one third 28t and one third 40t). The fuel consumption of trucks depends on their load, so that an assumption has to be made on this topic, e.g. 50% of the full load in average. A question concerns the influence of the choice of the materials (concrete versus bitumen) on the fuel consumption of the vehicles.

Another question regards possible emissions during the use phase, e.g. solar radiation may heat the dark bitumen surface and pavement marking, leading to VOC emissions which may have some toxic effects.

Maintenance is performed for example by adding a 2.5 cm bitumen layer every 10 years, and scraping a layer every 20 years.

The life span of a road is very difficult to define. End of life scenarios will probably concern a far future, which leads to large uncertainties when modelling this stage.

Different technologies can be compared; in general the impacts related to vehicles are much more important than impacts related to the construction itself. Sensitivity studies can be performed regarding the life span and possible end of life scenarios.

Recommendations for further research

Like buildings, roads have a long life span and therefore the operation stage plays an essential role in their global environmental balance. Fuel consumption of vehicles constitutes a major impact, and can be influenced by the design of a road (e.g. distance, slope…). Models exist to evaluate this fuel consumption, and one applied research activity could be to link such a model to an LCA tool. Studying the influence of materials (e.g. bitumen versus concrete) over fuel consumption would constitute a useful complement, as well as accounting for VOCs emissions e.g. resulting from bitumen heated by solar radiation.

If the LCA study covers different route alternatives, the land use should be included, and further studies are recommended.

3.2 Study of simplification and adaptation of LCA applied to buildings.

3.2.1 Use of default values

An LCA study of a building requires a lot of specific information; however, this information is not available on an early stage. Therefore the use of default values, here including key figures/numbers, average numbers etc. could be useful. The default or standardised values have several functions; providing information to the practical use of LCA and to define standardised input for comparative LCA.

A study has been performed to identify relevant parameters, and how they can be collected and used at different phases in a planning and decision process.

Development of key figures; when “complete” LCAs are made for several buildings to document their environmental impact, these results can be used to provide key figures, for instance average values for CO2/m2 residential building over it’s life span (60 years), kwh/work place/year, etc. These values can be used for comparison, but also directly as preliminary results early in a process.

While the requirements for the building, and also the planned patters of use are given early in the design phase, the amount of materials etc. are unknown.

The use and planned number of occupants give enough information to estimate the size of the building before any sketches exist, later in the process the architect’s sketches or drawings defines the size of the building.

For energy use, legislation, requirements or specific targets can be used as default values.

For the building, service life, total life span, and maintenance intervals and maintenance action can be based on standard scenario and default values.

Amount of materials, with their impact, can be described by making generic building elements, for instance a wall, with its generic EPD.

Default values are further needed as input data, for instance default transportation distance and energy and electricity mix. These can be defined on national or regional level.

Recommendations for further research

Several case studies, where LCA is done on different basis throughout planning and design processes, can be used to study the uncertainty and usefulness of default values.

3.2.2 Simplified building description

The complexity and uncertainties of LCA results is often seen as main barriers to more frequent use of LCA. It is natural that if unreliable data is used, unreliable results will be the output. However, rough estimates of the environmental impacts over the life cycle are still better than to ignore these impacts. For coming up with rough estimates there are a number of possible simplifications which can be done with the aim to promote LCA to wider user groups:

- Simplify the acquisition of building data by focusing on larger building elements.
- Simplify the inventory analysis by focusing on the most important substances that contribute to a certain impact category.
- Use easily accessible data, for instance Input Output analysis data.
- Reduce the time of the building data acquisition by improved CAD applications.

Data acquisition is the most prominent problem since buildings contain a large amount of different products and the availability of quality assured production data is restricted. Input data should be easy to find in the building project and there should be as little of it as possible. When the aim is to simplify, questions like which data for which life cycle stage is more important than others are important to tackle.

Next table presents a detailed building description for a complete LCA study.

Table 3-2 Input data in the different life cycle stages of a building

I. Product stage	Construction products	Structure:
		- Composition of the basement retaining walls (kg)
		- Composition of the pillars (kg)
		- Composition of the basement floor (kg)
		Enclosures (layer by layer):
		- Composition of the External Walls (kg)
		- Composition of the Interior Walls (kg)
		- Composition of the Roofs (kg)
		- Composition of the Windows and doors (kg)
	Energy systems	Heating and DHW equipment (total power and technology)
		Cooling equipment (total power and technology)
		Lighting lamps (total power and technology)
		Renewable systems (total power and technology)
II. Construction stage	Transport from plant to building	Construction products (total weight and distance)
		Energy systems (total weight and distance)
	On-site construction processes	Energy demand for construction equipment (kWh)
		Waste (total weight, type of final disposal)
III. Use stage	Operation	Final Energy Demand (kWh):
		- Heating demand
		- Cooling demand
		- DHW demand
		- Lighting demand
		- Renewable energy contribution

		Water demand (m^3)
		Mobility of occupants (km)
		Wastewater for treatment (m^3)
	Maintenance, Repair, Replacement and Refurbishment	Construction products (type of maintenance and frequency)
		Energy systems (type of maintenance and frequency)
IV. End-of-life stage	Construction products	Structure (type of final disposal and lifetime)
		Enclosures (type of final disposal and lifetime)

According to the results of several LCA studies in the case of standard buildings, some simplifications in the building description could be proposed:

- Leave the construction stage and end-of-life stage outside of the system boundaries. The contribution of these stages reaches usually 10-15% of the total energy impact of the building. However, if other indicators are selected for the assessment, these stages should be included.
- At the product stage, consider only the impacts associated to the structure and building envelope inside the system boundaries. The impact of the production of energy systems is usually much lower than the total building impact.
- At the use stage, consider only the final energy demand required for building operation inside the system boundaries. Although the mobility usually has a high impact (40-50%) in LCA of a building, due to the cost of obtaining reliable data, it could be excluded in a simplified approach. Excluding the users mobility, the final energy demand may represents the 80-90% of the impacts at the use stage. However in some cases building maintenance, repair, replacement and refurbishment processes may involve a high impact.

Even in the case of standard buildings, materials play an important role regarding impacts like waste and toxicity. But in the case of low energy consumption buildings, the statements above are no longer valid: the fabrication of building elements may contribute to around 30 % or even more in the total life cycle energy balance, see [Nässén et al., 2007] and [Wallhagen et al., 2011]. According to [Toller et al, 2011], the emissions from heating of buildings is important but the emissions of CO_2 from heating is lower than from other parts of the building sector, indicating the importance of emissions from for example production of building materials. Also emissions from mobile sources (including transportation but also work machines) account for approx. 30 % of the CO_2-emissions from the sector.

In any case, simplifications will strongly depend on the purpose of the LCA study. Therefore it is difficult to propose general LCA simplifications for buildings.

As most of the life cycle inventories of construction products are expressed in kg or m^3, it is necessary to know, layer-by-layer, all the products (with their thicknesses) of the building envelope and the total surface of each type of wall. Thus it is possible to obtain an inventory with the amount or weight of each of the products. The weight of each product can be calculated by multiplying its density by the surface area and the thickness of this product. These input data can be easily obtained from the architectural project of the building. If there is available EPDs for the products used, either specific or generic information, the amount of the product should be referred to its functional unit.

On the other hand it is necessary to know the final energy demand disaggregated by energy sources (natural gas, light fuel oil, heavy fuel oil, electricity, etc.) used for heating, cooling, DHW and lighting. The final energy demand should be expressed in MJ or kWh, since most of the life cycle inventories for energy demand are expressed in these units. The energy produced from renewable systems during their lifespan is much greater than the impact of manufacture and disposal of these systems. Consequently, in a simplified approach, the energy production from renewable systems could be subtracted directly from the final energy demand of the building. Nevertheless, other burden allocation criteria for electricity production from renewable systems are discussed in paragraph 3.4.2.

Recommendations for further research

Some simplifications in the building description can be considered, but research is still needed to validate this approach compared to detailed assessment:

- Simplify the acquisition of building data by focusing on larger building elements and reduce the time of the data acquisition using improved CAD applications.
- Use IOA data.
- Leave some stages outside of the system boundaries and neglect some processes of the building stages.

Some LCA studies only consider the product stage (structure and building envelope) and the use stage (final energy demand for building operation) inside the system boundaries. Nevertheless the construction and disposal stage may be very important regarding impacts like waste and toxicity. Sensitivity studies are therefore needed to evaluate the uncertainty related to simplification and check the reliability of the method.

3.2.3 Dynamic LCA

The calculation method behind most LCA tools consists in adding the impacts of the components of a system. For instance, if a house is made of 60 tonnes concrete, 5 tonnes wood, 1 tonne steel etc., the total impacts are 60 x the impacts of producing one tonne concrete + 5 x the impacts for 1 tonne wood etc. The life cycle inventories considered generally correspond to average values of present processes. The current practice in LCA is therefore to use a steady state model.

But in reality, characteristics of some elements are varying in time, e.g. the efficiency of a boiler decreases over time. Replacing a simple addition by a more realistic simulation of the life cycle allows such variation to be accounted for. This approach is illustrated in the following §3.2.3.1. Technical innovation is another reason for considering possible temporal variation of impacts, as well as the external background system and building renovation. For instance in Denmark, the energy supply to buildings is expected to include major reductions in emissions during the coming years (concerning both electricity and district heating). Beside, also the heat insulation and the individual supply of renewable energy are expected to reduce the emissions related to the operation of buildings.

Another aspect regards the consequential LCA approach. In the standard “attributional” approach, average impacts are considered for background processes. For instance, when studying a building heated by electricity, average impacts of electricity production are used. In the consequential approach, the influence of the studied system on the background processes is taken into account. In the example above, choosing an electric heating will add a peak demand during cold days and may require (if this choice is made at a large scale) implementing peak electricity production systems, therefore modifying the electricity mix and the related impacts. In such cases, a marginal electricity mix is used instead of the average mix.

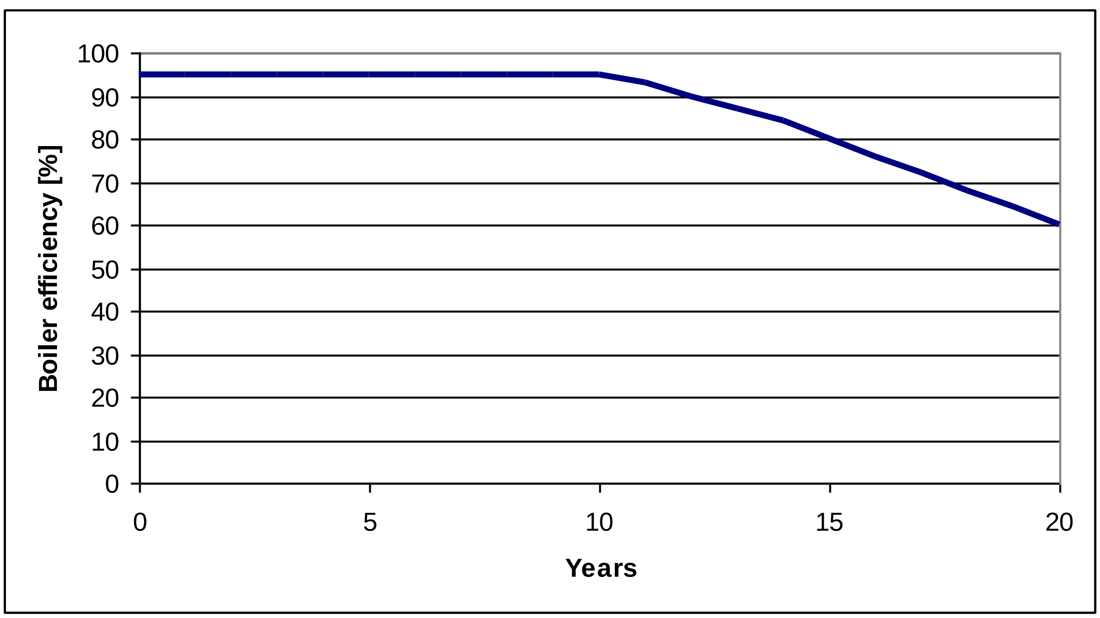
If for instance the use of LCA shows that electric heat pumps are to be advised so that various regulation and subsidy systems induce a high penetration of heat pumps on the market, this penetration increases the peak electricity demand in winter. If thermal plants are built to match this demand, complementing a pre-existing lower carbon production (which is the case e.g. in France), then a consequence will be higher CO_2 emissions than what was originally evaluated using a standard attributional approach. This may not be the case in other countries, or if due to mitigation policies the higher CO_2 emissions during peak demand have to be compensated, see [Finnveden, 2008]. However compensation could be applied for CO_2 but not for other impacts. A consequential approach may therefore be more relevant when a decision maker wishes to account also for consequences of his decision at a global level. But a dynamic model is needed in order to evaluate such interaction between decisions and effects. Searching for a possible equilibrium requires expanding the system boundary: for instance when identifying the marginal electricity production mix, not only one building has to be included, but the whole building stock and the electricity production system. An example regarding an evolution scenario of waste treatment is presented in §3.2.3.2 hereunder. The choice of waste treatment (e.g. incineration versus landfill) is decided at a more local level, which makes this study more feasible than a consequential approach applied to electricity production.

3.2.3.1 Temporal variation of the system

An example is presented in the case of a social housing apartment building in France (see next picture), equipped with a gas boiler and a solar thermal installation for domestic hot water.

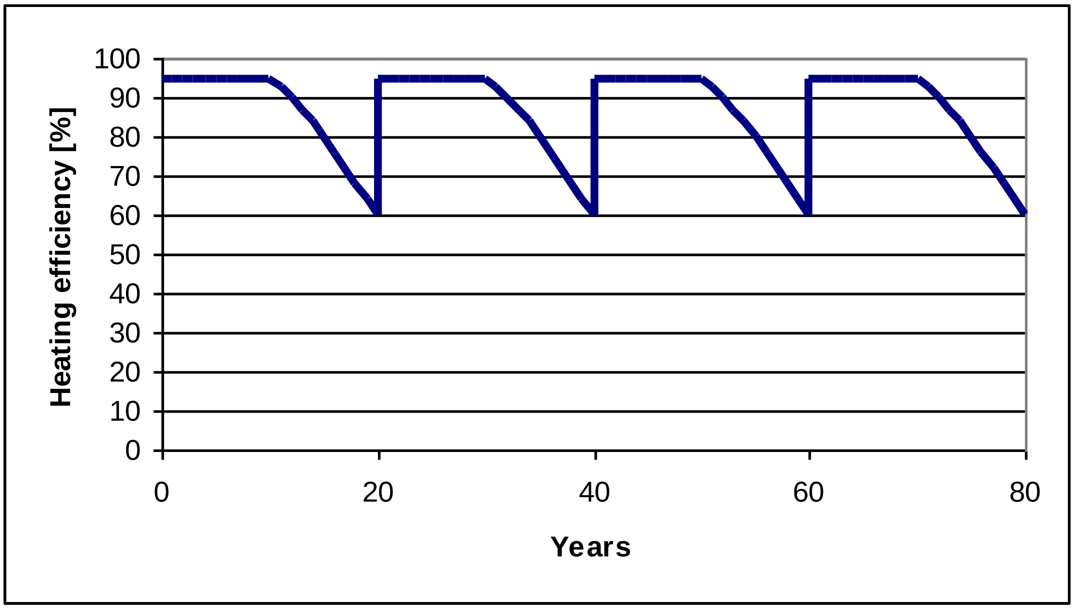
Social housing apartment building in Greater Paris area, including a solar domestic hot water system.

The efficiency considered for this boiler in a non-dynamic analysis is 95%, which corresponds to the present average of natural gas boilers. But his value decreases along the life span of the equipment. In the dynamic analysis, we assume that this efficiency remains stable only for a half of the boiler's life span and reduces eventually reaching only around 60% (see Figure hereunder).



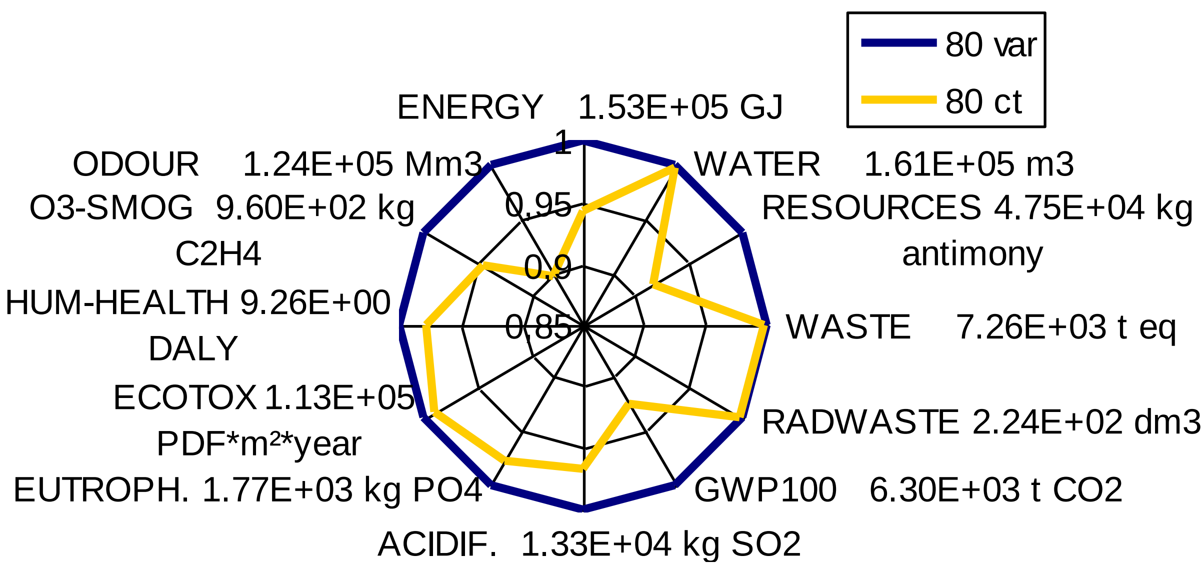
Efficiency of the boiler during its life span

The building life span is assumed 80 years, and the average life span of a boiler is typically 20 years, therefore the boiler should be replaced three times during the residential building life span and the efficiency curve of the equipment will follow the curve hereunder.



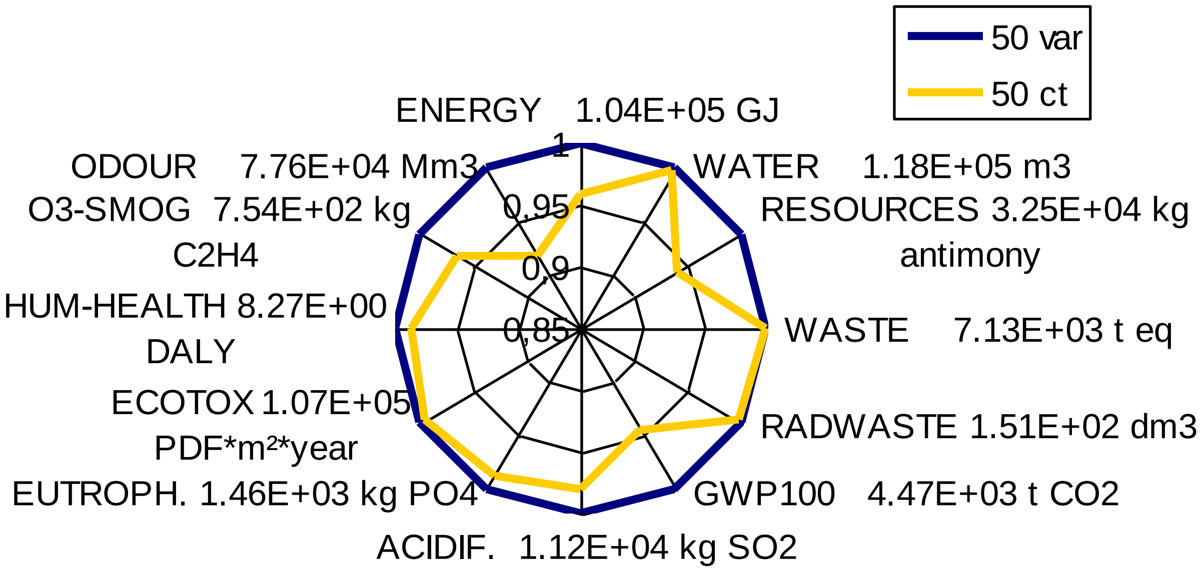
Boiler efficiency during the building life span (80 years)

The heating efficiency variation induces an increase of gas consumption, and therefore the impacts evaluated using dynamic life cycle simulation (“var”) are higher than using a constant efficiency (“ct”), as shown on the next graph.



Comparison of LCA results considering variable and constant boiler efficiency

The influence of the boiler efficiency depends also on the life span considered for the assessment, as can be seen in the next figure assuming 50 years instead of 80.



Comparison of LCA results considering variable and constant boiler efficiency over 50 years

The dynamic approach accounting for boiler efficiency variation is more precise, but the use of an average boiler efficiency that takes into account a typical deterioration scenario (e.g. 85% instead of 95 % for a new boiler) may be seen as an acceptable simplification. The simplification is of course valid if the building life span is a multiple of the boiler life span.

Use of dynamic LCA allows a variation of other characteristics (e.g. performance of insulation) to be studied, taking into account the long lifespan of a building. But data is then required regarding the evolution of such performances.

3.2.3.2 New technologies

In the example above, a more optimistic hypothesis would be to assume that in the future, boilers will have a higher efficiency. But this would make the evaluation even more uncertain. However the possibility to consider such a technological evolution scenario might be given to a user.

For instance LCA has been used to study new insulation materials including silica gel. But data was lacking regarding some rather uncommon chemical compounds used in the production process. Another difficulty was to account for the difference between prototype and large scale production, leading to very different environmental impacts.

As an example of applying LCA to innovative technologies, several studies have concerned the production of PV modules. Three production scenarios have been compared [Phylipsen, 1995], the main hypotheses are presented in the next table.

Process/parameter	Worst case	Base case	Optimal case
Silica reduction	Carbothermal	Carbothermal	-
Purification of silicium	Union Carbide process	Union Carbide process	Reduction of pure quartz using pure carbon
Melting process	Conventional	Improved	Electromagnetic
Wafer size	10 x 10 cm	12.5 x 12.5 cm	15 x 15 cm
Wafer thickness, related to saw thickness	300 μm	200 μm	150 μm
% of metal at rear surface	100 %	100 %	10%
% of metal at front surface	10 %	7 %	6%
Thickness of plastic cover	0.5 mm	0.5 mm	0.25 mm
Size of the modules	0.44 m^2	0.65 m^2	1 m^2
Life span of the modules	15 years	25 years	30 years
PV cells efficiency	13%	16%	18%

The corresponding greenhouse gases emissions are estimated 31g equivalent CO_2/kWh electricity in the base case, 167 g in the worst case and 10 g in the optimal case (to be compared to 666 g for the average Dutch electricity production mix and 591g for the European mix). The acidification potential is 106 mg equivalent SO_2/kWh electricity in the base case, 574 in the worst case and 33 in the optimal case (to be compared with 1.7 g for the average Dutch production mix and 3.8 g for the European mix). The primary energy used to produce 1 m^2 of modules (including an aluminium frame) is 520 kWh/m^2. The modules produce yearly in the base case 128 kWh electricity per m^2 (in Holland), corresponding to 305 kWh primary energy. The energy payback time is then 1.7 years (4.5 in the worst case and 0.7 in the optimal case).

3.2.3.3 Consequential approach

Like electricity production, waste treatment can be achieved using several techniques, and in general there exist a combination of processes, e.g. 40% landfill, 45% incineration, 7% composting and 8% recycling. This mix may vary during the life span of a building, so that only the present situation is known. Consequences of LCA may influence the mix, at least at a local level in the case of waste treatment (possibly decided at a municipal level).

A study regarding a renovation project of a social housing apartment building in Hungary (see next figure) offered the opportunity to test this modelling possibility. According to the present local conditions, the first evaluation took into account a district heating that uses only natural gas. The EQUER model includes a district heating production mix containing up to 7 sources (including heat recovery on waste incineration) and thus allowing various district heating energy sources to be compared.

Social housing apartment building renovated in Hungary (SOLANOVA project)

It is difficult to foresee the evolution of waste treatment in this Hungarian city. According to Eurostat[4], between 1995 and 2003 the amount of municipal and domestic waste raised in the older EU member states, whereas there is no common pattern among the newest member states. The waste treatment mix depends on a national and local policy. Nevertheless, the amount of landfill decreased in a majority of EU members simultaneously with an increase of the amount of municipal waste incinerated, because incineration offers benefits in terms of potential energy recovery and mass reduction. The reduction of the share of landfill is not entirely compensated by the growth of the share of incinerated waste because other waste treatment methods, as recovery and recycling, increased their share too. Five steps can be observed in the Eurostat statistical data regarding incinerated waste in the European Union:

1) A low incineration share, in countries where waste incineration was not used in the past and is still not common today, e.g. approximately 5% or less of waste is incinerated. This group is composed mainly by the newest members of the European Union (e.g. in Poland 0% of waste was incinerated in 1998 and 0.3% in 2003);

2) a high increase trend, in countries that had a very small share of incinerated waste in 1995 but important today (e.g. in Portugal the share of incinerated waste was 0% in 1995 and 21.7% in 2003);

[4] **Eurostat** : A statistical view of environmental issues, Eurostat news release, 69/2005 - 30 May **2005**, 4 p., retrieved in September 2005 from: http://epp.eurostat.cec.eu.int/pls/portal/docs/PAGE/PGP_PRD_CAT_PREREL/PGE_CAT_PREREL_YEAR_2005/PGE_CAT_PREREL_YEAR_2005_MONTH_05/8-30052005-EN-BP.PDF

3) an increase trend, in countries that presented an important share of incinerated waste in 1995 and even more important today, but the growth is less significant than in the latter case (e.g. in Netherlands: 25.3% in 1995, 32.9% in 2003);

4) a relatively constant trend, the share of incinerated waste is very important but remains constant (e.g. Belgium: 35.8% in 1995, 35.7 in 2003);

5) a decrease trend, due to the increased role of waste recovery and recycling, the incineration and landfill share decreases consequently in the late years (e.g. France: 37.4% in 1995, 33.7% in 2003).

In Hungary 5.2% of waste has been incinerated in 2003[5], hence Hungary can be included in the first or second group of countries for which we can expect an important evolution on mid-term regarding this issue.

Besides the effect on waste treatment related impacts, heat recovery on waste incineration also influences space heating related impacts. The district heating production mix varies during the analysis period considering the 5 trends observed in the Eurostat table, thus adding a dynamic variation to the sensitivity study.

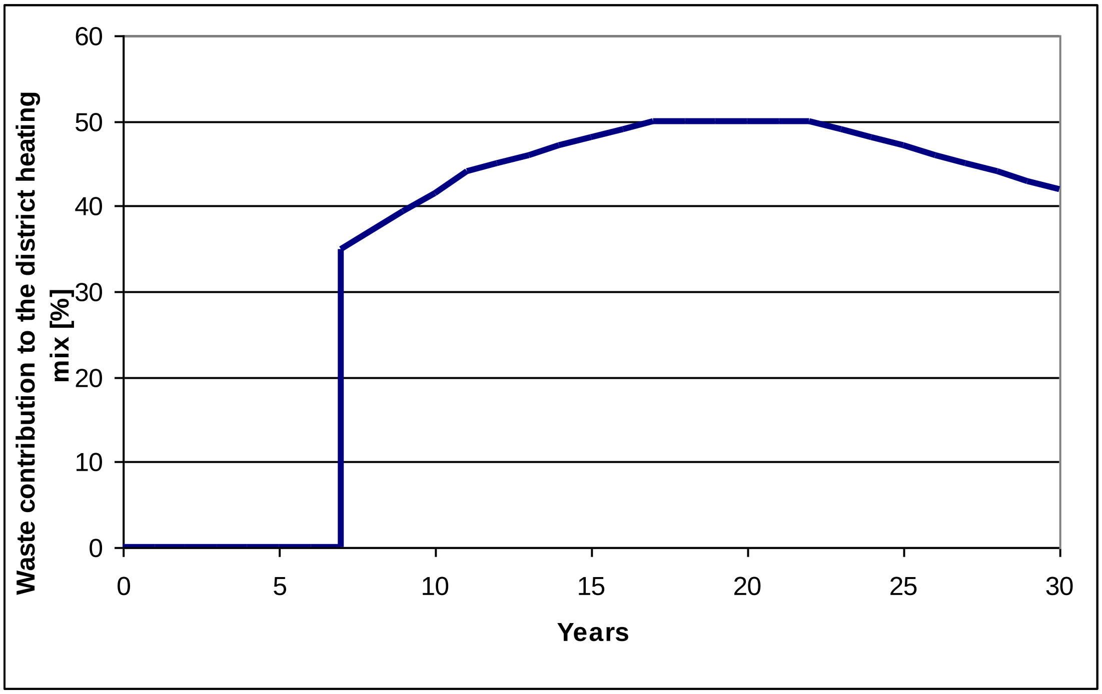
In order to model the phases corresponding to the 4th and 5th steps, a superior limit of 50% waste contribution to district heating was considered, according to data from various sources[6].

In the graph hereunder, the contribution of heat recovery on waste incineration in the district heating energy mix is assumed to vary along the analysed period (30 years, starting from the renovation of the building). For the first 6 years, this contribution is considered to be 0%, and then increases to 35% due to the construction of a waste incinerator (assuming 85% heat recovery efficiency). The share of district heating generated form waste incineration continues to grow rapidly in the next 5 years. This increase is slower in the next 6 years, then a constant contribution of 50% is maintained for six years, and finally this contribution decreases slowly down to 42% due to the increase of waste recycling. The remaining contribution is assumed to be assured by a natural gas boiler.

[5] Eurostat, see previous note 4

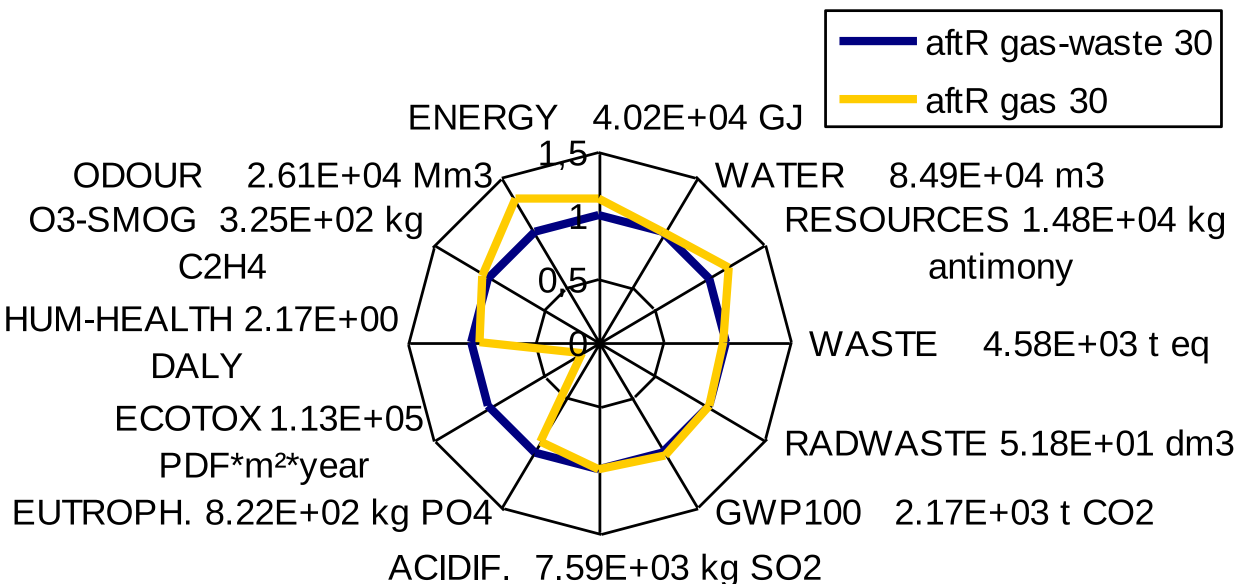
[6] District heating statistics in Norway, http://www.ssb.no/english/subjects/10/08/10/fjernvarme_en/

Data from the district heating company in Paris



Hypothesis regarding the contribution of waste incineration to the district heating production mix in the local context (Hungarian city of Dunaujvaros) on a 30 years period

The diagram hereunder shows the difference obtained considering a 100% gas district heating, and the mix presented above.



Sensitivity to district heating mix variation during 30 years

According to these results, replacing gas by heat recovery on waste incineration saves energy and reduces the exhaust of resources. The effect on eco-toxicity has to be checked, but we may conclude that a dynamic variation of the district heating mix modifies significantly some impact indicators, justifying the interest for consequential approaches. Of course the example above is only a specific case study: district heating is not available everywhere so that the heat recovered from waste incineration cannot be used for heating in some cases (electricity production may be an alternative), and the environmental balance compared to gas may be different.

3.2.3.4 Discounting emissions

In the current LCA practice, emissions occurring now or in a far future are equally accounted for. But are emissions equally important whenever they occur? Methane emissions have a high global warming impact in the near future, but this gas is decomposed faster than CO_2 in the atmosphere so that impacts related to an equivalent GWP due to CO_2 only are distributed over a longer period. The possibility of discounting emissions is discussed e.g. in [Hellweg et al, 2003]. This research field is not specific to the building sector, and may be organised at a more global level.

Recommendations for further research

Existing building LCA tools do not account for temporal variation of the building components characteristics (e.g. insulation conductivity, boiler efficiency, envelope air tightness…). Such a development would largely contribute to improve the precision of LCA results. The way to integrate technological evolution in LCA could also be studied (e.g. new insulation materials, renewable energies…).

Applying LCA results on a larger scale than a single building (e.g. municipality, country…) may influence some processes like electricity and heat production. Particularly, the present focus on CO_2 emissions may induce a larger use of electricity for space heating, with an enormous increase of peak demand (e.g. in France, the peak demand raised from 40,000 MW in 1980 to 90,000 MW in 2009). This peak demand, concentrated over a short period of time (the coldest days) leads to an increased use of electricity produced by thermal plants and exchanged on the market. The resulting increase of CO_2 emissions may have to be compensated due to mitigation policies, but other environmental impacts may be modified. Replacing the use of average impacts per kWh by marginal values according to a consequential approach would allow more relevant information to be provided to decision makers. On a municipal scale, (dis-)connecting a large number of buildings to district heating may also influence the energy mix to provide the heat, and the related impacts. Studying the application of a consequential approach in the building sector would therefore be very useful in order to evaluate more precisely the environmental consequences of e.g. climate protection policies.

In general, the development of user friendly interfaces to perform sensitivity analysis (e.g. comparing scenarios) would be greatly appreciated by LCA users.

3.3 Study of life cycle inventories

The effect of neglecting some substances in inventories will be studied for several indicators (e.g. human toxicity, eco-toxicity).

Some recommendations will be derived regarding a minimal list of substances to be included, aspects like data quality, and the use of European / national / local data will be discussed.

3.3.1 Minimal list of substances

The question of data gaps in LCI data when considering particular impact categories is a significant problem. That is, to what extent the "real" emissions are coinciding with the *available* emission data used for the calculations. This question is particularly problematic when considering the impact categories eco toxicity and human toxicity which relate to emissions of chemicals during different processes. LCA experts argue however that this problem is not basically a problem related to LCA but rather a societal problem since the knowledge of the use and fate of the constantly increasing numbers of chemicals in society is very limited. Coverage is generally better for emissions of substances of high political concern. However, these are not necessarily the most urgent substances to be kept under surveillance (Finnveden *et al.*, 2009).

Based on a number of Nordic case studies and a review of PVC databases, (Finnveden, 2000) conclude that both the eco toxicity and human toxicity impact categories are often included in studies but do contain severe data gaps. Typically, more data is in general available on air emissions than water emissions.

A recently published study by (Larsen *et al.*, 2009) incorporated the most recent knowledge concerning emissions of the production of offset printed paper into an LCA case study and thereby calculated contributions to eco toxicity and human toxicity which has typically not been included in LCA´s of offset paper before. The results show that when chemical emission-related impacts are included, the environmental profiles of different products vary much more than when these impacts are not included, using the EDIP97 LCIA method. In the study weighting by distance to political targets was applied, resulting in that the eco toxicity related to the production stage contributed significantly to the total environmental impact. Previous LCA studies of offset printed paper had always pointed out paper as the dominating source to the impacts. The study illustrates the problem of excluding emissions in the inventory, however to our knowledge no similar case studies related to buildings or building products exist.

In some countries, standards exist when performing LCA regarding a minimal list of substances that should be covered by the LCI data. However, the addressed number of substances varies considerably between these standards form a handful up to databases like Ecoinvent where several hundreds of substances are sometimes covered. At the same time, 100 000 chemical compounds are used in the European market.

The international instructions on EPD do not give any specified information regarding this matter. A general cut-off-criteria mentioned is that 99 % of the impact to a certain impact category should be included, related to inventory data coverage (The International EPD Cooperation (IEC), 2008). However, the PCR (product category rules) developed for different product categories within the international EPD cooperation may provide further guidance. A general such PCR for building products was suggested in 2006 (Erlandsson *et al.*, 2006) and had as objective to provide an international common operational methodology for environmental declarations of building products in compliance with the standard ISO 14025. To ensure better data quality, this document suggests rules for data quality classification with regard to representativeness, completeness, precision and consistency in allocation procedures. In relation to completeness (the topic of this section) it is recommended that all data shall be classified in the life cycle inventory as follows:

Class 1 – Data covers all known types of emissions

Class 2 – Data covers all emissions of the most frequent impact categories

Class 3 – Data based mainly on emission factors, input/output analyses or other rough estimations

Class 4 – Very poor data, or classification information is lacking

Further, rules are specified that quality class 3 is acceptable up to a maximum of 10 % of the total environmental impact in the resulting cradle-to-gate LCA for each impact category, and maximum 3 % regarding data with quality class 4 (Erlandsson *et al.*, 2006).

Building LCA tools similarly allows for describing the data quality of the LCI inventory data which then would enable following the rules stated by this PCR.

However, the problem remains that such complete data are yet easily accessible. For example in Sweden, the national building product declarations are self-declarations and do only cover LCI data as voluntary information. There are therefore no detailed instructions about the quality of such data and which emissions should be included.

The International Reference Life Cycle Data System Handbook states that for a first rough identification of LCI data needs, this should be determined in relation to the precision of the assessment result demanded by the intended application (European Commission Joint Research Centre, 2009). So in early design stage of a building when information is scarce, a screening LCA could be made by use of less precise data than an LCA of a detailed building design. On the other hand, LCA is more useful at early phases when crucial decisions are made. Some tools allow detailed LCA to be performed using default values for unknown parameters.

In addition, it naturally also depends on the selection of impact categories for the study. If eco and human toxicity are included, it can be argued that more emphasis should be put on high data representativeness regarding these categories. Similarly, if resource use is stressed in the purpose of the LCA (as in this project), extra emphasis should be put on using data that really covers the use of rare resources in the production processes of the used building materials and components.

To sum up, this problem is not unique for the building and construction industry, but is more universal and therefore has to be dealt with at a more general level. There is neither no common practice regarding a “minimal list of substances” to be covered by LCI inventories. However, to address the completeness of the data in the inventory should be done for example according to the suggested PCR for building products (Erlandsson *et al.*, 2006).

A more unique problem related to performing LCAs on buildings is the coverage of the inventories regarding the use and end-of-life stage of the entire building. Concerning the content of hazardous substances in building materials, these may both contribute to the impact categories human and eco toxicity during the use stage as well as in the end-of-life stage. However, this information is rarely included in the cradle-to-gate building material data. The effects for these stages have to be modelled separately depending on how the building is used and managed, where it is situated and relevant end-of-life scenarios. To be able to do that, documentation about the content of hazardous substances in building materials and components is necessary.

The Swedish direction at the moment is based on the new national environmental rating tool for buildings, Miljöklassad byggnad (Glaumann *et al.*, 2008), (Malmqvist et al, 2011) and the Swedish self-declarations on building products. For new buildings the requirement for achieving the highest rating includes the following criteria “Appointed building elements do not contain substances of very high concern (SVHC)[7] exceeding specified concentrations”. The same criteria have now also been adopted by the two main competing databases for material choice in Sweden and the open database BASTA. This implies that if any of these tools are used for a new building, the content of the most problematic hazardous substances in building materials and other products used during construction is at least documented. The rating tool Miljöklassad byggnad also poses demands on that amounts should be documented which would at least in theory provide a possibility to use this information for modelling human and eco toxicity impacts in the use and end-of-life stage.

The proposed PCR for building products also brings up this issue and recommends that a detailed list of the content in building products should be included in the environmental declaration. This information shall cover substance name, CAS number, weight % and risk characterisation code of all included substances in relation to the included weight % in the product which is specified further in this document (Erlandsson *et al.*, 2006).

Recommendations for further research

To learn more about the effect of using incomplete inventory data for building products it would be of interest to study this issue for example by some kind of case study in which different data sets of a selection of important building materials are compared with respect to calculations of the environmental impact. Particularly the impact categories human and eco toxicity would be important to study further. Potential data sets to compare could be full data sets in Ecoinvent, data sets that comply with the guidelines/standards of countries where only few substances are included, data sets in EPD´s, and if existing, more complete data sets given by the manufacturers of which their EPDs build on. The purpose would then be to learn more about the necessity of complete LCI data for different construction materials.

In relation to the scope of this project, in particular the use of rare resources is of interest. Therefore building materials or components which tend to make use of rare resources need to be highlighted. A simple case study for the project could for this purpose be to calculate the abiotic depletion potential on a number of building materials in Ecoinvent and discuss the results.

[7] The European REACH system

3.3.2 Indoor emissions

Indoor air quality is a central issue in modern buildings, as well in residential buildings and offices. People spend much of their time indoors, thus the air in the homes, in schools, and in offices should not cause risks for health problems. Pollutants of the air that originate from inside of a building can be

- chemicals, emitted either from processes like cleaning or from building products and furniture,
- gases like radon or carbon dioxide,
- particulate matter from burning solid fuels for cooking or heating, or from smoking,
- living organisms like mould and pests.

The following chapters are dealing with chemical emissions only, focussing on the emissions from building products. According to the Construction product directive (CPD; Council Directive 89/106/EEG) the term “building product” or more generally “construction product” means any product which is produced for incorporation in a permanent manner in construction works.

Users of a building often do not have the opportunity to decide on the building products that are used in their dwelling being either tenants or staff in an office or commercial building or having bought a turn-key home. In addition critical building products often cover considerable indoor surface areas. Examples are the paint of the interior walls or floorings.

Several methods have been developed to design buildings using materials that do not release dangerous substances and to assess buildings to this respect.

3.3.2.1 List of substances

As a base for the essential requirement 3 of the CPD (“Hygiene, health and the environment”) a so termed “Indicative list of regulated dangerous substances possibly associated with construction products under the CPD” (DS 041/051 rev.9, May 2009) has been set up. The list is subdivided into pollutants for soil and water and pollutants for indoor. The listed substances (or parameters) were chosen because they:

- are regulated on EU or national level,
- are components of construction products,
- are used for manufacturing construction products (included in raw materials),
- could be emitted or released from construction products into indoor air,
- could be released from construction products into soil, surface water and ground water,

- are used in regulations to characterise products or belong to key parameters for a group of substances or an environmental impact (such as pH, conductivity, DOC etc.)

Not only single substances are listed but also groups like chlorobenzene and parameters like sum concentrations for volatile organic compounds. In specific substances are quoted that are CMR (carcinogenic, mutagenic or toxic for reproduction) or PBT (persistent, bioaccumulative, toxic).

CEN/TC 351 was founded to develop harmonised test methods for the release of these substances. The background of the mandate to this committee was to enable producers to place their product on the market in all member states after assessment and testing for CE-marking only once.

The guidance paper H ("A harmonised approach relating to dangerous substances under the CPD", 2002) states the following three principles:

Aside from the protection of people (occupants and neighbours), it is only the immediate environment that falls within the scope of the CPD. Wider environmental aspects, such as destruction of the ozone layer, are not covered. […]

To conform with the scope of the CPD the harmonised approach relating to dangerous substances is limited to "works in use". Other phases in the life cycle of a product, i.e. its excavation or production stages, during the building process, during demolition, waste disposal, incineration or waste reuse (except where reuse is as a construction product in the sense of the CPD) are not considered for harmonisation under the CPD. In addition, activities such as maintenance, replacement or other construction activities carried out during the normal life of a building might cause dangerous substances to arise from products already installed in the works. These activities are considered to be outside the scope of the CPD. Of course, any construction products used, for example for replacement, remain within the scope of the CPD.

The requirement on products is expressed either as emission or migration of dangerous substances or radiation, during normal (i.e. foreseeable) use. It is therefore, when possible, the release of substances that is the characteristic to be controlled. However, even if it is not the content of the dangerous substance itself in the product that should be controlled, this might be the only practicable solution.

Thus the focus of the CPD is on the release of substances, not on the content. When a substance is e.g. bound to the matrix of the material and it cannot cause a risk during its intended use, there is no need for testing.

Volatile Organic compounds (VOC) are indoor air pollutants of major concern. They include a variety of chemicals, comprising aromatic and other hydrocarbons, alcohols, ketones, esters, isoprenes, aldehydes, phthalate, siloxanes, etc. VOCs are most often used as solvents. A wide array of products numbering in the thousands is emitting VOCs. Examples include: paints and lacquers, cleaning supplies, building materials and furnishings, etc. Moreover many household and office products also contain VOCs. Thus concentrations of many VOCs are consistently higher indoors than outdoors.

It should be stated that besides VOC several other “well-known” chemicals are on the list of dangerous substances: Formaldehyde, PCP and other pesticides/biocides, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH), flame retardants and plasticisers, Asbestos, etc.

3.3.2.2 Test methods and release scenarios for VOCs (volatile organic compounds)

VOC emissions from building products are measured in test chambers. Harmonised test methods have to determine the exact measurement method as well as the method of sample preparation. In specific the amount or surface area of the test material in the chamber has to be specified. The result depends also strongly on several parameters like the temperature, the air exchange rate, relative humidity and air velocity in the test chamber, etc. The test chamber measurements have to be performed to reflect realistic exposure situations, e.g. measurement series after several days or even long term measurements.

An example of an evaluation method and of release scenarios is given in figure 1. Measurements are scheduled on the third and the 28th day.

Fig. 1: FLOW CHART FOR THE EVALUATION OF VOC* AND SVOC*EMISSIONS FROM BUILDING PRODUCTS

AgBB
Ausschuss zur gesundheitlichen Bewertung von Bauprodukten
(Committee for Health-related Evaluation of Building Products)

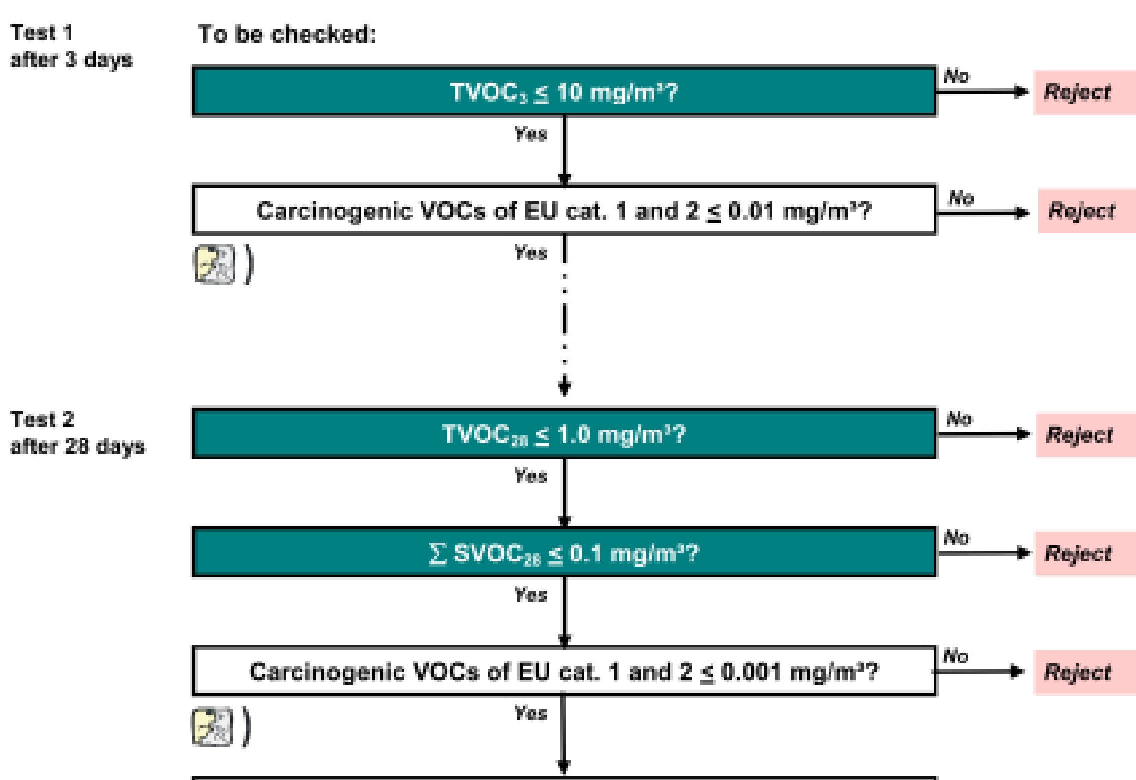


Fig. 1: Evaluation of VOC and SVOC from building products of AgBB (Ausschuss zur gesundheitlichen Bewertung von Bauprodukten) [AgBB: Health-related Evaluation Procedure for Volatile Organic Compounds Emissions (VOC and SVOC) from Building Products, 2008, see: http://www.umweltbundesamt.de/building-products/agbb.htm]

The Association for the control of emissions in products for flooring installation, adhesives and Building Materials (GEV) is a collective of responsible manufacturers of flooring installation and allied products/materials. Their goal was to promote materials with the lowest possible emissions in the market. Main focus is VOC emissions. The EMICODE ® system of classification was developed with classification criteria for the labels EC1 (very low emission), EC2 (low emission) and EC3 (not low emission, but still CMR substances are not allowed).

GEV MATRIX products	EC 1 µg/m³	EC 2 µg/m³	EC 3 µg/m³
1. Liquid products (primer and moisture barriers)	≤ 100	> 100 ≤ 300	> 300
2. Mineral products with mainly inorganic binding material (cement- and gypsum levelling materials, inorganic floor-sealants and mortars)	≤ 200	> 200 ≤ 600	> 600
3. Paste products and such with a high content of organic binding material (adhesives, fixations, organic floor-sealants, dispersion and reactive resin based levelling materials)	≤ 500	> 500 ≤ 1500	> 1500
4. Ready for use products that don't need any chemical or physical drying (insulation sheets, adhesive tapes, slabs)	≤ 500 after 1 day	> 500 ≤ 1500 after 1 day	> 1500 after 1 day
5. Joint-sealants on dispersion or reactive resin basis	≤ 300	300 ≤ 600	> 600

With exception of product group 4, measurement of the TVOC value is carried out after storing the prepared product specimen for 10 days in the test chamber.

Fig. 2: Classification of a product in accordance with its intended use in EMICODE [Classification criteria, edition 19.6.2009, www.emicode.com] after measurement after 10 days in a test chamber.

The main benefit of EMICODE is to give guidance to consumers and for procurement.

3.3.2.3 Indoor emissions as criterion of building assessment systems

Building assessment and certification schemes are important applications or tools for LCA in practice. Most popular are calculations of the Global warming potential, the Acidification potential, the ODP, the POCP and the Eutrophication potential of the bulk materials.

The Austrian "Total Quality"-Tool (TQ-Tool, see www.oegnb.net) uses the following relevant criteria:

Category 2 "Reducing human and environmental loads" with the subcategories 2.5 Building products (Avoidance of PVC and PUR/PIR, use of low emission paint, lacquer and adhesives), 2.6 Radon, 2.8 mould.

Category 3 "User comfort" with the subcategories 3.1. IAQ (Quality of filters of a ventilation system, concept for reduction of emission sources).

If the Assessment is done after commissioning the following measurements and ratings are designated:

Excellent	Very well	Good	satisfactory
Sum of VOC with evaporation point below 250° after 28 days			
´< 0,25 mg/m3)	< 0,5 mg/m3	< 1,0 mg/m3	< 2,0 mg/m3

Formaldehyde			
< 0,04 ppm	< 0,06 ppm	< 0,08 ppm	<0,1 ppm

A comprehensive evaluation of indoor pollution considering several impact categories (CMR, inhalative toxicity, etc.) for the TQ-Tool has been proposed [Ines Öhme et al.: SIBAT – Vorsorgende Sicherstellung der Innenraumluftqualität von Gebäuden – Anwendung von Toxitzitätskriterien in der Materialbewertung. Berichte aus Energie- und Umweltforschung 28/2005; download: www.hausderzukunft.at (in German)]. The assessment of various building products is based on partly the safety data sheets of the materials and partly on emission data of producers. The proposal has not been implemented.

In the German certification ("Gütesiegel nachhaltiges Bauen", see: www.dgnb.at) a criterion "Risiken für die lokale Umwelt" ("Risks for the local environment") is included. A detailed specification list has to be fulfilled for the rating from 1 to 10. The list comprises as well limitations of contents of substances in products and restrictions; they are referring to building elements (like 80% of the indoor wall surface), coatings, supplies (e.g. refrigerants) etc. The requirements concerning VOC content of carpeting and coverings, of adhesives, sealing and anticorrosive are: maximum 3% (for rating 10), 10% for rating 7.5 and 15% (carpeting and coverings) for rating 5. Databases are the EPD of the producers or the standard (average) EPD of the Ökobau.dat (the database is available at http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html).

The criterion will be revised to draw upon human and eco-toxicity impact categories once a consensus is reached and use in practice is feasible.

3.3.2.4 Indoor emissions within LCA

LC Inventory data of unit processes comprise a list of substances and materials that are either inputs (resources, land) or outputs (emissions to air, soil and water). The media (air, soil, water) are further specified to give the called compartments, the emissions are going to. LCI data are not distinguishing when and where exactly the emissions are released. So it is usually not possible to calculate health effects that are caused by local pollution sources. If indoor pollution is intended to be considered in LCA of buildings, an additional compartment, indoor air, has to be introduced and appropriate data of building products have to be gathered. This has been performed for small houses (single-family houses) by Meijer et al. [Arjen Meijer et al.: Human health damages due to indoor sources of organic compounds and radioactivity in LCIS of dwellings, Int.J. of LCA 10 (5), and 10 (6)]. Attention has to be paid on weighing the different contribution, particularly regarding radon versus VOC emissions.

Since 2005, an international group of LCA model developers, invited by the Life cycle initiative of UNEP and SETAC, has been searching for a generally accepted model and has proposed the USE-Tox model in 2008 [Ralph K. Rosenbaum et al.: USETox – the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment, Int J LCA (2008) 13]. Within the an indoor compartment for indoor exposure can be specified. The resulting compartment setup is shown in fig.2.

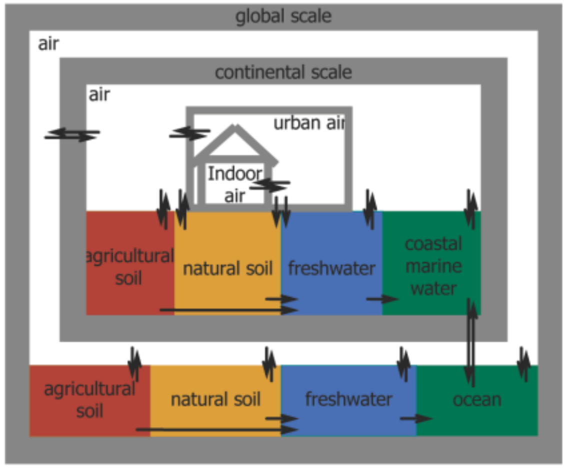


Fig. 2: Nesting the indoor model into the environmental fate and exposure model of USETox [Stefanie Hellweg, et al.: Integrating human indoor air pollutant exposure within LCA. Env. Science & technology 43 (2009) 6].

Six models with differing computational work have been proposed to get to the concentration of a substance in the room air: the Zero-ventilation model, the One-box model, the One-box model with correction factor, the Multiple-zone model, the EDDY diffusion model and the Computational fluid dynamics model [Hellweg, 2009]. So, if emission rates of all indoor surfaces at valid parameters of the room (temperature, pressure differences, etc.) are given, it will be possible to calculate the Human toxicity potentials. This is true if any concentration sinks, e.g. adsorption, can be neglected as well as any further chemical reactions there. It should also be pointed out clearly that emission rates of surfaces do not equal emission rates of products because layered structures and finishing materials (wallpaper, etc.) have to be considered. In the current version of USETox the indoor compartment is not realized, though.

The chain of cause and effect is modelled consisting of the consecutive steps (see fig. 3) for human toxicity:

1. Emission characterized by emission flow (emission rate)
2. Fate; the fate factor describes the distribution (masses) in the compartments as well as degradation of the substances
3. Exposure (kg intake per day in the case of human toxicity)
4. Effects, that are describing the risk: dose response (in cases per kg intake) for human toxicity
5. Damage

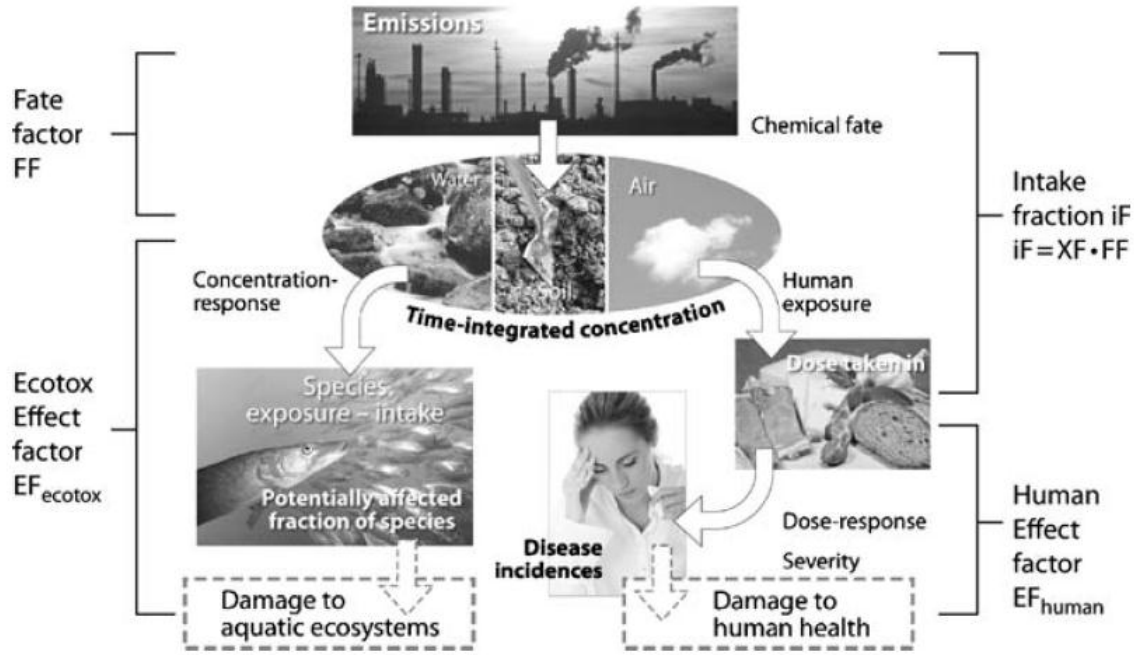


Fig. 3: Framework for comparative toxicity assessment [Rosenbaum, 2008].

A database has been set up for USETox with the properties of more than 3000 organics and approximately 20 inorganics.

The Human toxicity potential is also calculated in other LCIA methods and software. But the results are varying enormously and have no relevance for the indoor environment because they are emissions in the global compartment and the urban compartment. That was also the reason for the setup of the consensus model USETox.

3.3.2.5 Conclusions and recommendations

Integration of indoor emissions in LCA is still hampered by some facts.

Realistic emission rates of products and materials have to be determined based on harmonized test methods. The long term emission rates should be reflected in the data since the building’s use stage is a long time period. Methods will be defined by CEN TC 351, so emission rates (after 28 days, or extrapolation to longer time period) will be part of the EPD data in future. It has to be considered though that these are test chamber data and real emission rates might differ (temperature, wind speed, etc.)

Information on all building surfaces is needed to determine those products and materials that contribute with emissions to the room air. The built-in situation has to be considered and whether the emission rate is full or partly reached. Research is still needed to map these situations or at least to come up with some standard situations. In specific point and line sources (like joints) have to be further investigated.

Detailed design data of the building are necessary to model the distribution of emissions in the room air such as building zones with varying number of occupants and time schedule of use, ventilation rates, air volumes, etc. The USETox model with the upcoming next version with indoor compartment added show a possible handling of this problem.

Thus the amount of data is high and not all data will be available in early design stages. Furthermore indoor surfaces are also subjected to changes now and then. Occupants often don't have enough knowledge to realise the effects of their actions with respect to the indoor air quality.

The first step has to be an inclusion of relevant data to the LCI data (emission rates to an indoor compartment). Only the use phase is interesting for the indoor emissions. To be practical a database with building products has to be established. Data could be generic (like Ökobau.dat in Germany) or specific for manufacturers (EPD data). The majority of materials covering indoor surfaces should be accounted for. In a separate tool comparable to USETox the impact could be calculated then. Ventilation rates for houses should be used, probably in a One-box model as a beginning.

Recommendations for further research

Study models allowing indoor emissions to be accounted for in Building LCA, and protocols needed to produce the data corresponding to such models. Perform studies to validate these models. A question is if and how the dose response for human toxicity can be described within an LCA.

3.3.3 Use of European / national / local data

Data quality is one of the key factors that dramatically influence the reliability of LCA studies. Not sufficiently representative data will lead to a misleading and invalid study.

Depending on the scope of the study, the best is to use the geographically most representative data available, for example, in early design phases, generic data corresponding to national, World or European average is appropriate whereas in detailed design it is recommended to use the Environmental Product Declarations (EPD) of specific products by specific producers. Although the number of EPDs available is increasing quickly, they are still not available for many products and in many countries. As LCA studies of whole buildings require a lot of data on many products, practitioners mostly use general databases, such as Ecoinvent or GaBi. These databases contain inventory and impact assessment data of thousands of products, including building materials and energy systems. Data are usually national or regional averages. In Ecoinvent [Ecoinvent 2007], geographic codes indicate the country or region where the datasets apply. Data mostly reflect the situation in Switzerland and/or Europe. For some datasets, production processes outside Europe that play an important role for the European market are also included. This database is regarded to be of very high quality, and is widely used in the European LCA tools.

The question arises, whether the use of a general database is acceptable in LCA studies of buildings, how much this influences the results and whether it should be adapted to the local conditions or whether it is worthwhile developing new databases on a national/ regional level. Developing a national database requires a lot of resources, as extensive datasets must be compiled from a representative number of manufacturers if we aim at a high quality database.

3.3.3.1 Transfer of inventory data from a different geographical context

According to the ILCD handbook the direct use of data representative for another country is generally not suggested [EC JRC 2010a]. Also, the limited adjustment of the datasets, for example by replacing only the electricity background data without further analysis on which other modifications may be needed may lead to errors. But data availability limitations often make the transfer of inventory data from one geographical context to another necessary. In the future, the ILCD Data Network is expected to significantly improve the availability of consistent LCI data.

The basic principles of using not fully representative data are [EC JRC 2010a]:

- for non-comparative studies: it is only allowed if the overall LCA results are not changed relevantly compared to using fully representative data.
- for comparative studies: it is only allowed if the conclusions or recommendations are not affected.

When adapting a database, it must first be decided which modules to adapt. For certain products, which are predominantly produced locally/nationally and usually not imported/exported (e.g. gravel, concrete), local or national distinction is more important. Other products, for example aluminium, are globally traded. These products are produced in a few places in a few countries and then exported over large distances. Here it is usually regarded as sufficient to develop datasets on the level of continents, and not necessary to adapt the datasets for each country. Nevertheless, the impacts of different regional manufacturing conditions (e.g. electricity) are much higher for aluminium than for gravel.

The adaptation must analyse the original database, the methodology, assumptions and system boundaries. For the datasets that need to be adapted, it must be checked whether the applied technologies, the abatement technologies, raw material routes and waste treatments are similar in the two geographical contexts. The climate and the national legal requirements on emission limits, etc. may also influence the applied technologies.

If the conditions are similar, it may be sufficient to modify the energy supply modules. For example, different compositions of electricity mix will have a significant impact and this should be modified wherever necessary.

3.3.3.2 Example for the adaptation of the Ecoinvent database for Hungarian building products

The technology applied in Hungary is in general of high quality, comparable to Western Europe. In case of certain products, the production technology might be even more modern than in Western Europe, since in Hungary many factories were built in the last 5-10 years. However, the fuel types are different. In Switzerland, for example, due to the abundance of cheap hydroelectricity more electric furnaces are applied.

While the Swiss electricity mix is dominated by hydro and nuclear energy, in Hungary fossil fuel and nuclear power plants are responsible for 98% of the cumulative energy demand. Accordingly, the environmental impacts associated with the supply of 1 kWh in Switzerland are significantly lower in every impact category (as shown in the following *Table*). The values of the UCTE electricity mix (Western and Southern Europe) are between the Swiss and Hungarian values.

Table 3- Comparison of the environmental impacts of electricity supply (higher values – darker colour) [Ecoinvent v1.3]

Impact category	Unit	Electricity, medium voltage, CH (kWh)	Electricity, medium voltage, UCTE (kWh)	Electricity, medium voltage, HU (kWh)
CED n.r.	**MJ**	**7,440**	**10,622**	**13,407**
CED, fossil	MJ	1,440	5,835	7,888
CED, nuclear	MJ	6,000	4,788	5,519
CED r.	**MJ**	**1,988**	**0,911**	**0,252**
CED, biomass	MJ	0,032	0,083	0,011
CED, wind, solar, geo	MJ	0,034	0,123	0,007
CED, hydro	MJ	1,923	0,704	0,235
GWP 100a	Kg CO_2-Eq	0,126	0,485	0,621
AP	Kg SO_2-Eq	3,4E-04	2,6E-03	7,9E-03
ODP	kg CFC-11-Eq	8,9E-09	2,0E-08	4,9E-08
POCP	kg Ethylene-Eq	1,5E-05	1,0E-04	3,1E-04
EP	Kg PO_4-Eq	2,7E-05	1,3E-04	1,9E-04
Eco-indicator 99	Point	0,004	0,020	0,035

Not only the electricity mix, but the impacts of other energy carriers/systems may differ significantly between countries. For example, the environmental impact of the Swiss and the average Western European natural gas supply is similar, but the Hungarian values are 15-100 % higher. This is mainly explained by the longer transport distances and the higher system losses. 90% of the Hungarian gas comes from Russia [Ecoinvent 2007]. In the Western European mix, on average 34% of the gas supply comes from Russia, 24% from the Netherlands, 13% from Norway, 16% from Algeria and 5% from Germany. In the Swiss gas, the ratio of Algerian gas is less, and the Dutch and German are slightly higher. In the Ecoinvent database, the average transport distance of the Russian gas is assumed to be 6000 km, while European gas is transported regionally on average 600-800 km.

Therefore, the adaptation of the datasets for products primarily produced in Hungary considered the differences in the electricity mix and the gas supply, and these modules were changed accordingly wherever appropriate.

3.3.3.3 Example for a new dataset vs. adaptation

The following example compares factory data with the original Ecoinvent dataset and the Ecoinvent dataset that was adapted for Hungary. Life cycle inventory data for brick production were compiled in three factories representative for Hungary [Szalay 2008]. Data quality is good, data were mostly based on measurements (emissions to air, metering of gas and electricity consumption), and on corporate accounting (amount of raw and process materials, production volume); only a few pieces of data were estimated. The answers provided by the companies were tested for inconsistencies. The Ecoinvent dataset was adapted to the Hungarian conditions by replacing the electricity mix and the natural gas data. The following figure shows the non-renewable cumulative energy demand (CED) and the global warming potential for one kilogram of brick for the three datasets (brick HU – factory data, Ecoinvent HU – adapted Ecoinvent, Ecoinvent RER – original Ecoinvent).

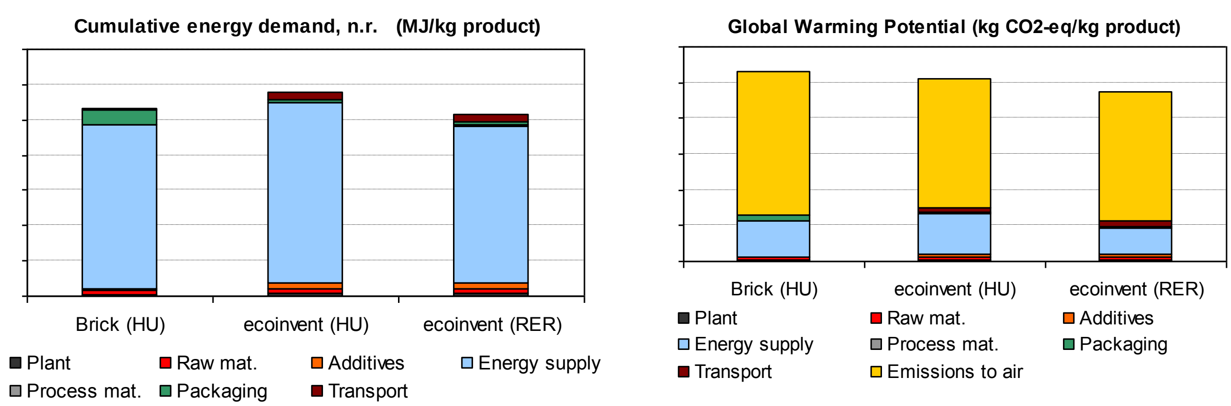


Figure: Comparison of the Hungarian production data for brick with Ecoinvent data (only ratios since data is protected)

Regarding the cumulative energy demand, 85-95 % of the CED comes from the energy consumption, mostly from the natural gas, and to a lesser extent from the electricity use. The net energy demand is slightly higher in Ecoinvent and the fuel composition is also different, which is why the adapted Ecoinvent HU data are appr. 10 % higher than the factory data. The effect of the materials and transports is insignificant. For global warming, direct emissions from the burning are dominant, but also the indirect emissions of the energy supply (production, transport, etc.) are significant. The Hungarian results and the adapted Ecoinvent results are very close to each other, the direct emissions are almost the same. The results suggest that the precision is improved by adapting the Ecoinvent data to the Hungarian gas and electricity mix: the total global warming potential in the Ecoinvent RER module is more than 10% lower, even though the net energy demand itself is higher. The adapted data proved to be reliable when compared to the factory data. Comparison on a larger sample would be needed to draw general conclusions on the need for contextualization.

3.3.3.4 Transport from the factory to the construction site

In most of the inventory databases, for example also in Ecoinvent, the system boundary “cradle to gate” is applied, which means that the analysis ends when the product leaves the factory. The transport from the factory to the construction site is not taken into account in the datasets. Exact data on the transport distances and means should be applied for a specific building, wherever these are available. However, in most cases it is hard to obtain these data or they might be of lower relevance depending on the goal of the study. One approach is to use ‘standard transport distances’. This is also applied by Ecoinvent [Ecoinvent 2007].

Table 3- Example for the standard transport distances of materials (extract from Ecoinvent)

	Consumption in Europe		Consumption in Switzerland	
	km train	Km lorry 32t	km train	Km lorry
Gravel/sand	-	50	-	20
Steel	200	100	600	50
PVC	200	100	200	50
Structural timber from Swiss forests	-	100	0	50

A further simplification can be the classification of building materials into a few transport categories. A study in Ireland, for example, classified the building materials into five categories depending on the location of the production, and applied standard transport distances for each category [Szalay et al. 2011]. Building materials primarily produced in Ireland belong to the categories one and two. For products in the first category, there are numerous production sites scattered around the country, while the products in the second category are produced in a few concentrated factories. Products belonging to the third category are mainly imported from the United Kingdom or the continent. For category four, construction timber, about half of the demand is supplied by Irish sawmills, with the balance coming from Scandinavia.

Table 3- Assumed transport distances and transport systems for building materials used in Ireland [Szalay et al. 2011]

Category	Material	Transport distance and transport system

1	Concrete, gravel, plaster	50 km by lorry 16-32 t
2	Insulation materials, gypsum board, windows, paint, tiles, brick	100 km by lorry 16-32 t + 30 km by van
3	Metals, plastic, engineered wood products, triple-glazed windows	500 km by freight ship + 300 km by lorry 16-32 t + 30 km by van
4	Construction timber	1000 km by freight ship + 200 km by lorry 16-32 t + 30 km by van
5	Installations	100 km by van

If the LCA study aims to compare a locally produced material and an imported one, varying the transport distance and evaluating the corresponding impacts is relevant. LCI data is available for various transport modes (lorries with various sizes, train, ship...), e.g. in the Ecoinvent database.

3.3.3.5 Impact assessment

Spatial differences may also influence the impact assessment. Environmental issues of concern are different from region to region, and this has an effect on the interpretation of the results (e.g. weights). Also, elementary flows may act in a different way depending on where they are emitted (e.g. SO_2 and particles). However, as the availability of spatial impact assessment models is limited, the ILCD handbook suggests that further research should be carried out before these issues can be taken into account [EC JRC 2010a].

Recommendations for further research

As the availability of EPDs and national databases is limited, and LCA studies of buildings require a lot of data, practitioners usually use general databases. It is recommended to adapt these databases to the local/national circumstances wherever appropriate. The sensitivity of the results should be studied in more detail when using the original, adapted or fully representative datasets.

3.4 Study of specific methodological aspects

There is at the moment no consensus on how to account for e.g. biogenic CO_2 in LCA, as well as allocation methods for co-products, modelling of recycling, and elaboration of end of life scenarios for different types of construction/renovation/demolition waste. For instance biogenic CO_2 emissions are not accounted for in some models, assuming that CO_2 storage during photosynthesis is sooner or later compensated by CO_2 release at end of life. On the other hand, different CO_2 balances are obtained using models according to the forest stewardship, and according to end of life processes (e.g. incineration versus re-use). Such aspects will be discussed among the group.

3.4.1 Biogenic CO_2

Two areas are focussed at when “biogenic CO_2” is discussed in the framework of LCA und Carbon footprint scientists: the land use /land use change aspect and the end-of-life aspect. The first issue is of particular interest for the national accounting for greenhouse gases as a requirement of many countries for the Kyoto protocol. The national carbon pool and changes of it have to be monitored; the development of forests in specific and land use in general gaining in significance in the last years [IPCC, 2006].

The second issue points to the fact that biomass could completely be recycled or reused either as a material or for energy purposes. National practices are differing quite a lot: Whereas landfilling of used wood is forbidden in some European countries (Austria, Germany, Switzerland, etc.), in others it is not (Spain, etc.). Some countries have established an extensive system of recycling, in other countries the used wood market is sucked by combustion plants. In the LCA of buildings these various possible paths are posing difficulties. Moreover buildings have a life time of around 80 years making it necessary to some extent to anticipate developments in the future.

3.4.1.1 Background

Plants convert carbon dioxide from air into saccharide by using direct sunlight (photosynthesis). Saccharide serves as a building block for polysaccharides like cellulose. This process is also vital for human beings as oxygen is set free. Moreover the uptake of CO2 is a desired means for reducing the CO_2 content of the atmosphere and hence to contributing to climate change mitigation.

But forests are very differently capable of uptaking CO_2: Young trees cannot absorb very much of it, rapidly growing trees also incorporate much and old trees again have a small net uptake since they at the same time loose branches broken e.g. by wind or snow. Their decomposition (rotting) causes a release of CO_2 (among other gases and vapours). So, as forests get old they develop a steady state phase characterized by no net CO_2 uptake (as much CO_2 is absorbed for growth as is released during rotting).

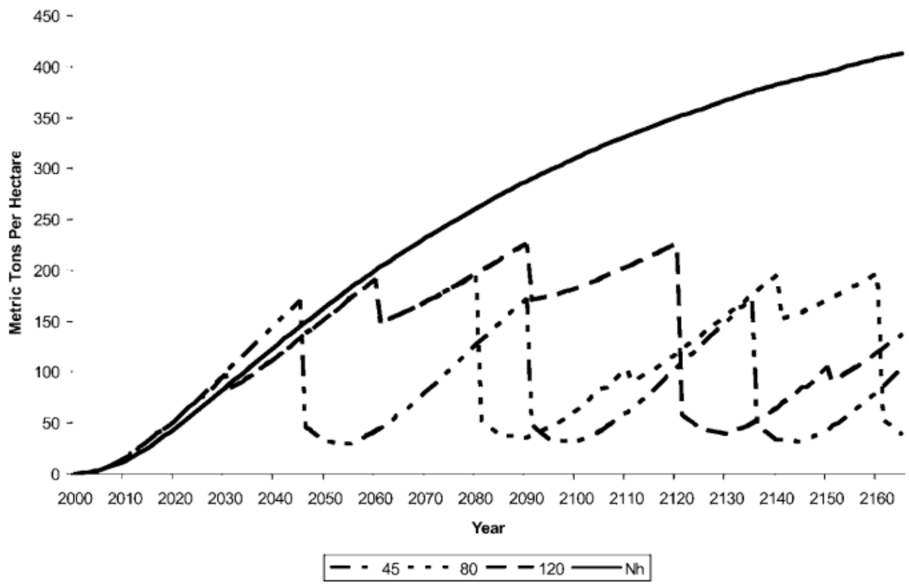


Fig 1: Carbon in forest pools for different rotations (in years), considering thinning and harvesting. The no-harvest scenario is the hypothetical upper bound without any disturbances. The area under each curve is the cumulative carbon in the forest [Perez-Garcia et al., 2005]

The study of Perez-Garcia et al., 2005, analysed the movement of carbon to three carbon pools: carbon storage in forests, carbon storage in forest products, and fossil fuel substitution (carbon difference from the use of fuels when substituting wood for some of another material such as concrete). The calculation was performed with the following choices: short- and long-term wood products were considered. Thinning gave short-term products (wood chips, sawdust, etc.), that were used for energy, harvesting gave 50% lumber (long-term product) and 50% short-term products. The decomposition of the long-term products was assumed to take place at the end of an 80-year useful life of the house at a rate of 10% per year. Fig. 2 depicts the carbon pools and their evolution in time for the 80 year rotation. Short-lived products are used for energy production, which would reduce purchased energy needs e.g. of sawmilling. The effect of the energy produced, and the carbon emissions saved, by substituting for fossil fuels becomes a permanent carbon pool. Products create an own carbon pool, but the substitution pool is becoming more and more significant.

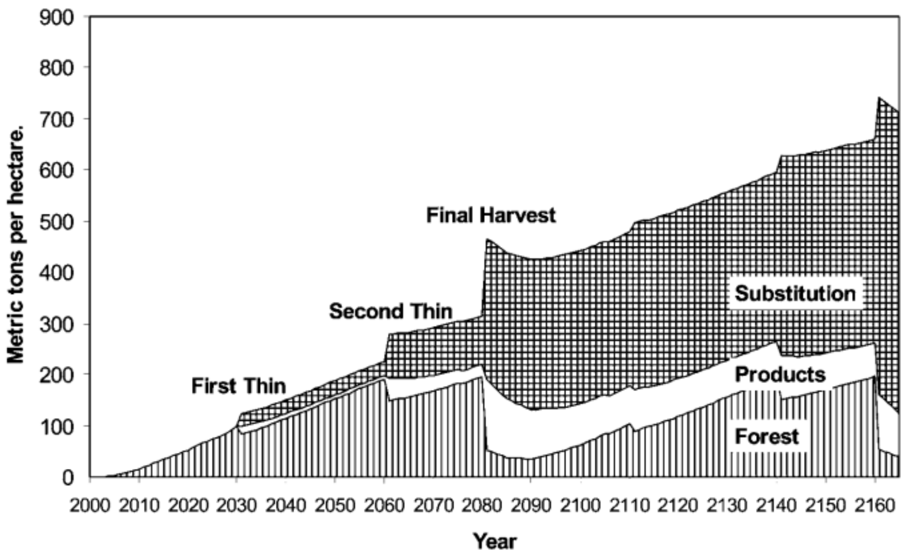


Fig. 2: Carbon in the forest and product pools, considering substitution of concrete as building material, for the 80-year rotation [Perez-Garcia et al., 2005]

Details of the calculation cannot be described. But it should be pointed out that biomass use is reducing the need for non-renewable products (fossil fuels or non-renewable building product), saving CO_2 that otherwise would have been emitted. Even when the forest is clear-cut and the products are completely decomposed the substitution remains.

It also should be mentioned that carbon storage and flows in the biosphere is even more complex. The soil itself is a huge carbon reservoir. This reservoir is affected by the plant cover. Losses of soil carbon occur when soil organic matter is exposed to oxygen and gets oxidized. Fires and tillage remove the soil cover and leads to losses of soil carbon as well as excessive grazing and drainage. Practices to maintain or increase the organic component in the soil are e.g. manuring. Reforestation together with retaining the soil fertility by leaving forest residues like branches, needles, foliage and roots at the site restores the original carbon content of the soil. These processes have to be taken into account when accounting for carbon flows. The switch in forest management strategies from enduring tree species to fast growing tree species or short rotation plantations, in specific if fertilizers are applied, too, have a considerable impact on the carbon stocks [Milá i Canals, 2003] and emission of GHG (e.g. N_2O) [IPCC GPG-LULUCF, 2003, chapter 3_2].

Efforts for a long-term storage of carbon dioxide are called carbon sequestration. Proposed techniques involve methods such as ocean fertilisation, reforestation and agricultural techniques. Long-lived wood products like e.g. wooden houses are also discussed with a carbon sequestration focus. However it is a point of concern for how long the captured carbon remains in the sink: e.g. areas that have been reforested to compensate for fossil fuel emissions would have to be managed in perpetuity. This is known as the permanence issue [IEA Bioenergy Task 38: Answers to ten frequently asked questions about bioenergy, carbon sinks and their role in global climate change, 2nd edition, 2005].

Greenhouse Gas emissions are a topic of scientific work on various levels, ranging from single products e.g. as the carbon footprint, to buildings (e.g. comparing wood frame buildings with functionally equivalent concrete buildings), to sectorial studies like the energy sector or the forest sector, to national balances for the assessment of the national Kyoto target, to the global carbon cycle.

3.4.1.2 Wood products for construction

The wide use of wood products is prerequisite for a continued extraction of CO_2 from the atmosphere. The uptake of CO_2 in biomass and the subsequent use of wooden products or energy replace fossil fuels and resources. An estimation of the substitution potential of wood in various sectors of European countries is given in [Gustavsson et al., 2006a].

A characteristic of the forest and wood products industry is that there are virtually no fractions of the biomass that cannot be used, either as a product or as energy. A proper functional unit thus always has to reflect this “twofold nature” of wood and be of the kind [Jungmeier et al., 2002a]

xx kg or m3 of the product
+ yy khW of electricity
+ zz kWh of heat.

Another characteristic is that in addition to the main product, e.g. sawn timber, also high amounts of co-products are generated, e.g. sawdust, bark, etc. If co-products cannot be used internally, e.g. for the generation of thermal energy for wood drying, they can be sold to other industrial sectors (e.g. chips from saw mills are used in the particle board industry). A whole network of biomass material flows was established of different wood processing industries that use co-products from other sectors as material input or for fuel. Due to this fact allocation is necessary as well of the burdens and the benefits like CO_2-storage. As an example the Global warming potential of a wooden window frame was cited [Jungmeier et al., 2002b]. If all incorporated CO_2 of the biomass initially harvested for the window frame is attributed solely to it and all biomass that is leaving the frame production line is treated as waste (which is more than 65%), the main product results in a highly negative global warming potential.

The main material and energy flows of the wood chain are shown schematically in Fig.3.

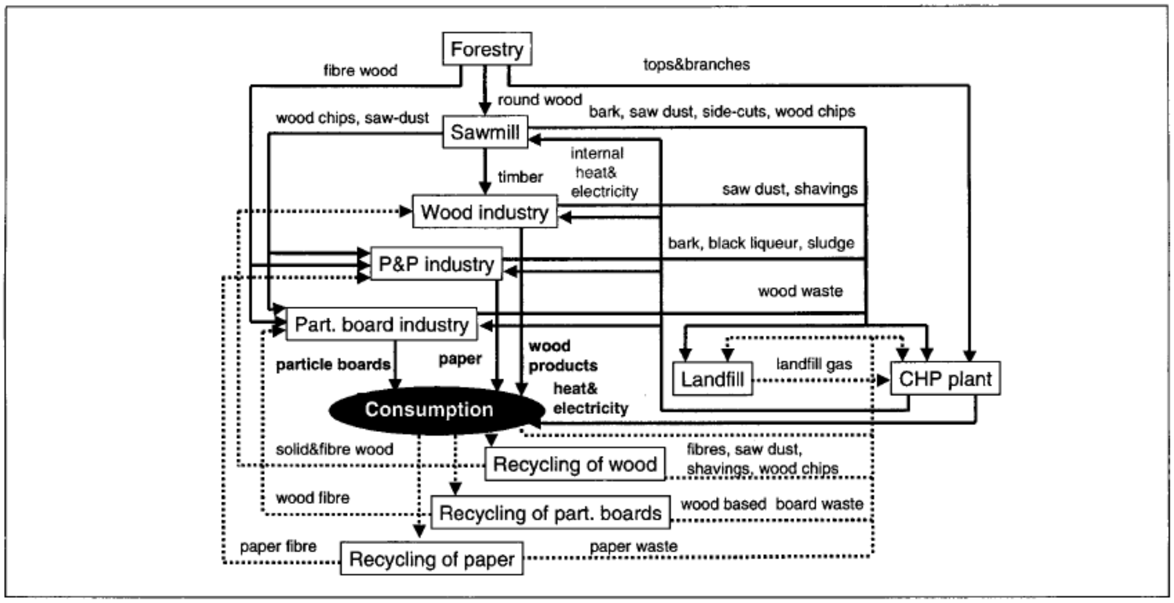


Fig. 3: Processes in the LCA of wood-based products that might require allocation (simplified; transportation and other upstream environmental aspects of processes are not shown) [Jungmeier et al., 2002a]

The interpretation that was drawn by the authors of a literature search study [Werner et al., 2007a] was (only 3 points out of 8 are listed here):

Wood products tend to have a favourable environmental profile compared to functionally equivalent products out of other materials. Particularly, consumption of non-renewable energy and cumulated energy demand, the potential contributions to the greenhouse effect and the quantities of solid waste are usually minor or very minor compared to competing products. On the other hand, wood products are associated usually with a higher consumption of renewable energy carriers (by nature).

The results of a comparative LCA are very sensitive to methodological decisions, including the selection of an allocation procedure used to model multi-output processes or recycling, or assumptions related end-of-life scenarios (e.g. methane emissions from landfilled wood, thermal energy recovery, etc.).

In LCAs of whole buildings, the materials used outside the areas of applicability of wood dominate the environmental profile of the building (see also next chapter “Buildings”)

The authors [Werner et al., 2007a] conclude that the results of an LCA cannot only be used for the comparison of different products or for the in-depth analysis of the environmental profile of a product over its life cycle.

It should be stated that wood is not the only construction material with incorporated biogenic CO_2. Especially favourable in terms of low environmental impact are straw and paper (boards and mats from recovered paper) which are used as an insulation material. Straw is an agricultural residue since crops usually are grown for food or for livestock feeding. Today most of the straw is not further utilised. Apart from CO_2 emissions for ploughing, sowing and harvesting impacts are on the following fields (they have to be allocated to the crop, too): land use (has the arable land been gained by conversion of forest or pasture/grassland?), sustainable farming (has the crop been grown following principles of integrated farming, e.g. no use of chemical fertilizers?), eutrophication and/versus soil fertility.

3.4.1.3 Buildings

Buildings are highly complex products, not only composed of many building materials and building elements but also differing in design and functions required by the client, in their construction process, in the actual use and maintenance, in the occupants' behaviour, etc. On the end-of-life stage of existing buildings only assumptions can be made. Because of this complexity comprehensive LCA studies on building are rare. In the context of this chapter comparisons of wooden buildings with other structural materials are of interest that nevertheless cover the whole life cycle of the buildings.

CORRIM, the Consortium for research on renewable industrial materials in US, has conducted a study to compare a wood-frame housing design versus a steel frame design for the Minneapolis region (cold climate) and a wood frame versus a concrete design for Atlanta area (hot and humid climate) over the complete life cycle of the modelled buildings [Bowyer et al., 2004]. The used wood was dumped as the disposal route of the construction wood. The study results were very much in favour of the wooden alternative (less primary energy content, less contribution to global warming, etc.).

Two studies for Sweden and Finland showed the same trends in their results [Gustavsson et al., 2006b], [Gustavsson et al., 2010].

As was already cited before, the building elements that for practical reasons cannot be substituted by wood, like the basement or the roof, contribute in excess to the impacts of the buildings [Werner et al., 2007a]. Wood is often not the main material by weight even of wooden buildings.

In addition to LCA studies the share of buildings that were assessed with a green building assessment scheme is rapidly growing. These schemes often require calculating some LCA impacts, e.g. the Global warming potential, the Acidification potential, the ODP, the POCP and the Eutrophication potential of the bulk materials. The most popular building assessment systems are the SB-Tool (international, http://www.iisbe.org/sbmethod), LEED (US, http://www.usgbc.org/DisplayPage.aspx?CMSPageID=2122), BREEAM (UK, http://www.bre.co.uk/page.jsp?id=1768), certificate of DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen (http://www.dgnb.de/de/zertifizierung/vorteile/index.php?edit_document=1). The Austrian TQB-Total Quality building is until now only available in German.

The Building assessment schemes often provide an own database for calculation of the materials' impacts (Primary energy use and impact categories are given). E.g. the DGNB provides the "Ökobau.dat", in Austria the Ecosoft-Database is available (www.ibo.at). Both include wood products with a negative contribution to the GWP since they were developed for "cradle to gate" analysis.

3.4.1.4 End of life scenarios for biomass

After the use phase of wood products, the material characteristics of wood (theoretically) still allow for a variety of options for the reuse of wood as material or energy carrier. This can be done several times leading to a cascaded use. So the products' carbon stock can be retained for longer than one product's service life time.

The subject of used wood, also termed post-consumer wood or recovered wood, has been covered by the European COST Action E 31 "Management of recovered wood" (http://www.cost.eu/domains_actions/fps/Actions/Management_of_Recovered_Wood).

In the Cost Action E 31 the following definition is used: Recovered wood is demolished products biomass (examples: used construction biomass, used pallets biomass) and used products biomass (if biomass is further used as the same product for another purpose, like e.g. used railway ties). The term "recovered wood" does not cover e.g. biomass in end solid wood products that is going to be used once more in a new setting (example: wooden chair) [Okstad, 2007].

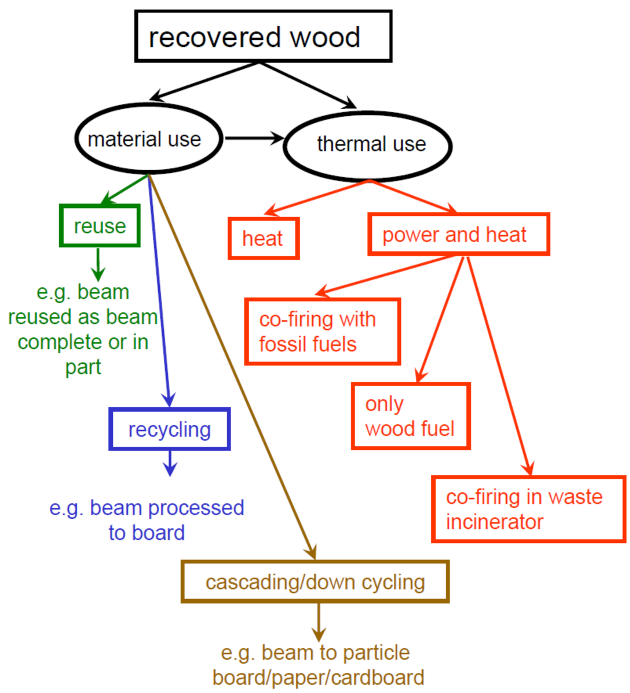


Fig. 4: Material and/or thermal use of recovered wood (Merl, presentation given at the 3rd European COST 31 Conference – Management of Recovered Wood. Proceedings 2 – 4 May, 2007)

Post-consumer recovered wood is one source of wood that has not always been considered in the past. This material was sometimes considered insignificant and most of the recovered wood was sent to landfill in the past until it was discovered as an environmentally and economically attractive secondary resource to be used for energy generation and as raw material for wood based products. In the last decade it became a relevant raw material for industry (particle boards, wood wool panels). The logistic problems are small since it is usually mixed with recovered wood from industry and building sites. The main problems are in fact possible impurities especially preservatives, though separation is performed by visual control. Recovered wood in Europe mainly originates from construction and demolition activities, residential and commercial sectors, furniture and packaging material. Demolished products biomass can be distinguished into primary biomass (uncontaminated; may be used for production of board products or biofuel products), secondary biomass (contaminated; may be used for production of biofuel products) and tertiary biomass (hazardous biomass; may be used for production of biofuels).

European wood recycling has grown steadily over the last decade, mainly due to increased consumption by the panel board industry. There is presently strong competition for recovered wood between the energy sector and the panel board industry. These sectors are the most important users of recovered wood. This competition is set to be even stronger in future. [Merl et al., 2007], [Hillring et al, 2007].

However, there are some issues relating to recovered wood [Merl et al., 2007]. Firstly, recovered wood is generated at several small locations in contrast to industrial or forest residues. Therefore there are logistical problems in contrast to collecting it and sorting it from other materials. Secondly, recovered wood could contain impurities (such as steel, paint, soil, concrete, plaster, plastic, etc.) or pollutants (such as biocide residues and preservatives), that limits its potential uses. However the most important issue is the fact that data on the quality and quantity of recovered wood is not usually readily available from official statistics. From industrial point of view it is very important to know how much material is available, its quality and its location.

Data for table 1 were collected from national delegates of COST Action E 31 following a questionnaire. At least for Austria this table contains all waste wood, not only post-consumer wood.

Country	Reuse	Recycling	Energy	Landfill	Composting	Others, unknown	Total
	[t/a]	[t/a]	[t/a]	[t/a]	[t/a]	[t/a]	[t/a]
Austria	38,750	310,000	325,500	15,500	77,500	7,750	775,000
Belgium	259,540	191,240	13,660	13,660	68,300	136,600	683,000
Bulgaria	1,633	40,825	57,155	8,165	-	55,522	163,300
Croatia	5,052	15,155	70,723	5,052	2,021	3,031	101,034
Finland	-	360,624	383.163	7,513	-	-	751,300
France	-	5,041,000	994.000	1,065,000	-	-	7,100,000
Germany	-	906,224	4.119.742	11,924	47,696	876,414	5,962,000
Greece	-	-	-	-	-	450,000	450,000
Hungary	1,600	3,200	6.400	16,000	3,200	1,600	32,000
Ireland	38,552	318,053	4.819	38,552	9,638	72,285	481,898
Italy	112,841	922,070	559.368	17,732	-	-	1,612,011
Netherlands	-	755,525	459.000	-	-	34,925	1,249,450
Norway	-	12,300	172.200	4,920	17,220	41,820	248,460
Poland	34,100	9,300	6.200	3,100	-	257,300	310,000
Portugal	-	28,320	2.360	4,720	-	200,600	236,000
Serbia	18,100	90,500	434.400	543,000	-	724,000	1,810,000
Slovenia	5,375	2,688	72.025	24,725	2,688	-	107,500
Spain	-	960,000	60.000	108,000	60,000	12,000	1,200,000
Sweden	19,600	19,600	705.600	19,600	19,600	-	784,000
United Kingdom	-	885,760	1.550.080	1,217,920	608,960	1,273,280	5,536,000
Total	**535,142**	**10,872,383**	**9,996,395**	**3,125,083**	**916,822**	**4,147,127**	**29,592,953**
t/(c*a)	0.0012	0,0239	0.0220	0,0069	0,0020	0,0091	0,0651

Table 1: Amounts of recovered wood and use of recovered wood in the countries [Merl et al., 2007]

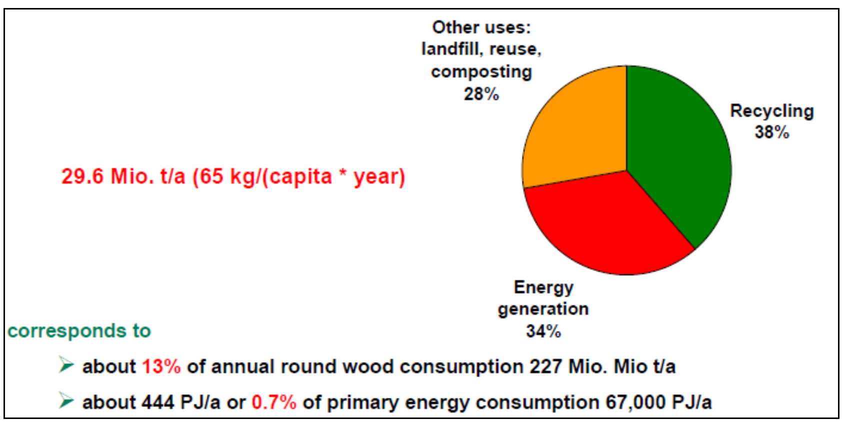


Fig. 5: Amounts of recovered wood in countries, source: [Merl et al., 2007] (taken from: Jungmeier presentation given at the 3rd European COST 31 Conference – Management of Recovered Wood. Proceedings 2 – 4 May, 2007)

Millions of tons are still sent to landfill each year as most of the markets for recovered wood require clean, solid timber. If we disregard France, Serbia, and United Kingdom only 300.000 tons of waste wood are landfilled per year, 100.000 tons of them in Spain. Environmental burdens arise for impregnated wood which is usually problematic with respect to toxicological effects in specific if metal based preservatives have been used.

3.4.1.5 Biogenic CO_2 in life cycle inventory and life cycle assessment

There is at the moment no consensus on how to account for biogenic CO_2 in LCA [Rabl et al., 2007], [Johnson, 2009] as well as allocation methods for co-products and modelling of recycling [Werner et al., 2007b]. And finally there is a need for guidance concerning the buildings' end of life. The handling of post-consumer wood is situated between waste treatment and exploitation of a secondary resource for material or energy purposes [Werner, 2007b] LCA compatible end of life scenarios for different types of construction/renovation/demolition waste have to be further elaborated.

3.4.1.5.1 Biogenic CO_2 accounting in Ecoinvent LCI database and Ecoinvent LCIA assessments:

The Ecoinvent database has been developed in Switzerland and is maintained by the Ecoinvent Center in Switzerland (http://www.ecoinvent.org). It is one of the world's leading databases with more than 4000 LCI datasets from a variety of areas of civilization. Most of the data reflect Swiss and Western European conditions. Several LCA software tools like SimaPro use Ecoinvent data.

A series of reports describe in detail the datasets, assumptions, system boundaries and calculation. Additional describing information (meta information) is provided about technology, temporal and geographical validity and so on. In addition to LCI data some frequently applied impact assessment methods are included and connected to the LCI data. The main results from LCIA are also presented in the reports.

Werner, F., Althaus, H.-J., Künninger, T., Richter, K., Jungbluth, N.: „Life cycle inventories of wood as fuel and construction material. Ecoinvent report No. 9, 2007 [Werner et al., 2007c]:

Natural wood production in Ecoinvent database accounts for the land on which trees grow and for the CO_2 absorbed by the trees [hardwood/softwood, standing, under bark, in forest Metainformation to the datasets, s. p. 13]. Technical wood production covers tree nurseries, tending, thinning, cutting, and hauling of the wood to the nearest forest road. Inputs are in specific fossil fuels used for these processes as well as land use for forests roads and resources (gravel, etc.) for forest roads. Thinning and cutting give as commercial outputs roundwood, industrial wood (for the use in paper or wood fibre industry) and residual wood (e.g. branches, small trees from tending or thinning). For lack of data several environmental burdens and consequences are not considered such as application of pesticides or soil compression due to the use of heavy machines [page 16]. In Ecoinvent database products are described that have been produced by typical processes like sawing, or chipping, by various drying processes and planning. During production of boards processes like cutting, peeling, gluing, steaming or heating, pressing, and drying take place and chemicals like resins, adhesives, wood preservatives are applied.

The handling of so called "post-consumer wood" is not integrated in Ecoinvent, except for a general discussion of advantages, disadvantages and problems related to incineration [page 4 ff]. For both the material and energy uses of post-consumer wood, the potential content of harmful substances from chemical wood conservation is a major limitation.

Doka, G: Life cycle inventories of waste treatment services – Part V: building material disposal, Ecoinvent report No. 13-V, 2007, Part II: Waste incineration, Ecoinvent report No. 13-II, 2007, Part III: Landfills – Underground deposits, Ecoinvent report No. 13-III, 2007 [Doka 2007]:

Three building material disposal routes can be chosen also for wood: direct recycling, recycling after sorting and disposal without recycling. Direct recycling is done at the building site. Only dismantling burdens (energy, particle (PM) emissions) are inventoried then. This fraction of used wood is regarded as valuable material. The cut-off attributes all further expenditures (including transport) to the used wood consumer.

Wood may be mixed with other materials at the building site in a waste through. It is transported off to sorting and to incineration. Dismantling burdens, transport and incineration burdens in a municipal solid waste incineration are inventoried in Ecoinvent database. Although energy production (heat or cogeneration) is part of the waste incineration process, this benefit is not passed on to the waste that is disposed [page 21 ff, in specific fig. 2.14, page 23].

If wood is sent to landfill, it is decomposed within 150 years. Carbon is transferred to landfill gas as CO_2 and CH_4 (a small amount also to leachate).

Each Ecoinvent LCI data set contains the input flows “Carbon dioxide, in air (resource in air)” and the output flows “Carbon dioxide, biogenic (to compartment air)”. The first is considering CO_2 uptake by photosynthesis in plants. The latter is the released CO_2 during natural rotting of biomass or technical incineration processes of biomass.

Several life cycle impact assessment methods are implemented in the Ecoinvent database: the CML 2001, Cumulative energy demand, Cumulative exergy demand, Eco-indicator 99, Ecosystem damage potential – EDP, Ecological footprint, Method of ecological scarcity, EDIP 97, EDIP 2003, EPS 2000, Impact 2002+, IPCC 2001. In the report [Frischknecht et al., 2007] the authors state:

> “Biogenic CO_2 and CO emissions and biogenic CO_2 resource extraction are excluded from the impact assessment.(…)If impact assessment results ar4e to be used with regard to carbon sequestration or clean development mechanisms, biogenic CO_2 and CO emissions and biogenic resource extraction need to be added to the assessment.
>
> CO_2 emissions due to deforestation of primary forests and land transformation are represented by the elementary flow ‘Carbon dioxide, land transformation’. The weighting factor of fossil CO_2 emissions is assigned to the elementary flow ‘Carbon dioxide, land transformation’.” (p.11)

3.4.1.5.2 Biogenic CO_2 accounting in Carbon footprinting (PAS 2050:2008):

Carbon footprint calculations have become a subject of growing public attention. Several "Carbon footprint calculators" for anyone have been set up, often implemented in Internet. The calculations consider only climate change related greenhouse-gas emissions with various system boundaries in time and spatially. The Intergovernmental Panel on Climate Change (IPCC) factors are typically used for Carbon footprint studies.

The first "standard" in this field, PAS 2050:2008, has been prepared by the British Standards Institute (BSI). PAS stands for Publicly Available Specification. The aim has been to specify requirements to provide a clear and consistent method for assessing the life cycle greenhouse gas emissions (GHG) of goods and services.

Carbon dioxide arising from biogenic sources of carbon is assigned a GWP of zero in specific circumstances specified in this PAS and carbon storage can be accounted for in this PAS:

§ 5.3.1 CO_2 emissions originating from fossil and biogenic carbon sources:

CO_2 emissions arising from biogenic carbon sources shall be excluded from the calculation of GHG emissions from the life cycle of products, except where the CO_2 arises from land use change (see 5.5).

§ 5.4 carbon storage:

(…)Where carbon of biogenic origin forms part of a product, the impact of this carbon storage over the 100-year assessment period shall be included in the assessment of the life cycle GHG emissions of the product, subject to the conditions described in 5.4.1 to 5.4.4. Note: Carbon storage may arise where biogenic carbon forms part or all of a product (e.g. wood fibre in a table), or where atmospheric carbon is taken up by a product over its life cycle (e.g. cement).

§ 5.4.1 Eligible products for the assessment of stored biogenic carbon

§ 5.4.2 Treatment of stored biogenic carbon

At disposal: Where products are disposed of in a manner that prevents some or all of the biogenic carbon being re-emitted to the atmosphere within the 100-year assessment period, the portion of biogenic carbon not re-emitted to the atmosphere shall be treated as stored carbon for the purpose of this PAS.

In recycled material: Where a product is recycled within the 100-year assessment period, the impact of carbon storage shall be determined for the product giving rise to the recycled material up to the point at which recycling occurred. Note: A product using recycled biogenic material receives a storage benefit from the carbon stored in the recycled material in accordance with this section.

Treatment of CO_2 emissions arising from products containing biogenic carbon: Where a product containing carbon of biogenic origin degrades and releases CO_2 to the atmosphere, the CO_2 emissions arising from the biogenic carbon shall not be included in the assessment of emissions associated with the product. Note: CO_2 emissions from products containing biogenic carbon are included in the assessment of the life cycle

GHG emissions via the calculation of the weighted average carbon stored over the 100-year assessment period (see 5.4.3), and do not need to be included here.

§ 5.4.3 Calculation of the CO_2 impact of stored carbon

Weighted average of stored biogenic carbon and atmospheric CO_2 taken up by products: The impact of carbon storage shall be determined from the weighted average of the biogenic carbon (measured as CO_2) in a product, or atmospheric CO_2 taken up by a product, and not re-emitted to the atmosphere over the 100-year assessment period. The method for calculating the weighted average carbon storage impact shall be that given in Annex C.

Inclusion of the GHG impact of stored carbon: The weighted average carbon storage impact calculated in accordance with 5.4.3.1 shall be included as a negative CO_2 value in the assessment of GHG emissions arising from the life cycle of the product.

§ 5.4.4 Recording the basis of the carbon storage assessment

§ 5.5 Inclusion and treatment of land use change

The GHG emissions arising from direct land use change shall be assessed for any input to the life cycle of a product originating from agricultural activities, and the GHG emissions arising from the direct land use change shall be included in the assessment of GHG emissions of the product. The GHG emissions occurring as a result of direct land use change shall be assessed in accordance with the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories. The assessment of the impact of land use change shall include all direct land use change occurring on or after 1 January 1990. The total GHG emissions arising from direct land use change shall be included in the GHG emissions of products arising from this land. One-twentieth (5%) of the total emissions arising from the land use change shall be included in the GHG emissions of these products in each year over the 20 years following the change in land use.

Note 1: Where it can be demonstrated that the land use change occurred more than 20 years prior to the assessment being carried out in accordance with this PAS, no emissions from land use change should be included in the assessment as all emissions resulting from the land use change would be assumed to have occurred prior to the application of the PAS.

Note 2: Direct land use change refers to the conversion of non-agricultural land to agricultural land as a consequence of producing an agricultural product or input to a product on that land. Indirect land use change refers to the conversion of non-agricultural land to agricultural land as a consequence of changes in agricultural practice elsewhere.

Note 3: While GHG emissions also arise from indirect land use change, the methods and data requirements for calculating these emissions are not fully developed. Therefore, the assessment of emissions arising from indirect land use change is not included in this PAS. The inclusion of indirect land use change will be considered in future revisions of this PAS.

Note 4: It is assumed that prior to the land use change taking place the net GHG emissions arising from the land were zero.

Emissions and sequestration arising from changes in soil carbon are outside the scope of this PAS, but will be considered further in future revisions of this PAS.

3.4.1.5.3 Land Use and land use changes

The LCIA category “land use” describes the (environmental) impacts of occupying, reshaping and managing land for human purposes. E.g. intensive forestry or agriculture with monocultures has negative consequences on the biodiversity. Other possible damages to the ecosystem are the reduction of biotic production, the loss of landscape elements, the sealing of surfaces, etc. Land use in LCIA can on the either be associated with land use occupation or transformation. Examples are e.g. as the long-term use of a certain land use type with a specific intensity (e.g. land use for arable farming) and a change of land use type (e.g. from natural to urban area). LCA studies of land use impacts have to consider complex cause-effect chains and dependencies.

Since the amount of wood that is traded internationally is increasing, As a result regional wood gets mixed with various other sources. It can no longer be taken for granted that wooden building products are made of wood of sustainable forestry and from regional sources, unless a complete “chain of custody” is established.

Principles and measures of Sustainable Forest Management for Europe have been first defined by the 2nd Ministerial Conference on the Protection of Forests in Europe in Helsinki, 1993. Avoiding irreversible degradation of forest soils and sites, conserving functional forest ecosystems, conservation and appropriate enhancement of biodiversity were the prime background issues of the Resolution “General Guidelines for the Sustainable Management of Forests in Europe”.

Criteria of certification schemes for sustainable management of forests go beyond those established principles respectively make them operational by giving specific targets for performance based indicators. In Europe wood may be certified by two schemes, namely PEFC (Programme for the Endorsement of Forest Certification schemes formerly Pan European Forest Certification scheme, www.pefc.org) or FSC (Forest Stewardship Council, www.fsc.org). In January 2010 56’005’024 ha have been certified by FSC within Europe, the largest areas being in Sweden, Poland and Russia. PEFC certified forest area in Europe amounted to 59,222,437 ha (1.5.2010), with largest areas being in Finland, Norway, Germany and Sweden.

3.4.1.6 Recommendations

Further detailed LCI data sets are necessary reflecting differences in forestry practice in various European countries as well as used wood recycling practices in various European countries. So it should be possible to account for products from sustainable forest management. A recent example in Ecoinvent (v2.2) is the addition of the data sets “electricity mix certified, Switzerland”.

In LCIA these datasets should be evaluated further accounting for re/deforestation. The simplest possibility is to assign a (weighting) factor to the biogenic CO_2 emissions like for the fossil part and a same, but negative weighting factor for the part that is taken up as resource by plants. At the moment product carbon footprint projects are conducted in many European countries with slightly different methods. The already mentioned PAS 2050:2008 is the first that was already communicated to the public. A platform for consolidation and harmonisation is the PCF World Forum.

With an enlarged pool of consistent and quality-assured LCI data sets that should be gathered in the ILCD Data Network, the availability of consistent data will stepwise be substantially improved and the need to use less representative data be minimised.

Concerning the end of life issue it has to be taken into account that more and more wood products are coated or sealed or connected with other parts etc. On the other hand markets for re-use or recycling of used wood require clean, solid timber (uncontaminated primary biomass; see classification in chapter “End of life scenarios for biomass”). Wood that has been sorted at the building’s site during dismantling is not allowed to be classified as primary biomass (in Austria, In Ecoinvent [Doka 2007] rather today’s common (Swiss) practice is reflected than an anticipated future practice.

We propose that as first step country data sets have to be generated e.g. based on data of the Cost Action E 31. This would reflect the common practice nowadays in different countries and would be an input for LCA studies on short lived wood products in the construction process (paletts, etc.) and on other fractions of the wood processing chain.

Long-lived construction products and building elements that have to be accounted for could – as a first approximation – treated the same country specific way. In the long run separate mechanisms will have to be developed to distinguish whether these were designed to give separable and untreated (or at least metal-free preserved) used wood fractions.

Recommendations for further research

Develop models to account for biogenic CO_2 at the different life cycle stages (biomass production, carbon storage in buildings, end of life processes) as well as corresponding LCI data.

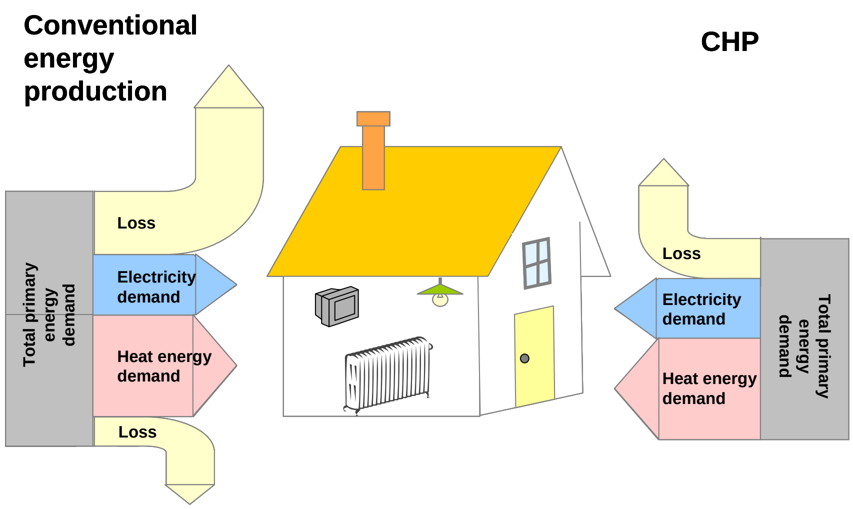
3.4.2 Co-products

An LCA regards the life cycle of a product as a system, which is significant through its defined function(s). By manufacturing a product (main product), some other products (by-products) can be also brought out. And some of these “by-products” are as well as useful as the aimed product in a defined system, then it is called no longer “by-product”, but a “co-product”.

From the viewpoint of resource demands, these co-products bring new material and process flows into the life cycle. As this may relate to the environmental impacts assessment, co-products can normally not be neglected in an LCA.

An instance of this situation is the technology of cogeneration or combined heat & power (CHP) – a power station which simultaneously generates both mechanical energy (which will be transformed to electricity as a rule) and useful heat (e.g. for domestic heating) from a single source.

Normally, the heat through electricity generation is wasted as by-product and will be simply given up into the natural environment through cooling towers or cooling water. In a CHP, this heat will be either used as process heat for power station or directly used for domestic heating.



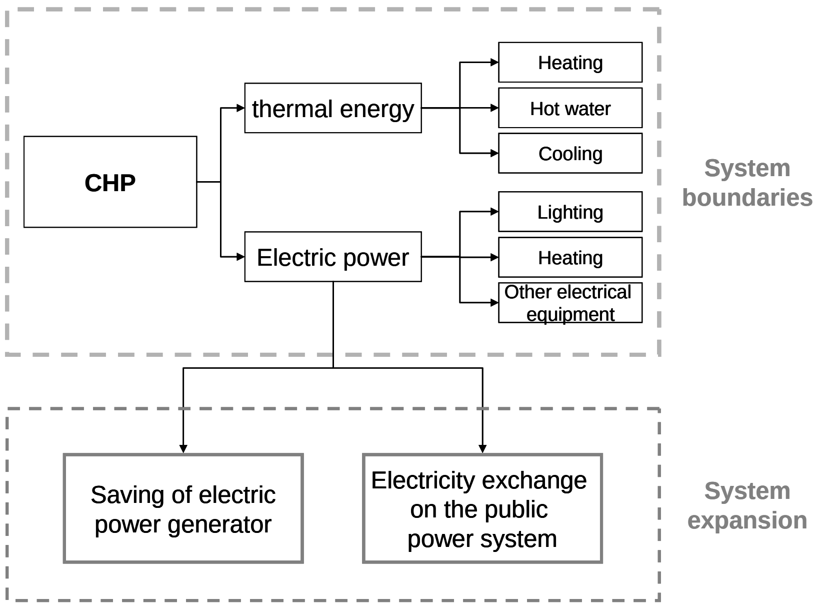
Comparison of CHP with conventional energy production

“Micro cogeneration” (less than 15kWel) and “Mini cogeneration” (up 15kWel to max. 50kW$_{el}$) are so-called distributed energy resource (DER) which are typical CHPs for domestic use. These sorts of plants are usually installed in single house or multifamily house, where the DERs are not only used for heating and hot water supplying, but also for air dehumidification or cooling.

CHP is one of the most efficient methods to reduce primary energy demand and carbon emission. While the energy conversion efficiency by conventional power station is around 40 per cent in average, the efficiency of CHPs can achieve 90 per cent. On the one hand the demand of energy is reduced through energy recycling, on the other hand a separate generator can eventually also be saved.

For domestic usage CHP is normally dimensioned to fit the heating household energy demand in place of the electric power. So a domestic CHP can be considered as a heating plant which is featuring with electricity generating. In this case, from the viewpoints of energy use and lowering the air pollution, the electric power as a co-product of heating energy generation can be directly and clearly allocated. Because, the extra fuel for the production of electric power is obviously reduced. Consequently, the emissions of carbon, nitrous oxides, sulphur-dioxide and particulate matter will be also lower.

By contrast, if one takes the axed power generator, eventually an additional advantage of CHP, account into an LCA, that will be hardly possible to allocate this into a building system without bringing new function (electricity production) and sub-processes (production of power generator) into it, what is surely redundant and deceptive for a building. Furthermore, usually the generated electric power (in total or in part) which covers not always the electric energy demand of the building, will be directly fed into the public power supply system. And the electricity for the household usage will be (re-)bought from the power supply system. That makes the allocation of the saved power station as a co-product into a building system much more difficult and the building system will be over-expanded.



Boundaries of co-products allocation

In order to identify the real resource demands and environmental impacts of a product or a process the treatment of co-products in an LCA is required and regulated by different ISO standards (e.g. ISO 14041).

Generally, all the co-products and their processes shall be allocated in an LCA when an environmental exchange occurs through these. But by allocation of the co-products attention of the following principles shall be paid:

- In some cases the allocation of co-products could cause unnecessary efforts to expand the system (e.g. sub-process or additional function to system). In such cases, co-products may be neglected. But this has to be justified by an appropriate sensitivity study because system expansion is the approach recommended by the ISO-standard.
- Inputs and outputs among different products must be possibly assigned to corresponding products or processes. For example, plastic waste can be treated through incineration. The co-product of this waste treatment is energy that can be

used for heating. However, there are also several emissions (e.g. toxic gases and carbon emissions) which otherwise will not be released and these must be take account of the co-production process.

- Inputs and outputs of a process shall not be modified through the allocation.

Recommendations for further research

Not only in the production stage but also in the end-of life scenario for certain building components co-products are influencing the performance drastically. Energy conversion is also one of the popular waste treatment methods besides recycling and repurpose. Especially the thermal exploitation of refuse is widely established and sometimes more reasonable than imprudent refashioning (e.g. frequent downstream recycling of plastics). Energy conversion provides different services: waste treatment and heat and possibly electricity production. Hence, co-products as well as by products shall be increasingly regarded in an LCA calculation.

In the Building LCA applications, system expansion could be studied in order to harmonize current practice in the different tools.

3.4.3 End of life and recycling

The end of life of the constructed asset results in three main material flows, materials to disposal, material for recycling including on-site use, and materials for energy recovery. The LCA of both products as well as whole buildings needs scenarios for the end of life. For comparative LCAs or LCA used for documentation of environmental impact, there are rules how to make the scenarios, for instance that you can only take into account recycling of a product if systems for this already are well established.

Doing consequential LCAs, for instance studying the impact of waste policies, establishment of recycling systems may be introduced to the system.

There exist presently several methods to assess the environmental benefit of recycling. In the CEN standard, the “stock flow” method is used, which may not completely correspond to the ISO standard on LCA, recommending system expansion. Other methods are proposed, based upon the concept of “avoided burden”. Three methods are described and compared hereunder, illustrating the need for clarification and harmonization in this field.

Recycling generates an impact (noted Ir), and usually a supplementary transport related impact (It) because the recycling facility is further than e.g. landfill. On the other hand it avoids the impacts corresponding to new fabrication (In) and to waste treatment (Iw). Recycling should be promoted if the related impacts (Ir + It) are lower compared to the total impact of new production from raw materials and waste treatment (In + Iw). The “avoided impact” by recycling is then : In +Iw – Ir - It. The impact of the waste treatment of the recycled (Ir_W) and the substituted new product (In_W) should also be considered if they are different, i.e.the avoided impact is then: In+Iw+Inw-Ir-It-Irw

Good practice consists in :

- rewarding the use of recycled products at the construction phase,
- rewarding sorting waste and recycling at the end of life,
- avoiding double counting of the benefit of recycling.

The impact reduction depends on the recycling rates rf at the fabrication and re at end of life. There exist different methods to model recycling in building LCA tools. According to the stock flow method, the impact reduction is rf . (In – Ir) at the construction phase and re. (Iw – It) at the end of life.

The steel industry proposes a reduction of rf . (In – Ir) at the construction phase, (re-rf).(In-Ir) + re.(Iw-It) at the end of life.

The avoided impact method evaluates an impact reduction of rf.(In+Iw-Ir-It)/2 at fabrication and re.(In+Iw-Ir-It)/2 at end of life.

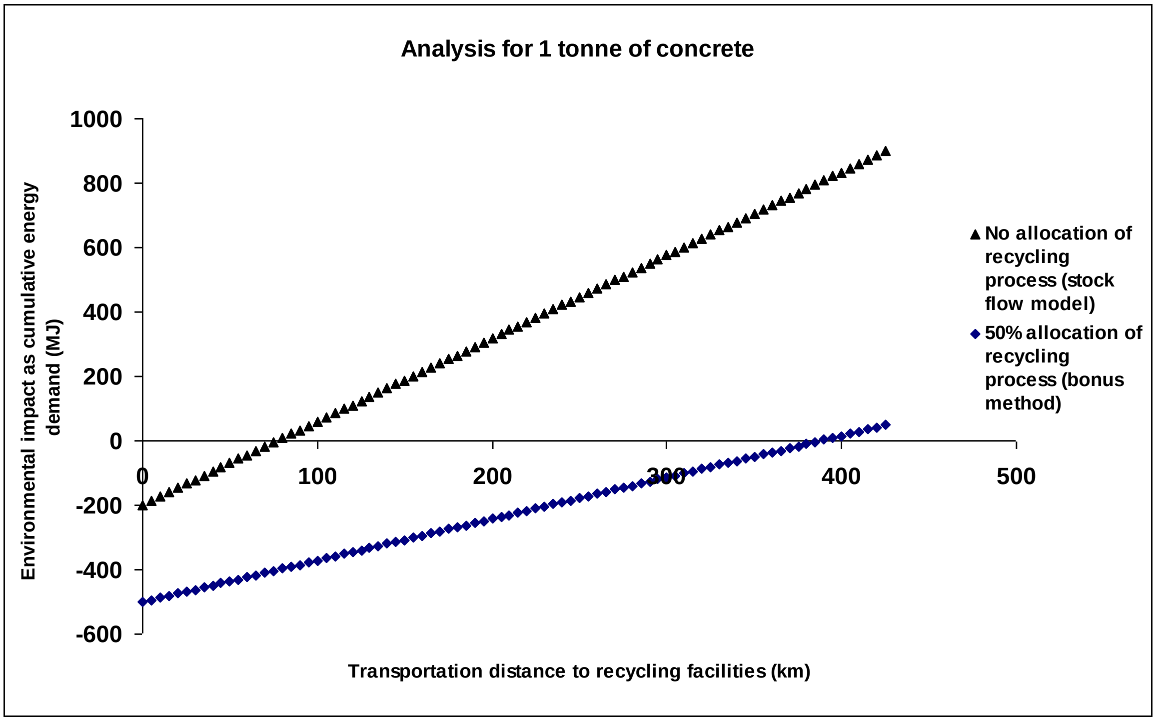
A comparison has been performed between the stock flow and avoided impact models in the case of the end of life of 1 tonne concrete[8]. Because the stock flow model does not account for recycling processes at end of life, it may result in assessing a better environmental performance for landfill or incineration compared to recycling according to the transportation distances to recycling facilities compared to landfill or incineration.

This is illustrated in the figure hereunder where the transport distance to recycling facilities was varied from 0 to 500 km. Data were taken in the LCI database Ecoinvent[9] and the impacts are expressed in cumulative energy demand (CED) for a functional unit of 1000 kg. The default scenario was considered landfill of concrete including a 30 km transport distance, according to the French EPD database[10]. The figure shows the impact reduction of recycling, compared to the default scenario, in terms of the supplementary transportation distance to the recycling facility (compared to the 30 km distance to landfill). Negative CED values correspond to an impact reduction by recycling compared to the landfill reference.

[8] Sébastien Lasvaux, Bruno Peuportier and Jacques Chevalier, Towards the development of a simplified LCA-based model for buildings : recycling aspects, CISBAT 2009 Conference, Lausanne

[9] www.ecoinvent.ch

[10] www.inies.fr



Comparison of 2 different recycling models: stock flow and avoided impacts

According to the avoided impacts model, recycling at end of life reduces the impact even if the transportation distance is increased up to 400 km. When using the stock flow model the distance threshold is shorter: about 80 km. Recycling is discouraged above this threshold.

The discrepancy between the methods is larger if re is very different from rf, which is the case for steel : in France for instance, about 90% of the steel is collected at end of life, whereas the average recycling rate in steel products is presently around 40%. The steel industry is therefore complaining against the stock flow model. But their proposal leads to a contradiction. The following table compares the impacts at the fabrication (Ifabrication) and end of life (Iend of life) phases in terms of the recycling rates, considering 4 theoretical extreme cases.

rf	re	Ifabrication	Iend of life	Itotal
0	0	In	Iw	In+Iw
100	0	Ir	Iw	Ir+Iw
0	100	In	Ir-In+It	Ir+It
100	100	Ir	It	Ir+It

Method proposed by the steel industry: if 100% of the material is recycled at end of life, the total impact is the same when using new or recycled material at fabrication.

The following table corresponds to the stock flow model.

rf	re	Ifabrication	Iend of life	Itotal
0	0	In	Iw	In+Iw
100	0	Ir	Iw	Ir+Iw
0	100	In	It	In+It
100	100	Ir	It	Ir+It

Stock flow method: the only avoided impact by recycling at end of life corresponds to the avoided waste treatment, but a transport related impact is added so that recycling increases the total impact even for a rather short distance (see previous figure).

The table corresponding to the avoided impacts method is the following.

rf	re	Ifabrication	Iend of life	Itotal
0	0	In	Iw	In+Iw
100	0	(Ir+In+It-Iw)/2	Iw	(Ir+It+In+Iw)/2
0	100	In	(Ir-In+It+Iw)/2	(Ir+It+In+Iw)/2
100	100	Ir	It	Ir+It

Avoided impacts method: recycling is rewarded the same at fabrication and at end of life, recycling at both phases is rewarded twice as recycling at only one phase.

Recommendations for further research

There exist presently several methods to assess the environmental benefit of recycling, showing that applying the ISO standard recommendation for system expansion is still complex. Further comparison of these methods and exchange between tool developers would help to identify good practice and harmonize the approaches. Many materials are concerned (concrete, steel, plastics), but also materials that can be incinerated with heat recovery (e.g. wood), because heat recovery can be modelled in a similar way as recycling.

3.4.4 Resources

The extraction of resources has an impact on the environment. The result is a decreased availability of the total resource stock. Non-renewable resources are finite, while the availability of renewable resources depends on the ratio of the regeneration rate compared to the consumption rate.

Many methods exist for the evaluation of the impacts of resource use, but a scientific consensus is missing on what the real issue is. Therefore, the ILCD handbook gives no recommendations which indicators to use at the endpoint level for natural resource use [EC JRC 2010b].

One problem is the question of aggregation: one extreme is the use of only one resource depletion indicator; the other is a broad range of indicators. Guineé, for example, distinguishes between biotic and abiotic resources [Guinée 2002]. Abiotic resources are non-living natural resources, such as fossil fuels and mineral ores, and they are mostly non-renewable (except, for example, wind). Biotic resources include living resources, such as wood etc. Dewulf distinguishes the following resources: atmospheric resources, land, water, minerals, metal ores, nuclear energy, fossil fuels and renewables [Dewulf et al. 2007]. Other categories are considered in Ecoinvent [Bösch et al, 2007]. The advantage of using several resource-related categories is that different resources have different characteristics and raise different concerns. Fossil fuels are, for example, consumed, but their energy content is conserved, although their quality or work potential is lost. Water is only temporarily removed from the circulation. Metal ores are dispersed all over the world in low concentrations, which makes their recollection uneconomical.

Another issue is to decide about the value of certain resources, i.e. to decide which resources are more important and which are less. This is not easy as future needs are unknown or not yet recognised. Wood, for example, became less dominant in the construction sector in the last century due to the introduction of steel and reinforced concrete. Semiconductors, on the other hand, were not widely used before, but became essential in the 20th century. Also, when resources become scarce, the prices rise, which results in a decreased demand, but also in the development of substitute resources, new technologies and the discovery of new reserves.

The ILCD handbook recommends dividing the existing impact assessment methods into four categories. This also reflects the fact that there is no consensus yet what the real issue is for resource depletion. ILCD selected several midpoint and endpoint methods for a more detailed analysis [EC JRC 2010b], described below. Some of these methods were analysed in more detail in the ENSLIC guidelines [ENSLIC 2008].

Category 1 assessment methods include the first step of the impact pathway, i.e. consider the resource use itself. The characterisation is based on an inherent property of the material, such as its heating value or exergy content. Characterisation factors in this category are relatively robust, but their environmental relevance is low according to ILCD. As they do not include the concept of resource scarcity, ILCD does not regard them as appropriate approaches for expressing the impacts of resource depletion. This category includes for example the following methods.

Cumulative exergy demand

Exergy is the quality of energy or the work potential of energy with respect to environmental conditions [Szargut et al., 1988]. Exergy of a resource expresses the maximum amount of useful work the resource can provide, and hence account for both the quantity and quality of energy. In energy conversion processes, energy is conserved, but exergy is consumed, as formulated by the second law of thermodynamics. While the exergy content of electrical, chemical, kinetic and potential energy is close to the amount of energy, low temperature heat is, for example, low quality energy. Dewulf advanced the previous exergy methods and determined exergy values for a large number of energy and material resources (fossil fuels, minerals, nuclear energy, land, renewable, atmospheric and water resources) [Dewulf 2007].

The advantage of exergy vs. the traditionally used energy is – besides taking into consideration the quality of energy –, that energy and material use are accounted for on the same scale. In LCA, for instance, oil is considered either as a material or as energy consumption, depending on its use as energy carrier or feedstock for plastic production. With exergy, these energy-material trade-off problems can be resolved.

Swiss Ecoscarcity 2007 – energy

The Swiss concept of ecological scarcity allows weighting of data resulting from a life cycle inventory and thereby aggregation of various environmental impacts into a global value by using the so-called eco-factors [BUWAL 1998]. The method considers several resource depletion categories, and energy is one of them. In the method, fossil fuel depletion is characterised by the net calorific value of fuels. Renewable energy is characterised by the amount of energy produced (e.g. in case of a solar collector not the incoming solar radiation, but the amount of actually produced heat). Wood is only considered renewable if it comes from appropriate forest management.

The aggregation of environmental impacts is based on the „distance-to-target" approach: the comparison of the actual use with the target use. Current flows are obtained from the latest available data for Switzerland, while critical flows represent the scientifically supported goals of the Swiss environmental policies. A higher actual flow of a substance compared to the target value corresponds to larger environmental significance and a bigger eco-factor. Weighting factors for emissions into air, water and top-soil/groundwater as well as for energy resources are given.

Category 2 methods address the scarcity of the resource. They have a higher environmental relevance than category 1 methods, but also a potentially higher uncertainty.

CML 2002

The CML 2002 method includes non-renewable resources (fossil fuels and minerals). The characterisation factor is called Abiotic Depletion Potential (ADP). The factor is based on the resource state and the extraction rate, expressed in kilogram of antimony equivalent, which was selected as a reference material. Guinée originally only included the ultimate stock reserves in the characterisation [Guineé et al. 2002]. Van Oers extended the calculations to the fossil fuels category [Van Oers et al. 2002].

EDIP 1997

EDIP includes non-renewable resources (fossil fuels and minerals). The severity is based on the global annual consumption of a resource and the economically exploitable reserve in 2004 [Hauschild and Wenzel 1998 and 2004]. Renewable resources are only considered if the extraction is exceeded by the regeneration rate. Characterisation factors are expressed in person-reserve, i.e. the quantity of the resource available to an average world citizen.

Category 3 methods focus on the use of water. It was decided to treat water in a separate category due to the special features of its consumption and availability.

MEEUP - water

One part of the MEEUP method focuses on the use of process and cooling water. The characterisation factor expresses the amount of water used.

Swiss Ecoscarcity – water

The Ecoscarcity method distinguishes six levels of water scarcity in a given region. This is the first method that differentiates the regional severity of water availability.

Category 4 includes the endpoint methods, which consider the entire environmental mechanism from the resource use to the decreased availability and the effect on the future availability and the increased efforts to satisfy the needs.

Eco-indicator 99

One of the damage categories in eco-indicator 99 concerns resource use, which includes non-renewable resources (fossil fuels and minerals). Damage to resources is measured in “surplus energy” per kg extracted material [Goedkoop and Spriensma, 2001]. This is based on the assumption that human activity will always extract the best resources first, leaving lower quality resources for future extraction. This damage will be experienced by future generations who will have to invest greater effort in extracting the remaining resources. This extra effort is expressed as surplus energy. A reference point in the future was chosen arbitrarily as the time mankind has mined 5 times the historical extraction up to 1990. Current technologies are assumed. No characterisation factor is given for uranium [Van Caneghem, 2010].

EPS 2000

This method includes non-renewable and renewable resources. Resource depletion is normalised and weighted using monetisation. The characterisation factor is the ‘willingness to pay’, including the cost of extracting and purifying the element. It is based on future technologies.

Impact 2002+

Impact 2002+ considers non-renewable resources. The mineral depletion is modelled in a similar way as in eco-indicator 99. The characterisation factor is expressed as total primary energy, including feedstock energy for energy carriers. The surplus energy and the actual fossil fuel energy contents are directly added.

ReCiPe

This method includes non-renewable resources. For minerals, the marginal increase of costs due to the extraction of a certain amount of ore (not the elements) is considered. For minerals, the characterisation is based on the marginal increase of oil production costs. The characterisation factor is expressed as surplus costs, taking into accout that after the extraction of the easily available resources mining in the future becomes more expensive.

The ILCD guidelines on the recommended impact assessment methods for resource use are now under preparation and public consultation [EC JRC 2010c].

Other assessment methods that are relevant for the building sector include:

Land use

Land use is a form of resource use, but it is suggested to treat it as a separate category due to its special characteristics [EC JRC 2010b]. Damage is caused by the occupation ('the maintenance of an area in a particular state over a particular time period') and transformation of land ('conversion of land from one state to another state').

Cumulative energy demand (CED)

The Cumulative Energy Demand or primary energy demand uses the total energy demand expressed in primary energy for the characterisation of resource use (MJ). Energy resources that can be found in nature, such as coal, crude oil and natural gas are called primary energy resources. Their transformation into 'secondary' energy resources, such as gasoline, diesel or electricity involves losses, which depend on the efficiency and level of the transformation. Every direct and indirect (e.g. construction of infrastructure) energy input is taken into account, obtained from process or input-output analysis. It is important to distinguish between non-renewable (fossil, nuclear) and renewable primary energy use (hydro, wind, solar, biomass etc.), accounting for the regeneration rate and resource availability: consuming wood or hydro-electricity in a building reduces the resource for other consumers whereas integrating a solar collector in a building does not decrease the resource for others.

The Cumulative Energy Demand is a frequently used indicator in LCA studies on buildings. Although it only considers energy, it is a very useful indicator as it is easy to interpret and in many cases it it highly correlated with some of the emissions and impact assessment categories (e.g. global warming and acidification), which makes it a suitable screening indicator in LCA studies. It also suits well to the concept of existing building regulations. The Energy Performance Buildings Directive (EPBD), for example, requires to express all energy uses in the building in terms of primary energy, but EPBD only considers the use phase of the building. Using primary energy in LCA building studies as an indicator could help the promotion of LCA in the building sector and the integration of life cycle thinking into the building regulations.

The categories listed above assume a certain impact pathway, which there is no agreement on. They presuppose that the endpoints are the effects of the future availability and this may not be the case. There are other ways of categorizing methods for resource depletion, see for example [Finnveden et al 2009] and [Guinée, 2002].

Recommendations for further research

There is no scientific consensus on what the real issue is regarding resource use. Therefore, ILCD does not give recommendations which indicators to use at the endpoint level.

It should be decided what level of aggregation is necessary for resource use, whether one or a few indicators or a broad range of indicators for different types of resource use should be used.

ILCD does not consider the method of cumulative energy demand (or primary energy demand) as an appropriate resource indicator. However, in the building sector this is very often used for expressing the environmental impacts of buildings for the whole life cycle. As the concept is close to the existing regulations on the energy performance of buildings, by using this indicator it would be relatively easy to introduce life cycle thinking into these regulations and promote the benefits of LCA.

Harmonization is still needed regarding the split between renewable and non renewable energy sources, which is often not consistent in LCA practice and energy certification.

3.4.5 Other indicators

The focus in this project is low resource consumption. But caring only about resources would present the risk to induce other impacts. For instance reducing the fuel or gas consumption of a building by replacing the boiler by a wooden stove could produce impacts on health, a replacement by a heat pump could increase the generation of radioactive waste.

Therefore, it is advised to consider a global set of environmental indicators, including various aspects: resources, but also climate change, waste, toxicity etc... The following table proposes such a set.

Ecological sector concerned	**Problem**	**Indicators usually used in LCA buildings [ENSLIC, 2008]**	**Recommended default LCA method [ILCD]**	**Indicators in EN 15978 standard**
Resources	Depletion of abiotic resources	- Depletion of abiotic resources, CML 1992 - Depletion of abiotic resources (antimony equivalent), CML 1995 and 2001 - Cumulative energy demand total or renewable (MJ) - Surplus energy to	Example : EDIP 97 updated 2004 (quantity of resources available for an average world citizen), [Hauschild & Wenzel, 1998-update 2004]	- abiotic resources depletion potential for elements (antimony equivalent), - Abiotic resource depletion potential of fossil fuels (MJ) - Use of non-renewable resources other than raw materials (MJ, net

		extract minerals and fossil fuels (MJ) - Resource factor - Cumulative exergy demand		calorific value); – use of renewable resources other than raw material (MJ, net calorific value); – use of non-renewable primary energy as raw material (MJ, net calorific value); – use of renewable primary energy as raw material (MJ, net calorific value);– use of secondary materials (kg); – use of renewable secondary fuels (MJ);- Use of non-renewable secondary fuels (MJ);- Components for re-use (kg) - Materials for recycling (kg) - Materials for energy recovery (not being waste incineration) - Exported energy (MJ for each energy carrier)
		- Water consumption (m3)	Model as developed in the Swiss Ecoscarcity [Frischkneschl & al, 2008]	– use of net fresh water (m3);
	Land use	- Land use	Method based on Soil Organic Matter (SOM), [Milà i Canals & al, 2007b]	None
Air pollution	Acidification	- Acidification potential, CML 1992, 1995 and 2001 (kg of SO2 equivalent)	Accumulated Exceedance (AE) [Seppala & al, 2006, Psoch & al, 2006]	Acidification potential of land and water (kg SO2 eq.);

	- Winter smog	- Winter smog, CML 1992 and 1995		None
	Summer smog	- Photochemical oxidant formation (summer smog), CML 1992, 1995 and 2001 (kg of ethylene equivalent)	LOTOS-EUROS method (POCP) as implemented in ReCiPe [Van zelm & al, 2008]	– formation potential of troposhperic ozone photochemical oxidants (POCP, kg Ethene eq.).
	Odour	- Odour, CML 1992 and 2001 (m3)		None
	Ozone depletion	- Ozone depletion potential, CML 1992, 1995 and 2001 (kg CFC-11 equivalent)	- Ozone depletion potential 2001, based on the WMO 99 data	– depletion potential of the stratospheric ozone layer (ODP, kg CFC11 eq.);
	Global warming	- Global warming potential, IPCC, 1994, 2001 (kg CO2 equivalent)	Global warming potential, IPCC 2007	Global warming potential, (kg CO2 equivalent)
Water pollution	Euthrophication	- Euthrophication, potential, CML 1992, 1995 and 2001 (kg of PO_4^{3-} equivalent)	Accumulated Exceedance (AE) [Seppala & al, 2006, Psoch & al, 2006]	– eutrophication potential (kg PO_4^{3-} equivalent) ;
	Ecotoxicity	- Aquatic eco-toxicity, CML 1992 and 2001 (kg of 1,4-dichlorobenzene equivalent)	Usetox consensus model [Rosenbaum & al, 2008]	None
Soil pollution and waste	Soil pollution	- Terrestrial ecotoxicity, CML 1992 and 2001 (kg of 1,4-dichlorobenzene equivalents)	Accumulated Exceedance (AE) [Seppala & al, 2006, Psoch & al, 2006]	None
	Waste	- Amount of solid waste (kg) - Amount of radioactive waste (m3)		- non-hazardous waste disposed (kg); – hazardous waste disposed (kg) – radioactive waste disposed (kg)

Damage to health		- Human toxicity, CML 1992 and 2001 (kg body weight) - Heavy metals, CML 1995 (kg body weight) - Carcinogenics, CML 1995(kg body weight) - Disability Adjusted Life Years, (DALY) Ecoindicator 1999 - Ionising radiation, CML 2001	- Disability Adjusted Life Years, (DALY) Ecoindicator 1999	None
Ecotoxicity and damages to biodiversity		- Depletion of biotic resources, CML 1992 and 2001 - Impacts of land use, CML 2001 - Potentially Disappeared Fraction (PDF), Ecoindicator 1999	- Potentially Disappeared Fraction (PDF), Ecoindicator 1999	None

Some ILCD recommendations might be irrelevant in the building sector, and some deeper studies may be done. The recommendations may depend on the level chosen for the indicator (midpoint or endpoint). This kind of choice may depend on the goal and the public of the study. There exist also ILCD recommendations for human toxicity at the midpoint level (not shown here), as for the ecotoxicity.

Recommendations for further research

Beyond the resource topic, toxicity and biodiversity are becoming essential issues of concern. The use of damage oriented indicators will therefore become necessary to inform clients about the environmental performance of buildings. Such information requires a more precise description of buildings, and more precise LCI data about products. The elaboration of a comprehensive but not redundant set of indicators is also needed.

3.5 Consultation of tool developers

A first draft of the good practice report (D3.1) has been circulated among Building and construction specific LCA tool developers in Europe and other countries (e.g. Canada, USA, Australia). Feedback has been collected, and the document has been adapted to produce the final version.

3.6 Suggestions for further research topics

The main knowledge gaps and research activities identified are summarized in the table hereunder.

Knowledge gap	Research activities
Reliability of Building LCA, Possibilities to simplify Building LCA and corresponding uncertainties	Uncertainty analysis regarding cut off rules, simplification of life cycle inventories, regional contextualisation for missing data possibility to reduce the uncertainty using Input-output analysis
Effects of temporal variation	Development of dynamic LCA to account for temporal variation of parameters and technical innovation
Relationship between the studied system and the background system	Development of a harmonized method to model the background system, e.g. using an impact matrix Development of consequential LCA in the construction sector
Effects of indoor emissions	Study models allowing indoor emissions to be accounted for in Building LCA, and protocols needed to produce the data corresponding to such models Perform studies to validate these models.
Biogenic CO_2 balance	Develop models to account for biogenic CO_2 at the different life cycle stages (biomass production, carbon storage in buildings, end of life processes) as well as corresponding LCI data
Modelling recycling processes	Harmonization of models by implementing the recommended system expansion approach
Relevant set of environmental indicators	Follow up of ILCD recommendations regarding end point indicators (resources,

	human health and biodiversity) Harmonization between LCA and EPBD indicators on energy
Applying LCA to neighbourhoods	Definition of functional units Including biodiversity, urban agriculture and transport related issues
Applying LCA to roads and other infrastructures	Definition of functional unit System boundaries Specific LCI for construction and renovation techniques Use of scenarios (traffic, renovation...)

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