LoRe-LCA

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

Report on scenarios for LCA in constructions

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Executive Summary

The concepts of scenarios and scenario dimensions as they are used in life-cycle methods applied to buildings are examined in this report. In the report a scenario is defined as a comprehensive description of future states. It is further assumed that any given scenario is expounded by the use of several scenario dimensions within the scenario in question. A “scenario dimension” is defined as a specific variable by which (in combination with other scenario dimensions) a scenario is described.

The scenarios and scenario dimensions considered in this report are those that are developed specifically for use with the life-cycle methods used to evaluate life-cycle environmental impacts that are elsewhere examined in the LoRe-LCA project. Scenarios and scenario dimensions are analyzed in terms of a scenario typology based on that established by (Borjeson, Hojer et al. 2006) and shown in Figure 1.

The following scenario dimensions relating to the following specific life-cycle features have been analysed in isolation:

- Building alternatives

- Building lifetime

-Lifetime of exchangeable building elements

-Renovation scenarios

-Energy demand during use-stage of the building

-Type of energy used during the use-stage of the building

-Occupant related impacts

-End-of-life

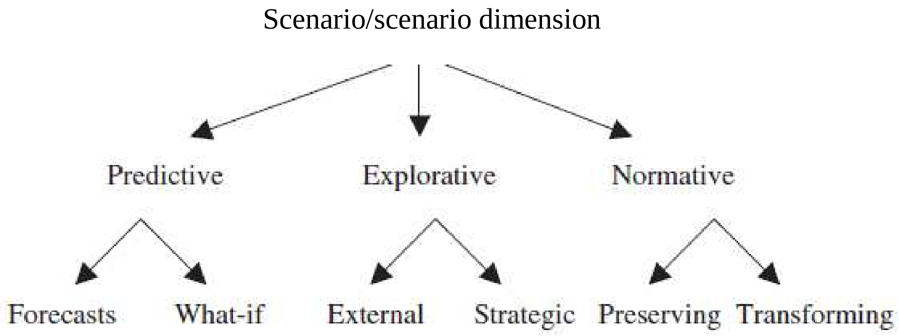


Figure 1: Scenario typology according to (Borjeson, Hojer et al. 2006).

Application of this kind of scenario analysis to life-cycle methods seems very novel, and the report can therefore be seen as an introduction to how such analysis may be carried out, at the same time it seems that it is an important area of research that deserves more attention from the point-of-view of improving and increasing the application of life-cycle methods in real building projects. This may be done by defining the scenario for the project in question very specifically according to the goal and the scope for the life-cycle study that is carried out as part of the project development.

According to such a method of analysis and the cases studied, the following recommendations have been established:

The studied cases show that there are 2 ways of interpreting building alternatives that are analysed in the case studies. On the one hand they are clearly cases of predictive what-if scenario dimensions, (in the sense that life-cycle methods are used to compare environmental impacts from building alternative A with building alternative B etc.), meanwhile on the other hand, they may be considered as somewhat normative in the sense that building alternatives may be established with the goal of meeting specific regulatory requirements or requirements of a certain environmental rating tool.

Assuming that we are interested in environmental impacts per year, the extent to which it is important to accurately specify the lifetime of a building depends on the relative magnitudes of the impacts from material production, construction and use stages. In the studied cases the value of the scenario dimension often varies between 50-80 years based mainly on a technical perspective on lifetime. Notable is that also when studying refurbishment choices of an existing building, 50 years are used. In light of the fact that from many different directions impacts during the use stage are set to decrease, the effect that an accurate specificationof this variable is only set to increase. Predictive methods that may be employed with advantage are those that have been applied in van Nunen & Mooiman (2011).

A similar argument may be applied to separate exchangeable elements, although conditioned with the proviso that the total impacts from exchangeable elements seems according to evaluated cases to be less than for the lifetime of the building as a whole. It could be argued that for example for commercial buildings, the economic lifetime of certain building elements should rather be considered than the technical which is the current case.

Energy demand may be able to be modeled with some accuracy with advanced modeling tools using a predictive scenario technique. Better scenarios based on behavioral studies may be necessary to better account for the effect of non-technical aspects, particularly user behavior, but also the development of process energy demand over the lifetime of the building.

Type of energy is very significant when considering impacts such as global warming potential. The complexity involved in elaborating future scenario dimensions related to energy mix that are relevant is huge. Here it has been noted that the use of explorative scenario dimensions relating to institutional and political factors may be interesting, as long as such scenarios can be established in a way that is suited to the building project e.g. where such scenario dimensions are generated on a regional basis and that these dimensions can be used for each and every building project in a given region.

Finally, end-of-life is a life-cycle stage that is associated with the most uncertainty, and here it is useful to use explorative scenario dimensions also to describe possible outcomes in the light of this uncertainty. It is also an area in which future research is needed.

Several of the scenario dimensions discussed in the report may be increasingly important to better elaborate if the operational impact of the building tend to be low (mainly due to low-impacting energy mix and/or high energy efficiency standard). In such cases, the impact related to material use will have a proportionally higher importance and scenario dimensions related to material-related issues may be more relevant to elaborate in a better way. Such scenario dimensions include life time of both building and exchangeable building elements, renovation and end-of-life scenario dimensions in particular.

In addition, and cross-cutting for all the identified life-cycle features analyzed, is that in considering the kind of scenario that should be applied, it is very important to take into consideration the goal and scope of life-cycle method as it is applied in each case. In this report the different scenario needs according to “what-if” and normative types of building alternatives are contrasted. In general, whilst normative building alternative dimensions seem to require higher accuracy and precision in generation of scenario dimensions, it is stressed that such requirements need to be evaluated on a case-by-case basis.

Recommendations for significant issues to consider and use of different types of scenario and scenario dimensions for specific purposes or contexts is briefly outlined in the report but recommended to be further elaborated for use in practical cases.

Purpose and scope of Work Package 4

The main objective of WP4 is to collect experiences on national, European and International level of use of LCA in design processes. The WP is aiming at finding examples where active use of LCA and environmental assessments has resulted in more sustainable constructions.

The WP covers a number of different case studies, both the use of LCA tools in practical examples, in cooperation with architects and others involved in the process, and case studies for more specifically study LCA features which were pointed out as important and problematic by WP3 of this project. One such feature includes the use of different scenarios in LCA´s of buildings or building-related products. WP4 will also collect and analyse information on how different scenarios are treated in different case studies, which is the aim of the present deliverable D4.2

1 Introduction

The aim of this particular deliverable is to deepen one of the methodological issues brought up in WP3, that is the use of different scenarios for LCA and life-cycle methods in constructions. Scenarios (or descriptions of future states) are necessary when making life cycle calculations since these aim to describe the future potential environmental impacts of the systems studied. The choice of scenarios has a large impact on the LCA result and therefore it is important when alternatives are compared.

There is a wide span between tools that are fixed regarding scenarios or do not cover life cycle stages in which scenarios are necessary – to the generic LCA tools (like SimaPro and Gabi) in which all scenarios are created in the tool by its user for the particular purpose. In between there are tools in which it is more or less possible to treat scenarios in different ways.

In the following, different scenarios when carrying-out LCA´s of buildings and construction works is discussed and current practice and experiences are described. To what extent and how scenarios are treated in different building LCA tools will be described. The use of scenarios is further discussed for example in relation to different purposes of LCA. The descriptions here are based on both the authors´ experiences of using different LCA tools for buildings as well as how different scenarios are treated in referenced case studies and other literature. A particularly important question here is the extent to which the features of the scenarios developed affect the decision making process when using LCA and life-cycle thinking in a construction project.

Below follows processes/activities for which the future have to be described in one or more scenarios in order to enable calculations of the total life cycle impact during the building life time. Each section starts with giving a short description of why scenarios may have to be made and then follows a description on how scenarios are commonly treated in tools and case studies.

After this introduction, this report briefly introduces a hierarchy of scenarios and scenario dimensions, and a typology that will be used to analyse the use of scenarios and scenario dimensions in LCA. Subsequent sections deal with specific scenario dimensions that are used in scenarios that are used in LCA and life-cycle methods. Dimensions are divided between issues connected to operation and maintenance and issues connected to end-of-life in LCA and life-cycle thinking.

2 Scenarios and Scenario Dimensions in Life-cycle methods for buildings

2.1 Scenario terminology used in this report

The report is written assuming the following meanings of the following terms:

“Scenario”: “a comprehensive description of future states”.

"Scenario dimension": "A specific variable by which (in combination with other scenario dimensions) a scenario is described". Often abbrieviated to just "dimension".

In the current report we have considered the following *scenario dimensions*:

- Building alternatives

- Building lifetime

-Lifetime of exchangeable building elements

-Renovation scenarios

-Energy demand during use-stage of the building

-Type of energy used during the use-stage of the building

-Occupant related impacts

-End-of-life

To generate a *scenario* based on the above *scenario dimensions*, each of these *scenario dimensions* shall be defined according the wishes of those creating the *scenario*. These definitions imply that a complete *scenario* involves a complex specification of information (through each scenario dimension) about many different features of the future as it relates to the life-cycle method in question. In this report, we are chiefly concerned with the content that makes up each of the scenario dimensions presented above.

It is suggested that in elaborating a scenario in such a way, it is intimately connected to the goal and scope established by the LCA in question.

2.2 A typology of scenarios

To facilitate a rewarding analysis of the way in which scenarios are used today in building projects with expressed environmental goals, and in life cycle assessment for buildings, in this section we introduce a methodology for analysing scenarios. This typology is based on (Borjeson, Hojer et al. 2006) and is shown in Figure 2 below.

Such a typology of scenarios is useful for research in the field of futures studies, and examples of its application can be seen in e.g. (Larsen and Gunnarsson-Ostling 2009). From the perspective of the LoRe-LCA project, such a typology provides a useful framework with which to analyse the way in which scenarios and scenario dimensions are used in LCA for buildings and other building projects with high environmental goals.

Figure 2 shows a two-tiered structure of the scenario /scenario dimension typology. In the first tier, scenarios/dimensions are analysed according to the logical modality of the question that is answered in the scenario/dimension in question. To begin with, predictive scenarios/dimensions answer the question "what *will* happen?" Meanwhile explorative scenarios answer the question "what *can* happen?” Further, normative scenarios deal with the question “what *is necessary* such that an established norm (i.e. goal) can be achieved?”

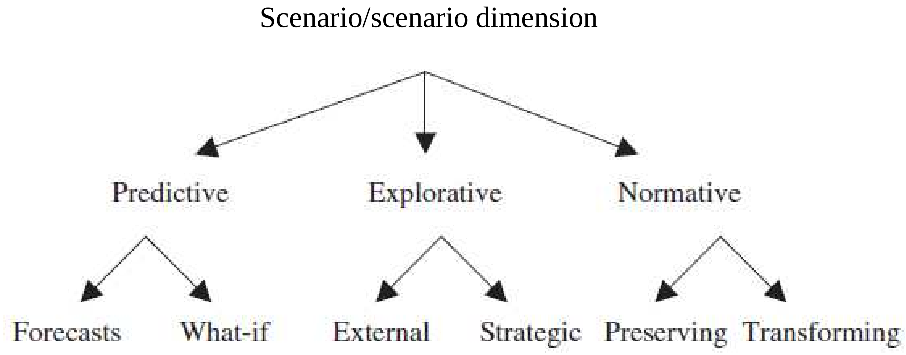


Figure 2: Scenario typology according to (Borjeson, Hojer et al. 2006).

As also shown in Figure 2(Borjeson, Hojer et al. 2006) the second tier of the typology divides each modality into two further groups, explained below:

Predictive are forecasts when the *most-likely* scenario based on a set of well-established initial conditions (present states and presently observed processes) in generated. A predictive what-if scenario/dimension is generated according to essentially the same methodology, with the difference that such a scenario is used to describe a future based on well-established initial conditions in combination with the outcome of a near-term future event of particular significance. LCA for buildings may be interpreted as a what-if scenario description when comparing the environmental impact of one possible building design with another possible design (this is elaborated further in 3 Building Alternatives).

In general, an explorative scenario/dimension differs from the predictive based on the difference between the modal sense of *likely* and *possible*. Such a modal focus makes it possible to extend the range of a scenario to future states that may occur based on *changes* between present and future that cannot be strictly justified based on observed and well-established initial conditions. Having said that, the power of explorative scenarios/dimensions resides in the fact that in complex systems future developments with major consequences are sufficiently unpredictable that an explorative approach yields information that is not *accessible* with a predictive approach. An explorative approach consequently aims at establishing a *set* of scenarios/dimensions differing based on a wide range of quantitative and qualitative parameters. A further relation between predictive and explorative scenario work that (Hojer, Borjeson et al. 2006) point out is the fact that in the set of scenarios that an explorative approach generates, the reference scenario/dimension is often still generated according to a predictive approach. It is this expansion from considering only one scenario/dimension of a predictive nature to considering many scenario/dimensions in an explorative way that may be the most interesting feature of this typology with respect to how scenarios/scenario dimensions in life-cycle methods for buildings.

The second tier of classification in Figure 2 divides explorative scenario/dimensions between external and strategic types, where strategic types describe factors that are within the sphere of influence of the scenario user, and external types factors outside this sphere. Again, this is clearly not a mutually exclusive bifurcation, rather it is important to be able to distinguish between internal and external features in generation and scenario use. Furthermore, often sets of external scenarios may be developed for use as a test bed for an organisation's (internal) strategic decisions. On this last point see e.g. (Van der Heijden 2005). Indeed, the separation between strategic and external scenarios/dimensions is not one that will be important for the current analysis.

In the final tier 1 category type in Figure 2, normative scenarios have the specific aim of meeting an established future target in a near or distant future. The second tier subdivision shown in Figure 2 is between preserving scenarios on the one hand and transforming on the other. In a preserving scenario, the specifically identified future goal is achieved with minimal changes to underlying institutional structures, and (Hojer, Borjeson et al. 2006) denote these as *optimising* scenarios (our italics), where the question that is answered is how do I optimally (often from the point of view of an economic optimum) achieve a certain societal goal. Such a type of normative scenario is related closely to a predictive scenario, and in the case of aiming towards long-term goals suffers from the same problem, namely that such methodologies do not give sufficient weight the issue of future uncertainty. Needless to say preserving scenarios are of significant use for understanding paths to short- and near-term goals.

Preserving scenarios are contrasted in Figure 2 with transforming scenarios, where it is understood from investigation of the well-established initial conditions that the established target in the normative scenario cannot be reached without a *transformation* of the underlying structure of society. An example of such a study is description of the transport and mobility system meeting 2050 climate change targets described in (Akerman and Hojer 2006).

2.3 Application of scenario typology in this report

In section 2.1 we have delineated between a scenario (as an all encompassing description of the future) and scenario dimensions (descriptions of specific features in the overall scenario).

Meanwhile, in section 2.2 we have presented a typology that can be applied in scenario analysis.

To avoid confusion, it should be mentioned that the terminology of section 2.2 may be equally applied to scenarios as to scenario dimensions (as defined in section 2.1).

(Åkerman 2011) points to a similar application in other scenario generation work where scenario dimensions may belong a particular type as shown in Figure 2, whilst the overall scenario of which that particular dimension is a partial description may be of a different type. An example mentioned by (Åkerman 2011) is the use of a *predictive scenario dimension* for global energy supply in (Akerman and Hojer 2006), as a part of a *normative transformative scenario* for a sustainable transport system for Sweden.

That different types of scenario dimension for different types of information may be included in the same scenario is important to be aware of in analysing the methods used in construction projects described in this paper.

3 Building alternatives

The term "building alternatives" in this case is used to refer to those alternatives that are often the focus of the life-cycle method in question, where the life-cycle method is used to answer the question "what will the overall environemental impacts from building alternative x be compared with building alternative y, z, ... n?"

Such a question seems naturally to fall under the classification "what-if" according to the typology presented in Figure 2.

An example of this application comes from a case study reported in deliverable 4.1 concerning the renovation of apartment buildings in Mallorca, Spain, where the range of alternatives considered here are as follows:

a) Existing building,

b) Refurbished building including all the environmental improvements in order to achieve at least a 50% reduction of environmental impacts,

c) Refurbished building according to the standard practice (almost no target or environmental improvement).

d) Construction of new building under the current regulations. This scenario was only considered in certain life cycle stages with the aim of obtaining a broader comparison.

e) Demolish and rebuild under current regulations.

Likewise, (Wallhagen, Glaumann et al. 2011) describe a case-study for an office building in Sweden. Using the life-cycle based tool ENSLIC (Malmqvist, Glaumann et al. 2011), the resulting greenhouse gas emissions calculated on a life-cycle basis are calculated for a total of 12 separate measures that reduce the building's energy demand, where each separate measure may be judged a what-if scenario.

The Hungarian examples from deliverable 4.1 also present some very clear "what-if" comparisons in the different renovation measures that are presented and considered. Further examples are what-if scenarios such as the life-cycle cost calculations given in (Brown, et al., 2011).

Having pointed out the significant "what-if" character of the building alternative scenario dimension, it should here be pointed out that many building alternatives may also be described as normative *at the same time* given the fact that building alternatives may be drawn up to achieve specific established goals. That is to say that building alternatives are drawn up with the aim of fulfilling certain goals, e.g. 50

% reduction in bought energy demand, to meet building code, or to meet the requirements of a specific environmental rating tool.

4 Life time

The choice of anticipated life time may be discussed. Regarding buildings, it could be argued that it should depend on the type of building and where it is situated. Due to the impossibility of knowing how long a building will stand for, practice has evolved suggesting the use of a lifetime between 50-80 years. Depending on the type of conclusions drawn in the study, a number of lifetimes may be tested.

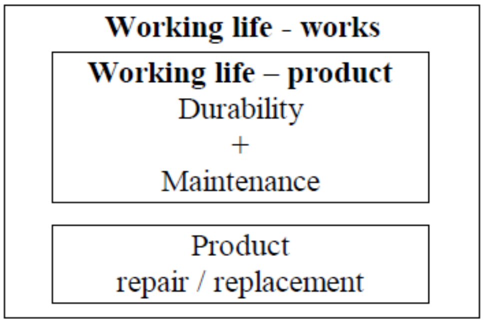
Furthermore, buildings contain a multitude of separate elements (e.g. windows, doors, internal walls, external walls, floor coverings etc.) each of which will have its own lifetime, separate from the lifetime of the entire building. In carrying out an LCA study of a building it may therefore be necessary to take into account a multitude of different lifetimes for a given element or group of elements.

(European Organisation for Technical Approval, 1999) for example gives the following definitions for working life of works and construction products (see also Table 1 and Table 2) :

Working life of works - the period of time during which the performance of the works will be maintained at a level compatible with the fulfilment of the Essential Requirements (mechanical strength and stability, safety in case of fire, hygiene, health and environment, safety in use, protection against noise, energy economy and heat retention).

Working life of products - the period of time during which the performance of a product will be maintained at a level that enables a properly designed and executed work to fulfil the Essential Requirements (i.e. the essential characteristics of a product meet or exceed minimum acceptable values, without incurring major costs for repair or replacement). The working life of a product depends upon its inherent durability and normal maintenance.

Table 1: Relation between working life of works and working life of a product according to (European Organisation for Technical Approval, 1999).



In the subsections below, the lifetime of an entire building is discussed separately from the lifetime of building elements.

4.1 Lifetime for entire building

In the case studies of this project, the calculations have normally been done for a lifetime between 50 and 80 years. For example, the ELP tool used for Hammarby sjöstad in Sweden (see more in deliverable D4.1) used 60 years for buildings, which was a decision taken by the tool developer alone based on literature (see, for example (Malmqvist, et al, 2011a)). Since the ELP tool was used in Hammarby sjöstad for also calculating impacts related to other construction works than buildings, the life time of 60 years can be questioned. It should probably be longer especially if holding the opinion that roads cannot be considered to have an end-of-life stage.

Most current LCA tools for buildings however enable the tool user to select the used anticipated life time which is adequate in order to adapt this scenario dimension to the purpose of the study and the type of building or construction works studied. This is the case for example for the tool that has been used in one of the French case studies described in deliverable D4.1, EQUER, where a user may typically define the lifetime of the building as between 60 and 80 years. EQUER also allows for users to perform sensitivity analyses for the lifetime of the building. In the case study of an educational building described in deliverable D4.1, a building lifetime typical for an educational building has been used. In many tools, for example the Swedish EcoEffect tool, the user can define any life time.

In Spain a building's lifetime of 50 years is often used as a default value since it is judged difficult to foresee the real lifetime. However the lifetime presents significant differences depending on the country and the type of building. In the Spanish case studies included in deliverable D4.3 there is a section including a sensitivity analysis for the building's lifetime. Different lifetime values have been considered: 25, 50, 75, 100 and 125 years. In order to achieve comparability of the results, the annualized impact has been assessed. This study showed that for the house in question global warmning potential (gwp) decreased from about 3.8 t CO_2-e/year to 2.95 t CO_2-e/year for a building lifetime of 125 years, a decrease of approximately 25 %.

Meanwhile, in a Swedish case study included in LoRe-LCA deliverable 4.3 it was shown that the total global warmning potential per year was decreased by up to 40 % when changing the lifetime from 50 to 100 years. In this case this was very much due to the fact that impacts from the use phase (in this case based solely on gwp impacts from bought energy demand) were so low due to the fact that the building project in question will be supplied with 100 % renewable energy.

In the case study for the family house in Szombathely reported in deliverable D4.3 a lifetime of 80 years was taken into consideration for the whole building. The sensitivity analysis of different life spans for the same building is given in Deliverable 5.2 of the LoRe-LCA project. Meanwhile, (Wallhagen, Glaumann et al. 2011) for Swedish cases also assume a lifetime of 50 years, referring to the fact that this is a value used in other life-cycle studies of buildings.

The life span of buildings in German cases is for 50 years in general, and building regulation in Germany requires that the minimum durability of buildings must be at least 50 years. In one German case study included in deliverable D4.3, LCA calculations were performed for different refurbishment alternatives of existing buildings. In these cases it naturally does not make any sense to calculate the environment impacts for a 50 year life span since the date of construction. In these cases, calculations instead covered 50 years further life time starting from the point of declaration day. It can perhaps be conceived as a bit peculiar to be using 50 years both when assessing a new building to be constructed and an existing building to be refurbished. It says something about that the choice of 50 years often is related to a life time which can be argued to be technically possible but still not as long as all other assumptions and scenarios modeled in the study are not becoming too uncertain.

4.1.1 Possible methods for determining the life of an entire building

The lifetime of an entire building is of course a complex issue. Firstly, it is necessary to distinguish between a technical life and an economic life, according to the subheadings below.

Technical lifetime

The technical lifetime is considered first, and it is this lifetime that seems to be considered most in LCA work that is carried out. Such an interpretation of lifetime also seems to be that which is considered in (European Organisation for Technical Approval, 1999), as shown in Table 1. Before defining a technical life of an entire building, it is necessary to describe what is meant by the notion of an entire building, in light of the fact that various renovation, extensions and changes may be performed throughout the lifetime of any given building. It is suggested that in considering an entire building we consider the technical life of the components in the building that are irreplaceable for the building, and that this usually refers to the load-bearing structure in its entirety. As such the technical lifetime of the building may be considered the time over which the load-bearing structure of the building fulfils the load-bearing function for which it was established. Such a notion necessitates periodic renovation of building components that have shorter lifetimes.

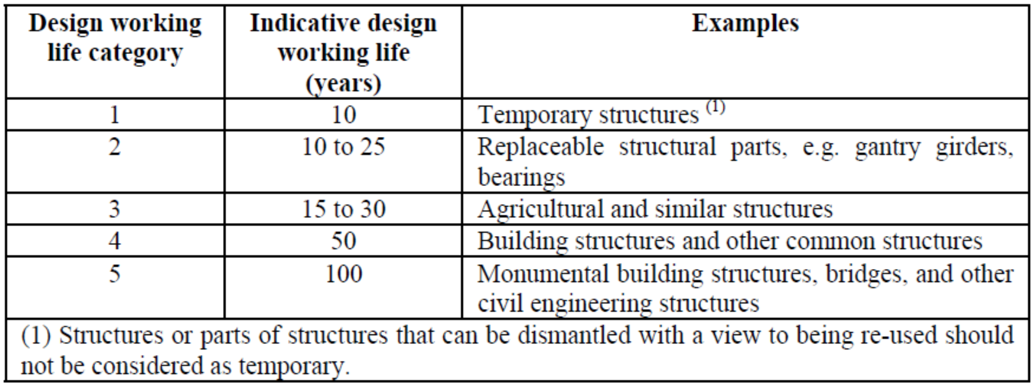
Literature sources debate which period to take into account in the calculation of the life-cycle environmental impacts. According to certain literature, the physical lifetime of residential buildings with solid/massive constructions is assumed to be between 60-100 years:

The results of Quack [Quack, 2001] showed that it is sufficient to consider a period of 40-60 years in the life-cycle assessment of buildings without compromising the results. Note that in this case, the end-of-life phase is truncated, which, taking into account the uncertainties related to the disposal of materials in the future, is a pragmatic but meaningful step. This issue is discussed further in the section specifically on End-of-Life below.

Oswald [Oswald, 2003] distinguished between the technical life of a building and the useful life without major alterations. The technical life span determined by the structure was defined as 100 years, while one use phase without major alterations was 40 years. The periodicity of renovations is discussed further in the section about the technical life of separate building elements.

Shown in Table 2, (European Organisation for Technical Approval, 1999) and (European Commission, 2004) establish guidelines for a design working life of differing infrastructural objects, suggesting 50 years for buildings and common structures.

Table 2: Indicative design working life for different structures depending on their functions (European Organisation for Technical Approval, 1999), also included in (European Commission, 2004).



Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures (1)
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures
(1) Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.		

Meanwhile, The standard ISO 15686 Buildings and constructed assets – Service-life planning (see for example (International Organisation for Standardization, 2000)), while giving detailed information as to a system for determining service lives *on a component level*, gives relatively little information on how the lifetime of a whole building may be determined. The section below described the methods recommended for describing the lifetime of components. In order to establish a lifetime of a given entire building based on these, it is suggested that the lifetime of the building is set to the shortest of the Estimated Service Life of a Component (ESLC) of the components that make up the buildings load-bearing structure, where the ESLCs are established based on the procedures described in ISO 15686-1 and ISO 15686-2. The use of such a methodology and referral to said Standards seem however to be lacking in the assembled examples of LCA use in practice. Contact with manufacturers in Sweden carried out as part of the case study included in LoRe-LCA deliverable D4.3 suggests that this may be due to the fact that application of the methodology itself is not sufficiently widespread amongst practitioners.

Referring to a question raised in the introduction to this report, it is not altogether clear how the accurate lifetime of the building as a whole will impact the recommendations of a life-cycle method, and in turn how that will impact the decision making process of which such an analysis is a part. Where essential building components in 2 possible what-if alternatives that are being compared seem to have comparable lifetimes, it seems that it is not of such great importance exactly what the chosen lifetime for the whole building is, as long as it is the same reasonable assumption (such as those above) in the 2 alternative what-if scenarios. This may be the case for example comparing 2 types of construction with inert non-organic material such as brick, stone or concrete. Having said that, it may be more important if it is intended to compare construction materials such as concrete and wood, or when comparing specific heating technologies in a life-cycle cost calculation. Such considerations are treated more specifically in Section 0.

Economic lifetime

As mentioned at the beginning of section 4.1.1 as well as defining a building's lifetime technically, it can also be defined in economic terms. This is interesting in light of the fact that in certain cases buildings with a technically sound load-bearing structure are no longer economically profitable. In Sweden in small towns and municipalities from which the population is migrating to large cities, certain apartment buildings can no longer be rented out due to the decreased population, and are consequently not economically viable. The building that is the focus of the Kungsbrohuset case study, presented in deliverable 4.1 of this project, was constructed in place of a building (built in the 1980s) that had been demolished not due to failure of the building structure, but due to the perceived bad indoor environmental quality, which had as a consequence that it was not valued highly economically.

Furthermore, considering the time value of money, the length of time over which actors today are interested in future cash flow is limited. For example, sometimes a lifetime may be set to the official amortization time, which is normally 50 years for residential buildings in Hungarian cases. (Brown, et al., 2011) uses a period of 50 years in investigating life-cycle cost for renovation measures.

4.1.2 The importance of describing an accurate building lifetime

What-if Scenarios dimensions for two alternatives with functional equivalence

Absolute environmental impacts are of course of principal importance from the point of view of environmental performance. In this section, however, a simple method is proposed to determine the importance of an accurate lifetime description for providing support in deciding between two or more proposed alternative buildings with functional equivalence.

In understanding this, specific variables can be identified in application of the life-cycle method that, from case to case may be useful in comparing alternatives and the importance of the lifetime in making this comparison:

- Absolute environmental impacts from irreplacable materials
- Yearly environmental impacts due to the operation phase (principally energy)

In a review article, a comparison has been made by (Sartori and Hestnes 2007) of studies where such a procedure has been carried out, where some of the results of which are shown in Figure 3. In this figure each straight line represents the cumulative impact (in this case primary energy demand) due to a particular building (where each building is comparable to the others in terms of functional equivalence). In such a figure, the intersections between the straight lines represent the building lifetime at which two given buildings have the same total environmental impact. It can be seen in the figure that for all cases considered, between construction and a lifetime of 80 years, intersections only occur at lifetimes of up to about 25 years, which is a considerably lower age than the building lifetimes considered in the examples given above (in spite of the relatively wide range).

Another such analysis has been carried out, based on data from ((Wallhagen, Glaumann et al. 2011) for renovation measures on an existing office building, shown in Figure 4. In this case the indicator in question is cumulative global warming potential, ton CO_2-e. Applying the same analysis as above, it can be seen that if such a life-cycle method is to be used to provide support for decision making between what-if scenarios, then in the cases shown in Figure 4 the building lifetime should not significantly affect the final decision since there are no intersections between lines that occur at any reasonable lifetime.

A final note on this method is that the examples shown in Figure 3 and Figure 4 only take into account 2 possible indicators, and in the application of an LCA methodology, many indicators are used. Such a method may advantageously be used to provide decision support in a full LCA methodology where a particular weighting methodology or other such multi-criteria decision analysis is applied.

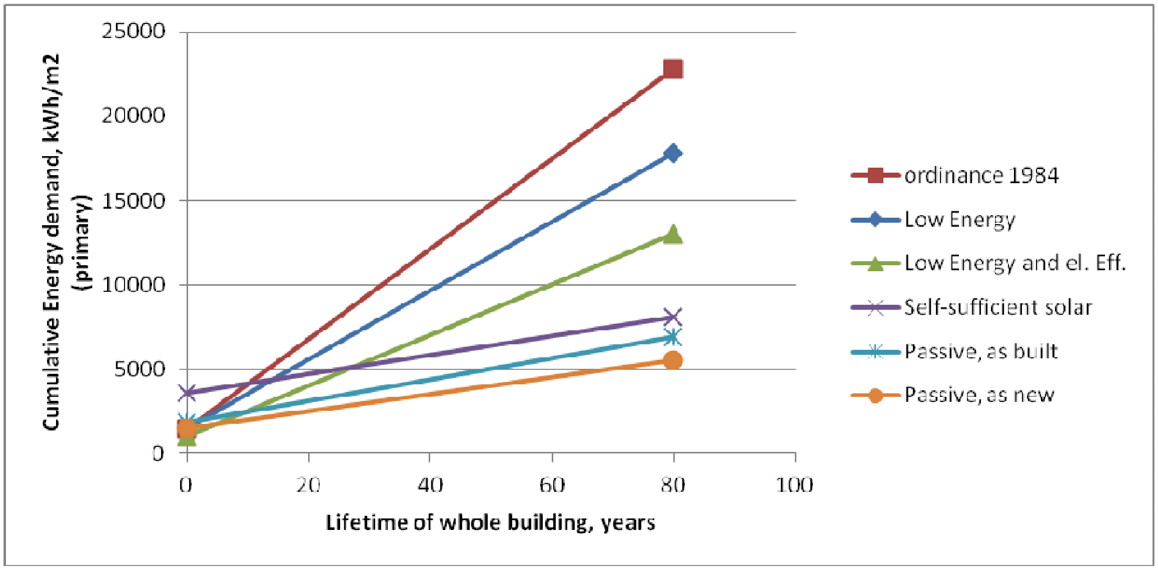


Figure 3: Cumulative energy demand for different designs of a comparable building as presented in (Sartori and Hestnes 2007).

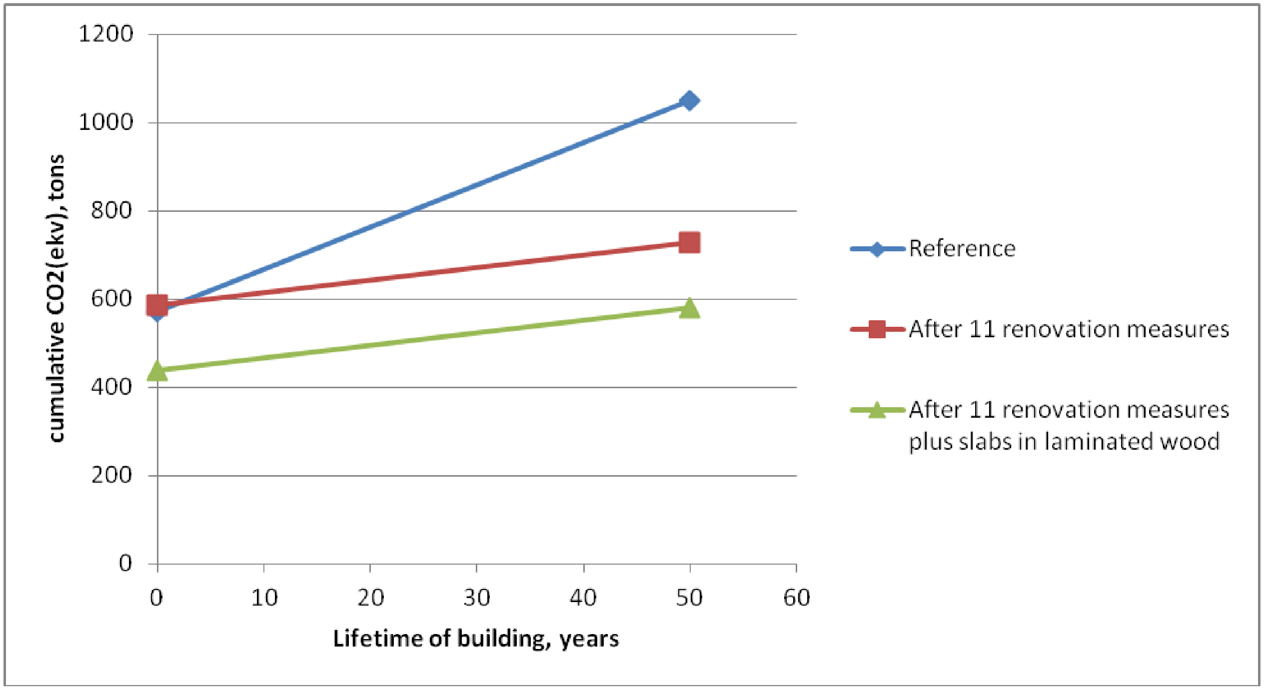


Figure 4: Cumulative greenhouse gas emissions due to a building with different renovation measures applied from (Wallhagen, Glaumann et al. 2011).

In determining absolute environmental impacts

When life-cycle methods are employed for purposes other than that described in the previous sub-heading, such as evaluating the total environmental impacts of a building stock in a given municipality, the absolute environmental impacts are important. Here, it is interesting to consider the examples shown in Figure 3 and Figure 4 again. In particular, in Figure 3, it seems that at reasonable building lifetimes, say 40 years and upwards, the cumulative absolute impacts (in terms of primary energy) are well-represented by the approximation that they are directly proportional to the building lifetime (i.e. the impacts before the use stage can reasonably be neglected). Therefore the yearly impact can be well-approximated by the operational impacts alone (i.e. the impacts due the energy demand for building operation) and are independent of whatever reasonable assumption may be made for the lifetime of the building.

Having said that, when we start to consider other impact categories and other types of building, such an approximation no longer seems to be reasonable. This can be seen primarily for the building alternatives in Figure 3 titled self-sufficient solar; passive, as built; and passive, as new. Here, the yearly operational impacts are low enough relative to the embedded impacts, that the total impacts will be noticeably and arguably significantly different if we assume a lifetime of 40 years or a lifetime of 80 years. This argument becomes even clearer when considering results from (Wallhagen, Glaumann et al. 2011), shown in Figure 4 and the Swedish case study on the Väsjön development in deliverable D4.3. In these cases, the yearly operational GWP impacts are very low compared to the embedded impacts due to the building as a whole (by way of explanation, the low operational impacts seen are due to the fact that operational energy from the building in question comes from largely CO_2 neutral electricity (so-called Swedish electricity mix) and the municipality of Gävle’s and Sollentuna´s, respectively, district heating mix where biofuel is used to a large extent).

In a wider context, buildings in the future will be built with the aim of reducing operational energy demand (see for example (European Parliament, 2010)), such as the cases self-sufficient solar; self-sufficient solar; passive, as built; and passive, as new; in Figure 3. Therefore, in buildings that will be constructed in the near future, an accurate specification of the building lifetime will be very important in understanding the absolute environmental impacts from that building.

As also mentioned under the previous sub-headings, Figure 3 and Figure 4 represent only 2 (albeit important) of the multitude of indicators that are analyzed in LCA. Therefore, it is a question for further research how the analysis above may be applied to weighted LCA impacts.

As far as technical lifetime is concerned, studies seem to agree that a lifetime of 50 years is *a minimum value* for building lifetime. It seems that often lifetimes somewhat longer are used, but never shorter (for “normal” buildings). Having said that, observations of current infrastructure suggest that building technology, at least from the start of the 20th Century, and arguably from the start of the 19st Century seem sufficiently durable that lifetimes considerably greater than 50 years, and possibly greater than 100 years are in fact more realistic than current assumptions. Such a statement with respect to single-family homes in the Netherlands is supported by recently reported research by (van Nunen H. and Mooiman A., 2011). On the other hand in growth regions and especially regarding commercial buildings, shorter life times are more common due to economic reasons. In such cases, it can be argued to use economic life times instead.

4.2 Lifetime of building components

Having conceived a scenario where the varying lifetimes of building elements will be taken into account, a primary question is the delineation that will be used to separate the entire building will into separate elements for analysis. Here the LoRe-LCA case studies give many examples of how this work may be carried out, as described below:

In the French LCA tool EQUER, for example, the building is decomposed into zones, possibly gathering several rooms with a similar use (e.g. several classrooms in a school). Each zone is defined by walls, including several materials and possibly windows and doors. Each element has a life span and the tool calculates the impact related to the replacement of these elements, i.e. end of life and fabrication. In the present version of the tool, it is assumed that a component will be replaced by the same component. The present user interface simplifies data input by considering the same lifetime for all windows and doors, another value for all building finishes (painting, wall paper…) and the building life span for all other elements. It is assumed that no renovation is performed anymore after 90% of the building lifespan.

Once a suitable delineation of elements has been decided upon, it remains to define the lifetime of specific elements.

The values considered in the French case studies described in deliverable D4.1 are 15 years for building finishes and 30 years for windows and doors. Furthermore, French EPDs include information about a reference life span for each product. The tool does not explicitly support taking into account shortened element lifetimes due to changed function in a building.

In all Spanish case studies, a lifetime of 25 years has been assumed in the calculations for all replacable building elements that were considered in the calculation. These values correspond to usual and common values found in the literature. In addition, in one of these case studies, a sensitivity analysis for maintenance intervals is carried out, considering 15, 25 and 35 years.

In the case study for the family house in Szombathely, Hungary in deliverable D4.3 data from the following sources was taken into account for setting life times for individual building elements:

- Steiger (1995) using data published by the Swiss Office for Federal Buildings.

- Adalberth (1997) uses the maintenance norms of Swedish housing companies and values were based on experience.

- Mithraratne [Mithraratne, 2001] compared many, mainly New Zealand literature sources, e.g. Johnstone (2001), Jacques (1996), Fay (1999) and Adalberth (1997). In case of contradictions and for data gaps expert judgements were made. Three replacement cycles were established for standard, high and low maintenance.

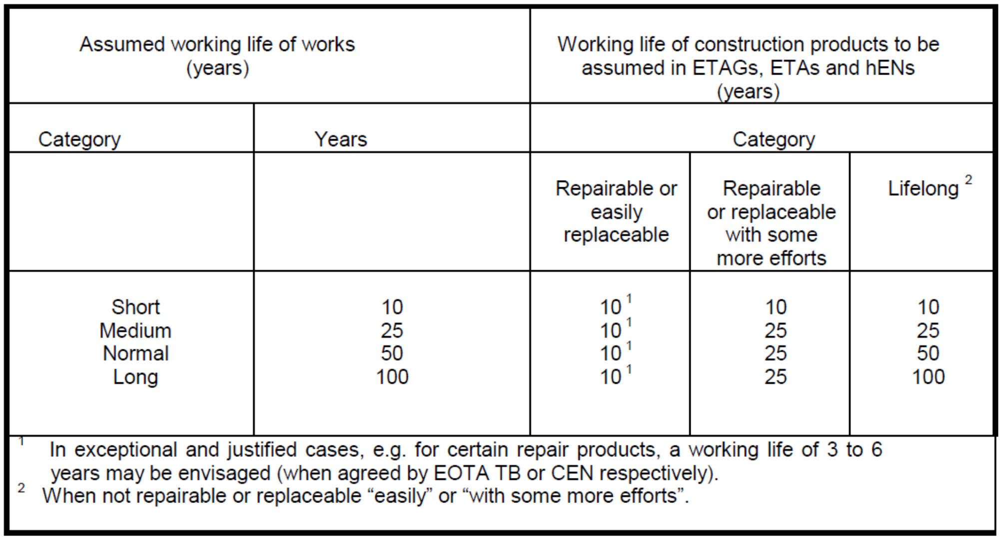
- Oswald [Oswald, 2003] applied replacement cycles of materials based on a Swiss study by Meyer-Meierling.

- Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR): Info-Blatt Nr. 4.2. Lebensdauer von Bauteilen und Bauteilschichten also gives information, and can be downloaded from http://www.holzhaeuserfuerberlin.de/wissen/Lebensdauer-von-Bauteilen.pdf .

4.2.1 Technical definitions for the lifetime of building components

Table 3 shows how the (European Organisation for Technical Approval, 1999) deals with the total working life of a constructed work where the 2 left-hand columns give a range of possible lifetimes for constructed works between 10 (designated a “short” working life in the table) and 100 years (designated a “long” working life). The table also shows recommended working lives of construction products to be assumed in Guidelines for European Technical Approval (ETAGs), European Technical Approvals (ETAs) and Harmonized Standards (hENs) depending on assumed working lives of the works.

Table 3: Assumed working life of works and assumed working life of construction products (European Organisation for Technical Approval, 1999)



Assumed working life of works (years)		Working life of construction products to be assumed in ETAGs, ETAs and hENs (years)		
Category	Years	Category		
		Repairable or easily replaceable	Repairable or replaceable with some more efforts	Lifelong [2]
Short	10	10 [1]	10	10
Medium	25	10 [1]	25	25
Normal	50	10 [1]	25	50
Long	100	10 [1]	25	100

[1] In exceptional and justified cases, e.g. for certain repair products, a working life of 3 to 6 years may be envisaged (when agreed by EOTA TB or CEN respectively).

[2] When not repairable or replaceable “easily” or “with some more efforts”.

In Swedish case studies, for example the life-cycle cost analysis carried out by (Brown, et al., 2011), standard Swedish references such as (VVS-Företagen, 2010) are used. A selection of the values given in this text are shown in Table 4 below. (VVS-Företagen, 2010) states that the values given in Table 4 are based on “investigation and experience” but gives no more detailed references. The use of the ELP tool in the evaluation of Hammarby Sjöstad worked with scenarios for other recurrent renovation processes, and the values used for these service life times and renovation intervals were taken from the national institute for building research and through consultation with municipal housing companies.

Table 4: Lifetime of building elements as given in (VVS-Företagen, 2010).

Building component	Lifetime
Radial fans	25 years
Axial fans	15 years
Supply-exhaust air handling unit	30 to 40 years (though many taken out of operation earlier due to noise)
Exhaust air heat pump	Approx. 20 years
Passive ventilation system	Unlimited, on condition that chanels and dampers are not constricted.
External walls can external roves	60 years
Windows	30 years and upwards, dependant on material quality and maintenance routines

Radiators and steel heat pipes in an airtight system with little requirement for filling with circulation water	Over 80 years
Radiators and steel heat pipes in less airtight system that is often refilled with circulation water	Short lifetime
District heating heat exchanger system	30 -40 years

Table 5**Error! Reference source not found.** gives comprehensive values that are applied in Germany according to national guidelines. The specific durability of building elements are adapted from German Federal Ministry of Transport, Building and Urban Development (2011).

Table 5: Durability, date of replacements within the calculated life span and expected replacement frequency of all building elements for German case study on refurbishment in D4.3

Building element / Material	Age (2011)	Durability	Date of replacement (1976-2061)	Replacement frequency
Strip foundation: concrete C20/25	35	100	-	0
Strip foundation: reinforcing steel	35	100	-	0
Foundation slab: reinforcing steel	35	100	-	0
Foundation slab: concrete C20/25	35	100	-	0
Basement flooring: Cement screed	35	80	2056	1
Waterproofing coating: bitumen emulsion	35	40	2016, 2056	2
Basement wall: precast concrete unit	35	100	-	0
Exterior wall: precast concrete unit	35	100	-	0
House entrance door frame: steel	35	50	2026	1
House entrance door panel: glass	35	50	2026	1
Window frame (apartment): plastic	35	45	2021	1
Window frame (stairway): steel	35	45	2021	1
Window panel: glass	35	45	2021	1

Core insulation: mineral wool	35	80	2056	1
Façade: washed concrete	35	80	2056	1
Exterior paint: dispersion paint	5	15	1991, 2006, 2021,2036, 2051	5
Balcony balustrade: precast concrete unit	35	70	2046	1
Load-bearing interior wall: precast concrete unit	35	120	-	0
Partition: wood	35	50	2026	1
Non-Load-bearing Interior wall: precast concrete unit	35	120	-	0
Door in the stairway: steel	35	45	2021	1
Fixed glazing: glass	10	25	2001, 2026, 2051	3
Basement door: steel	35	55	2031	1
Interior door (basement): Wood	35	55	2031	1
Apartment entrance door: Wood	35	55	2031	1
Room door: Wood	35	65	2041	1
Interior paint : dispersion paint	5	15	1991, 2006, 2021,2036, 2051	5
Elevator shaft: precast concrete unit	35	120	-	0
Ceiling: precast concrete unit	35	80	2056	1
Floor finish: cement screed	35	80	2056	1
Floor insulation: mineral wool	5	30	2006, 2036	2
Floor covering 1: linoleum	11	20	1996, 2016, 2036, 2056	4
Floor covering 2: paving tile	35	60	2036	1
Flat roof: precast concrete unit	35	100	-	0
Protective paint: bitumen emulsion	15	20	1996, 2016, 2036, 2056	4

welding sheet: bitumen	15	20	1996, 2016, 2036, 2056	4
Roof insulation: mineral wool	15	20	1996, 2016, 2036, 2056	4
Sealing sheet: bitumen	15	20	1996, 2016, 2036, 2056	4
Elevator system	10	25	2001, 2026, 2051	3
Gas fired boiler	15	20	1996, 2016, 2036, 2056	4

A method of estimation that has not otherwise surfaced through the case studies is that established by the international standard ISO 15686 (The standard includes a total of 11 substandards, and an interested reader is recommended to consult specifically the standards documents themselves. Most significant in estimating lifetime for building components is the procedure that is outlined in ISO 15686-2 Buildings and constructed assets – Service life planning – Part 2: Service life prediction procedures (International Organization for Standardization, 2003) that describes a standard method for establishing a Reference Service Life of a Component (RSLC).The detailed method is summarized here as follows:

1. Definition. Here such aspects as user needs, building context, type and range of agents, performance requirements and materials characterization are defined.

2. Preparation: Here specific agents and mechanisms are defined, and performance characteristics and evaluation techniques are chosen.

3. Pretesting: In this stage, initial checks of the identified techniques are carried out.

4. Exposure and evaluation: These are the actual tests, which are carried out in short- and long-term exposure procedures

5. Analysis and interpretation: Prediction models based on results of 4. Are established.

6. Critical review and reporting.

In a Swedish case study included in LoRe-LCA deliverable 4.3, 4 large material suppliers were asked whether or not they used procedures connected to this standard, and they did not.

In German cases, building elements are assigned according to the national standard DIN 276-1-http://en.wikipedia.org/w/index.php?title=DIN_276-1&action=edit&redlink=1Building costs; Part 1: Building construction.

4.2.2 Economic definitions for the lifetime of building components

As discussed in the case of entire building lifetime above, lifetimes can be defined by technical and economic methods. Economic definitions may be more relevant when the function of a building changes, such as when new tenants may require different interior designs, eg. floorplans, lighting systems etc. In such cases, elements may be removed from the building well before they have served out their technical lifetimes. Such cases seem like they may occur relatively often in the lifetime of a commercial office building, for example, though they may also occur in residential buildings (especially kitchens).

Examples of the application of such a concept seem to be lacking in the assembled examples from (Malmqvist, et al., 2011b) and (Malmqvist, et al., 2011a).

4.2.3 The importance of describing an accurate lifetime for building elements

A sensitivity analysis performed in one of the Spanish case studies that is included in deliverable D4.3 of this project performs a sensitivity analysis based on intervals for renovation, with results for global warming potential shown in Figure 5. This shows that there is a 25 % increase in total GWP when the replacement interval (i.e. the lifetime of building components is changed from 35 years to 15 years.

Whether the lifetime of exchangeable building components is an important variable to describe accurately in an LCA seems to depend on the goal and scope of the LCA. It seems that if it is used to compare the effect of different components with otherwise identical functional equivalence, then lifetime data that are specific to each component need to be considered. Current LCA methodologies do not seem to be employed for such a purpose, probably because reliable data for lifetime on product level is not currently available.

Needless to say, in understanding the effect of lifetime data for building components on absolute impacts from a given building, at least one of the cases of the LoRe-LCA project shows that the lifetime of exchangeable components may change the global warming potential by up to 25 %. The effect on other impacts may be higher, but clearly on this order of magnitude.

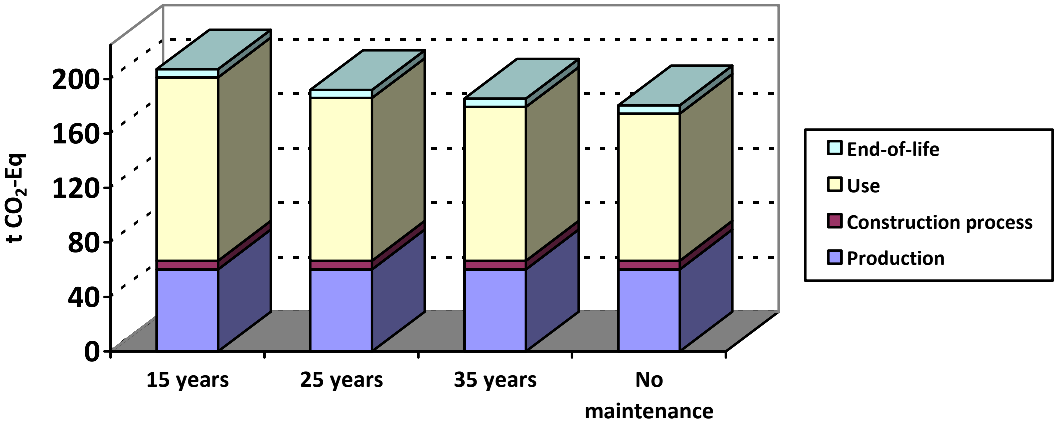


Figure 5: Results for global warming potential based on a sensitivity analysis in the LCA of a single family house in Spain.

The effects of the choice of specific items for which maintenance is required is taken up in Section 5.1.

Finally, in our case studies no degradation of the construction products was considered during their lifetime. This is in line with the definition 'working life' of products mentioned above (from Guidance Paper F, (European Organisation for Technical Approval, 1999)). It was assumed that replaceable elements were replaced at the end of their lifetime during the whole lifecycle of the building.

From the above it can be concluded that life times for individual building elements often are included somehow in LCA studies of buildings. Case studies display differences in coverage of building components and exchange rates range from 15-30 years. Sometimes it is simplified to using the same replacement interval for all elements like in the Spanish case studies referenced above. In other cases, different life times are set and these are often based on investigations or legislation/recommendations regarding exchange intervals which relate to the technical life times of building elements. Due to the fact that particularly for commercial buildings, much of the interior parts of the building is exchanged with every new tenant, it can be argued that at least for these types of buildings, economic life times could be more relevant to use. An additional argument to account for shorter life times related to this economic perspective is that in cases when the operational impact of the building tend to be low, the impact related to these materials and the fact that they will be replaced a number of times during the life time will possible become increasingly important.

5 Maintenance and operation

If environmental product declarations (EPD´s) are used as input data in the LCA study, the processes related to maintenance of the specific products should in principle be covered in this data set. However, if cradle-to-gate data is used, such processes are not included (e.g cleaning of a floor material, etc.). If making an LCA of a building there are also maintenance processes that are related to the entire building which cannot be connected to specific products (e.g garden maintenance, some use of chemical products, etc.) for which scenario dimensions ought to be included if making detailed LCA studies.

Nevertheless, if EPD´s of products which need frequent maintenance cover these processes, it can be argued that a decent simplification is to not model include further scenario dimensions related to maintenance. Furthermore, modeling of scenario dimensions for frequent maintenance is normally not of high concern in LCA tools for buildings. For example, the LCA calculations in the EcoEffect tool (SWE) only relate to the energy use during operation of the building and the production of the building materials. Since maintenance of these materials is normally not included in the LCI data used, this is neither covered for in the EcoEffect calculations (e.g cleaning of floor materials). If to be studied, scenario dimensions relating to maintenance have to be modelled separately.

5.1 Renovation

Scenario dimensions for renovation during the life time of the building or construction works are then more important since it generally encompasses more costly and energy-consuming processes. Scenario dimensions for exchange of building materials during the building life time are commonly established by designating service life times to the different building materials, components, elements, installations so that the amount of a building material is multiplied by the building life time/service life time for the calculations over the entire anticipated life time. Lifetime of exchangeable building components is treated elsewhere in this report, section 4.2. Under this heading, it is interesting to analyse what specific elements have been selected for renovation. Another possible scenario dimension related to renovation is whether it should be assumed that the building after renovation will have a higher performance, with subsequent less environmental impact (this is considered more in detail in subsequent section on retrofitting).The case studies show differing ways in which need for renovation has been taken into account for the buildings in question. In the German case study included as part of deliverable D4.3 , all building elements that were required to be changed according to national guidelines (German Federal Ministry of Transport, Building and Urban Development, 2011) were assumed during an 80 year lifespan for the building, see **Error! Reference source not found.**. The table also shows the years at which specific renovations are carried out. It should be noted that the building in question was built in 1976, which is important when understanding the dates that are predicted for renovation.

This example may be compared with the Spanish case study in deliverable D4.3, where only HVAC equipment (boiler, split AC, solar thermal collectors, etc.) and external surfaces (plaster skimming, floor tiles, glazing window & aluminium frame, wooden door) were renovated during a 50 year lifespan (Table 6).

Table 7shows a comparison of the final results from the Spanish and German case studies respectively. Due to differences in input data, it is unwise to draw broad conclusions from the table. However, it seems that that which is important is to compare specifically the production impacts and the renovation impacts – in the German case where more comprehensive renovations are assumed, the impact of renovation is considerably greater in proportion to the production impacts that in the Spanish case. It is therefore possible that were a more comprehensive scenario dimension for renovation assumed, the lifetime global warming potential for the Spanish case would be higher by up to 20 percent.

Table 6: Description of renovation scheme used in CIRCE's case study of single family dwelling

Materials	Weight (kg)	Maintenance interval (years)
Plaster skimming	8,878.7	25
Floor tiles	5,408.5	25
Ceramic-china roof tiles	2,938.9	25
Double glazing window 4-6-4	197.1	25
Lacquered aluminium frame	400.6	25
Wooden door	42.6	25
Energy generation equipment	**Weight (kg)**	**Maintenance interval (years)**
Natural gas boiler	70	25
Split AC	60	25
Solar thermal collectors	80	25

Table 7: Comparison of results of case studies from CIRCE and CalCon for global warming potential

	CIRCE case study for single family dwelling		CalCon Refurbishment case study	
	Ton CO_2 equivalent	Percent	Ton CO_2 equivalent	Percent
Production	50	29%	688	7%
Refurbishment	11	7%	494	5%
Energy demand during use	108	62%	8432	85%
End of life	5	3%	340	3%
	174	100%	9954	100%

It seems that in absolute terms, assumptions about the extent of renovation may have a noticeable effect on the environmental impacts as arising from a specific renovation. Having said that, in comparing what-if building alternatives, it seems that more information is required to distinguish between alternatives.

While the above examples give significant consideration to technical needs for renovation, which in some sense seem somewhat predictable, there are of course cases where renovation may be mandated specifically due to change of tenant (in a commercial or residential building). The possibility of such renovations does not seem to feature in the above examples, and it would be interesting to investigate this question more fully. To do this, apredictive approach could be used, where current data addressing the extent to which new tenants are interested in renovating.

In the Spanish case study considered above and given in full in LoRe-LCA deliverable 4.3, input data are based on static technical parameters since these are simpler to implement in systems modelling. The LoRe-LCA deliverable D3.1 (Peuportier, et al., 2011) gives some information about a case where a degradation in boiler efficiency over the lifetime of the boiler has been modelled, though one conclusion from this specific case is that it may be sufficient to assume a constant efficiency over the entire operational lifetime of the building based on a satisfactory average for the entire operational lifetime of the system in question.

Of the cases studied, none account for a scenario giving improved performance after a major renovation. This may be interesting to model primarily if any special considerations in the design related to future flexibility are important, or if special appliances are installed which facilitate future connection of for instance solar power equipment.

5.2 Retrofitting

In the above examples, building renovation is considered, where renovation is considered to mean maintaining the operational standard of the building as built. This is distinct from the case of retrofitting, where the specific aim of a retrofit is to specifically improve the standard from the time at which it was built.

Having established this distinction, it is interesting to note that in Germany, when large scale renovations are carried out, it is legally mandated that any new installations carried out at that time are state-of-the-art for the *time at which the renovation is carried out*, rather than *the time at which the building was built.* As such there is no *de facto* difference between a renovation and a retrofit in Germany according to this definition. In the German case study in deliverable 4.3, this is simplified such that calculation is performed as renovations were only carried out to maintain the standard at the time the building was built.

As such, none of the assembled examples give a case where retrofits are carried out. A possible reason for this is that retrofitting itself is unpredictable – using the German situation above as an example – since the state-of-the-art for building technology in the future is unknown and difficult to describe. It may be useful here to consider exploring possible future pathways for technological development here, though it is a further question the extent to which inclusion of such scenarios may affect how a life-cycle method affects decision making.

5.3 Energy consumption during a building's lifetime

The effect that a buildings energy demand has on the total environmental impacts from the building have been shown in several examples to be very significant. See for example Figure 3 and Figure 4 earlier in this report.

Such figures also show that for buildings where the energy demand during use stage is minimized (as will become the case according to (European Parliament, 2010)), the relative impacts of energy use during the use phase will be reduced. Figure 4 also shows that where energy during the use stage is based on biofuel (as it is in the cases shown in the figure), the impact in terms of global warming potential of the use stage can become very small.

The expected future "type" of users, number of users, and how they will use the building will play a considerable role for the real environmental impact taking place during the life time of the building. For example there are often very large differences between the energy use between different users due to different life styles, values and knowledge, e.g (Gram-Hanssen 2010). Depending on building type assumptions can be made regarding the future user-related impact. For example if it is a home for elderly, in a cold climate temperatures might need to be kept higher than for ordinary dwellings. However, in most cases, it is not possible to predict how the users will behave and use the building and therefore scenario dimensions for this need to be assumed.

The common way to treat user behaviour is to assume a scenario dimension of "normal" occupant behaviour regarding energy use, water use, airing habits, wear and tear of surface layers, etc. That is input data on energy use is based on the energy calculations done for the project, with the inherent assumptions addressed by the energy calculation software. If the building is designed for a user group with special needs, for example elderly people, this has to be accounted for in the energy calculations.

In the following subsections, the energy demand of the building is addressed first, and subsequently the type of energy used to meet this demand and it's environmental impacts are considered.

5.3.1 A Building's Energy Demand

In considering energy use in different scenarios, firstly the question of how much energy a given building will require needs to be addressed. Examples show that there is no lack of more or less advanced tools for facilitating such a calculation.

The Swedish tool Enslic (Malmqvist, Glaumann et al. 2011) involves a simplified calculation methodology, where the total energy demand is separated into several categories: space heating due to transmission losses, ventilation losses, hot water demand, building electricity (electricity for vital building functions i.e. fans, pumps, security lighting) and user electricity (all other electricity that is connected to processes). Energy demand for user and property electricity and hot water demand is based on guideline values according the Swedish National Board of Housing, Building and Planning. Meanwhile, space heating demand due to transmission losses and ventilation losses are calculated from a simple climate model and building description (simple dimensions, thermal properties of climate envelope and properties of HVAC equipment).

It is possible when using Enslic to use custom values for the different sub-categories included in the total energy demand during operation, and in this way values for space heating generated using a more advanced model (from a dedicated energy demand simulation program) can be inserted.

If Enslic facilitates modelling the effect of user behaviour intrinsically, it is in the fact that the it is possible to input a desired indoor temperature set point that is used as in-data in the calculation of space-heating demand. No relation between energy demand and user behaviour is used in Enslic, and there are no specific possibilities for taking account of the use of an energy management system in the building or not.

In Spanish case studies, energy demand is based on the official tool developed in Spain for the Energy Efficiency Certification of new buildings. Energy demand for heating and cooling is based on a technical definition of the building envelope, mechanical equipment for heating and cooling, statistics for the local climate and set-point temperatures for heating and cooling. Standard behaviour is assumed in the case studies, which assumes for example a uniform heating set-point indoor air temperature of 20 ^{o}C and a cooling set-point temperature of 25 ^{o}C. The tool is applied in the case studies in deliverable D4.3 and focus is on building energy demand for heating, cooling lighting and hot water and therefore any variation in energy demand due to appliance usage is not considered. In common with many other energy simulations, the tool does not take into account the way in which user behavior may affect energy demand (e.g. for heating, cooling and lighting).

In sensitivity analysis performed for a case study included in LoRe-LCA deliverable 5.2, 2 possible scenario dimensions for user behaviour are described.

Table 8: ***Assumptions regarding two types of users' behaviour according to French case studies included in LoRe-LCA deliverable 4.3***

	Economical behaviour	Spendthrift behaviour
Heating set point	19°C	22°C
Air infiltration including window opening	0.1 ach	0.5 ach
Annual internal gains due to electricity consumption (appliances ...) per dwelling	1,500 kWh	2,600 kWh
Cold water consumption	80 l/day/person	120 l/day/person
Domestic Hot Water (DHW) consumption	20 l/day/person	50 l/day/person

Case studies do not seem to consider however how occupant behavior may affect the energy demand for lighting. Tools do not explicitly take into account the very real possibility that actual building performance is greater than the modelled performance, and neither does it take into account the effect that energy management routines (or absence thereof) may have in affecting the future energy use of the building.

The French tool for LCA in buildings, EQUER can be connected to the energy simulation tool COMFIE. As an energy demand simulation tool, COMFIE gives output in hourly and yearly loads. As far as a real simulation of the way the building is used in practice, scenarios in COMFIE can be defined for each day of the week and each hour, data regarding : the thermostat set point (for heating and possibly cooling), ventilation flow rate, lighting set point, energy use for appliances, number of persons, and use of solar protection (e.g. roller blinds). Several types of week can be defined in a yearly pattern, e.g. to simulate holiday periods. The scenarios depend on the type of building (residential, office, school…). The location of the thermostat sensor has also to be indicated. Internal ventilation flow rates can also be controlled: the user has to indicate e.g. a temperature threshold inducing the operation of a fan between two zones. Having said that, the tool does not explicitly take into account the variation between actual building performance and calculated design performance. The effect that an energy management system may have on building outcome cannot directly be considered in the tool.

No specific consideration was taken into account in relation to user behaviour in the Hungarian case study. Representing an average user, default values were applied in relation to internal temperature, air-change rate, internal gains, DHW consumption and energy demand for lighting in accordance with Hungarian Government Decree on the energy performance of buildings.

In Germany, calculation of primary energy demand relating to heating, cooling and lighting in a particular building (The U-value is determined individually) under regular conditions (average climate, room temperature, number of user, etc.) is generally required by the national Energy Conservation Regulations. This methodology is further used in the German case study in LoRe-LCA deliverable 4.3. Aspects such as electricity demand for appliances are not covered, justified by the fact that this depends on choices made by building tenants. A separate calculation is only necessary if the building has on site renewable energy production. Since user behaviour is individualized, alterable and not predictable, it was not considered relevant to include this in the German case studies in LoRe-LCA deliverable 4.3.

Clearly the actual energy demand in the building is a very important parameter in life-cycle methods applied to buildings. A significant question is the extent to which the actual performance of the building lives up to the calculated performance, energy-wise. Depending on the extent of the difference, this may affect the recommendation in considering what-if scenarios of two or more planned alternatives.

The complexity of the building system does make accurate calculation of energy performance a difficult task. Primarily, though tools mentioned above do allow practitioners to choose different indoor temperatures, it is another question as to how well these temperatures reflect the actual temperatures that will occur in the real building, given user’s different preferences and the ability for real HVAC systems to deliver the simulated temperature set points. It seems that in establishing scenarios for set points and for a building’s calculated energy demand, it would facilitate the life-cycle method if in performing energy performance calculations reference could be made to probabilistic scenario dimensions for set points based on measurements. Indeed it would be useful if in calculating energy performance of a not-yet-existing building, data from existing buildings of the same type could in some (more extensive) way be used to inform the calculation. In this way the benefit of past experience could be used to inform the design process for the building.

In the Swedish tool ENSLIC {Malmqvist, 2011 #1661}, default values pertaining to bought energy use are given for building electricity (for office buildings this value is 30 kWh/m^2 heated floor area, year and for residential it is 15 kWh/m^2 heated floor area, year) which can be increased in the case that ventilation heat recovery and a heat pump is installed in the building. Default values are also given for user electricity (the same value for office and residential buildings at 30 kWh/m^2 heated floor area, year, which can be decreased by up to 20 % in the case that large appliances (fridges, freezers, washing machines and dryers) with the highest energy efficiency are chosen.

5.3.2 Type of Energy

The second significant question that needs to be addressed to describe the environmental impacts of energy use during the occupation stage of the building is what of the type energy is used to meet the building's energy demand. For heating purposes, various types of HVAC solutions exist (for example boilers, furnaces, heat pumps and district heating). Energy sources for such systems also vary widely, with primary sources spanning wind, solar, hydro, coal, fossil gas, fossil oil, biofuels and beyond. Infrastructures beyond the building itself are also significant in determining impacts due to the building's energy demand. In cases where energy is supplied on large distribution networks (electricity and city-scale district heating), performance of energy conversion stages in plant that delivers energy to the network is important. Furthermore, for such large networks the issue of marginal energy delivery to the network is another issue that is often given consideration. As previously considered in this report, buildings have a long lifetime, and there is therefore a question of how the energy demand will develop dynamically over time, since of course this in itself is not a static parameter either.

In Enslic (a tool that only calculates GWP impacts and bought energy demand), the user can in principle input any GWP intensity for energy use. In practice, the tool separates between heat demand and electricity demand. Built into the system are GWP impacts due to district heating on various Swedish networks (e.g. Stockholm, Gävle for current production) as well as heat production from various fossil fuels. For electricity production, Nordic or Swedish mix can be assumed, or specific cases pertaining to 100 percent wind power, or 100 % solar power. Notably, the notion of marginal production in district heating or electricity production is not used.

In one of the Spanish case studies in D4.3, a sensitivity analysis for the electricity mix, comparing the present mix in Spain, the average mix in Europe and 2 hypothetical scenarios (the first one with a share of RES of 40% in the electricity mix, and the second one with a share of RES of 80%.

In the French tool EQUER, the primary energy mix is defined by the user for electricity production and district heating (if this is considered). It is possible for example to define a mix corresponding to certified electricity (e.g. produced from renewables). A specific electricity mix is considered for electric heating because of the winter peak demand inducing a larger use of thermal plants, and dynamic LCA is being developed on this issue.

The primary energy mix in German cases (renewable or not) is also given in the database – Ökobau.dat (German Federal Ministry of Transport, Building and Urban Development, 2011b).

As with previous scenario dimension analysis, we consider first the situation where 2 or more building alternatives are compared. Considering a hypothetical example, where building A is compared with building B, and even if energy from the same source is selected (e.g. Stockholm district heating) the result of the life cycle calculation will be dependent on what value for specific environmental impact per unit delivered energy is used. This is because the total impact due to the building's energy demand is dependant also upon the quantity of energy that is demanded by the buildings, which will probably differ. The extent to which it is important to accurately define the specific environmental impact is dependent on other scenario dimension specifications, such as the energy demand of the building, and the embedded impacts in construction materials.

It seems that in this case, the decision support that will be provided by the applied life-cycle method needs to take into account scenario dimensions for type of energy where environmental impacts from future energy delivery infrastructure are taken into account, in light of the significant uncertainty that is associated with this. Specific examples here are taken from the Swedish case study shown in deliverable 4.3 to this report, where the specific GWP from district heating production (from renewable sources) is as low as 5.2 g CO_2-e/kWh, as compared to the figure 50 g CO_2-e/kWh that was relevant for the same district heating network at the time the work included in (Malmqvist & Kekski-Seppälä, 2011).

Another interesting and related example is given in LoRe-LCA deliverable 3, where the change in fuel mix on a district heating grid (based on the content of municipal waste in the mix) over a 30 year period is included in the scenario dimension for energy mix, as shown in Figure 6.

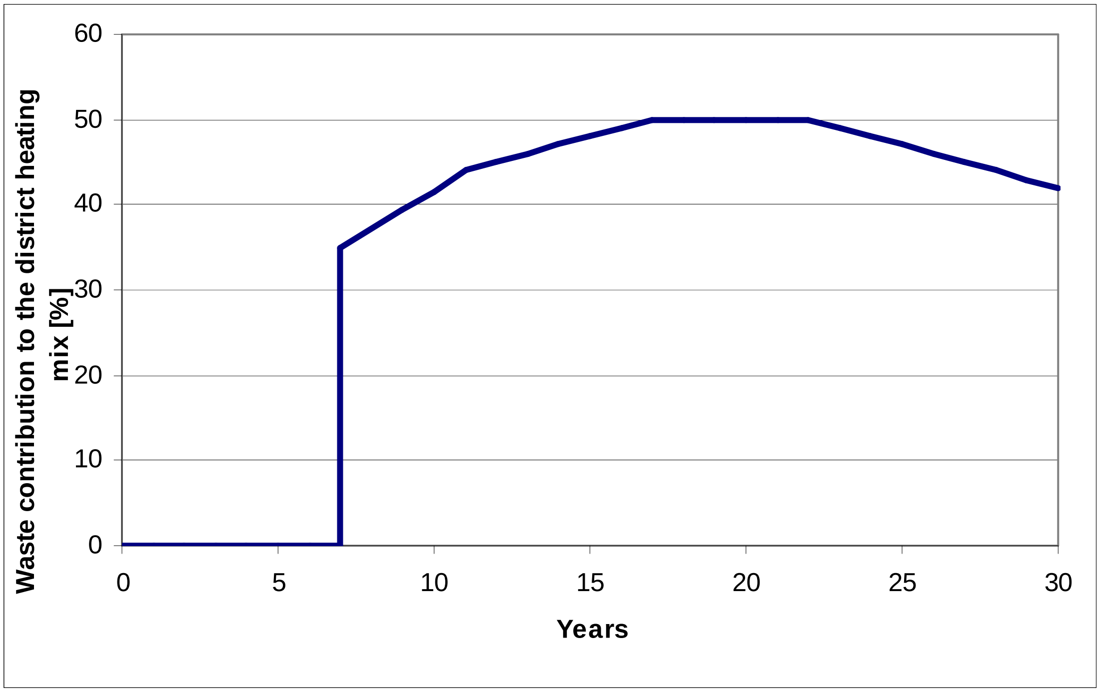


Figure 6: Contribution of waste to the district heating system according to dynamic LCA, from a study described in LoRe-LCA Deliverable 3.1.

To sum up this section, in the studied cases both more detailed simulations of energy demand and simpler (to higher extent based on different default values) are used. User behaviour is usually assumed as being “normal”, thereby not considering any special scenario dimension descriptions for this. The exception is the French tool in which a possibility to select between different building usages is possible, which then influences the energy calculation.

Regarding energy type, the normal procedure in the case studies is that the tools used include options to select different energy mixes which, then, stay the same for the entire life time. To try to elaborate better energy mix scenarios is extremely difficult. At the same time, the used energy mix in the study in general plays an important role for the results of building LCA´s. In cases in which impacts from operational energy dominates the results – scenarios for energy mix increases in importance. However, due to all uncertainty reasons it is for most cases considered to be best to make use of the current energy mix in a specific national context. However, depending on purpose, it can be recommended to include sensitivity analyses for different relevant energy mixes.

6 End-of-life

In general, a flaw in life-cycle methods is that as generally conceived they do not really model a specific life-*cycle*, they rather model a lifetime. In the case of buildings (as has been done in a previous section of this report) so-called “life-cycle” methods require the specification of a specific lifetime as a key parameter in the calculation. The discrepancy between life-cycle and lifetime becomes most apparent in life-cycle methods when considering specifically that part of the “life-cycle” method that deals with how the material used in the building is dealt with after the building itself ceases to exist.

In many LCA case studies on buildings, the end-of-life is omitted due to the difficulties of stating how for example recycling of building materials will be handled in a distant future. A number of studies however focused particularly on the end-of-life of buildings, e.g (Thormark 2006).

It is often also difficult to find out from existing case studies how the end-of-life was modelled if it is stated that it is included. This is the case with the use of the ELP tool in Hammarby sjöstad, for example. In the Swedish EcoEffect tool an ambition was to somehow account for the benefit of using reused/recycled building materials and measures taken in order to facilitate future recycling of building components and materials. So far, for the end-of-life scenario dimension, models are such that reused demolished building materials are accounted for as “free materials” in the calculations, that is they are not associated with any impact at all. However, the way to treat end-of-life scenario dimensions discussed in the EcoEffect tool is to do as follows: for simplicity reasons only one recycling loop is considered. The different building materials in the EcoEffect database have been acquainted with a certain type of waste treatment (different types of recycling or landfill) according to a set of given criteria. A recycling value is then calculated for the material which constitutes *the environmental impact related to new production of the material minus transports and processes related to making the waste product as usable as the replaced new material.* If the recycled material is then chosen in the database, the impact will be the impact from new production of the material minus the recycling value. This implies that the building developer already at the planning stage needs to express which materials will be recycled or landfilled in a future dismantling of the building. The EcoEffect tool makes use of a specific *recycling declaration* in which this is stated.

In the French tool EQUER, the user can choose among different measures in describing end of life scenario dimensions for each given building element: landfill, incineration (with or without heat recovery) and recycling. LCI data on recycling only exist for a limited number of materials: metals (steel, aluminium) and glass. Example scenario dimension description for end-of-life for a case study is shown in Table 9.

Table 9: Example for end-of-life scenario dimension description for a French case study described in D4.1

inert materials		Other materials			
concrete	other inert*	metals	wood	plastics	Other non dangerous waste **
recycling	Inert landfill	recycling	incineration	landfill	landfill
314,663 kg	199,251 kg	6,863 kg	14,422 kg	1,309 kg	2,586 kg
Total inert 95% : 513,914 kg		Total others 5% : 25,180 kg			
61,2%	38,8%	27,3%	57,3%	15,5%	

** : gypsum, gravel, sand and stone*

*** : windows and doors, solar panels, glass wool*

The considered transport distances are 20 km from the building site to landfill, 10 km to incineration and 100 km to recycling.

In Spanish case studies in LoRe-LCA deliverable 4.3, impacts related to building demolition, transportation of demolition material and the most probable final disposal scenario are applied for all the materials from the building and from HVAC equipment. In order to simplify the analysis, only 2 final disposal options have been considered: direct recycling and direct final disposal without recycling (land-filling or incineration). Presently more than 80% of construction demolition waste is land-filled in Spain, although the future scenario dimension descriptions involve a decrease of waste that is land-filled. Nevertheless it is important to highlight the high uncertainty when considering an end-of-life stage scenario description, as it will occur after more than 50 years.

In Hungary, the ratio of recycling is very low in the construction sector. Without the soil, which can be theoretically fully utilized, the average recycling ratio is about 30 %. Of that, about 75-80 % of the road construction waste is recycled, but only about 15 % of the building waste. However, the recycled ratio is expected to rise in the future.

In the case study for the family house in Szombathely reported in LoRe-LCA deliverable 4.3 a cut-off method was used. It means that the recycling is cut off, the waste material leaves the system without an "ecological rucksack", in other words it is burden-free for the new product. Demolition on site, transport to the sorting plant, etc. are considered in the old product, and the recycling process in the new product. Waste with high recyclable content is rewarded only by being relieved of the burden of landfill [ecoinvent v1.3]. In the ecoinvent v1.3 database, biogenic CO_2 and CO emissions and biogenic CO_2 resource extraction are excluded from the impact assessment. This assumption was used in the case study also and the CO_2-uptake and the CO_2-release at the end of the life was not considered.

This touches upon the issue focused in the Austrian case study of biogenic CO_2 in deliverable D4.3. Here, two different allocation principles regarding how to account for the end-of-life of wooden products are studied. In the *cut-off* alternative incineration of waste wood is considered as a waste treatment process and the entire environmental impact associated with the incineration is allocated to the building. In the *substitution* alternative the generated energy is credited by subtracting the associated burdens of the substituted energy. Four scenarios for substituted energy are elaborated in the case study and at least one future energy scenario (IEA Baseline 2050) gives favourable figures for the impacts related to end-of-life of wooden products (in this case GWP of planed square timber) compared to the other scenarios, with the cut-off principle naturally being least favourable. The case study shows that impacts related to the end-of-life of both building products and buildings are not only determined by the selected waste treatment scenario dimension, but also the chosen allocation procedure.

Due to the system boundaries and the uncertainty of the user behaviors, recycling as well as reuse of building elements is not considered in the German cases. However, the disposal and the energy recovering and environmental impacts by combustion of building elements after the service life are taken into account in the case studies.

The Enslic tool which is aimed to be used for making rough calculations in early design phases (see for example the Väsjön case study of deliverable D4.3 and (Wallhagen, Glaumann et al. 2011) does not take into account end-of-life aspects, and (Wallhagen, Glaumann et al. 2011) cite several other studies that do the same, e.g. (Peuportier 2001), (Ortiz, Bonnet et al. 2009) and (Blengini 2009).

Of all processes in the lifetime of a building it seems that it is end-of-life that is riddled with most uncertainty. This is partly due the long lifetime of buildings, such that the events related to the end-of-life description in the LCA occur a long time into the future, and are therefore naturally associated with significant uncertainty. A significant initial question to be addressed therefore is what will be done with the materials included in the building at the end of a building's life. The current EU waste hierarchy adequately identifies and classifies options:

-prevention. It can be assumed in the context of end-of-life considerations that such an option is specifically not available here.

-reuse. Reuse pertains to the situation where a material is used again without significant change to the properties of the object in question. This may be the case for example for bricks.

-recycling: In this case materials recovered from the demolished building are changed significantly from their previous form.

-recovery: e.g. energy recovery

-disposal: e.g. landfill

When objects are assigned to landfill it seems that the end-of-life procedure is essentially simplest from a life-cycle point of view, however it is the other options (that must be considered before landfill that are more complicated). In the case of recycling and reuse, both are affected by an allocation problem.

In the case of reuse, for example, there are properties of a given material that are conserved between one use and the next. In this case, it seems that there is a system boundary problem as to where the burden for the processes which are required to establish the properties in question are allocated – to the first use of the object or divided between a hypothetical number of uses? A similar argument could be made in the case of recycling, though property conservation is probably less of a feature, depending on the material in question. Indeed, during the process of dismantling a given building, there is furthermore a system boundary question about where specifically the dismantling process ends and where the processes required for recycling or for reuse begin. It is not impossible for example, that in order to facilitate reuse, specific dismantling procedures need to be used that otherwise would not have been employed.

There is a great variety in the case studies/studied tools regarding how end-of-life scenario dimensions are used (or not) in LCA of buildings. Examples include to cut-off end-of-life totally, the choice between landfill or recycling or a possibility to select a greater variety of waste treatment scenario descriptions to the cut-off of impacts related to recycling processes as the recycled products are entering another “system”. It is also therefore difficult to draw any general conclusions from the case studies. However, this indicates the problematic issue of establishing scenario descriptions for the end-of-life and that this question needs further research activities.

It has been established previously in this report that environmental impacts due to materials used for buildings will only increase in relative importance with the expressed desire to increase the energy efficiency of new buildings. Given the fact that how materials are dealt with at the end of the specified lifetime of a building are intimately connected to such impacts, the relative importance of satisfactory end-of-life descriptions will also increase.

7 Scenarios and Rating Tools

The case studies show many examples where environmental rating tools have been applied, rather than strict LCA methodology to evaluate the environmental performance of entire buildings. The requirement for and use of scenarios in such rating tools is significantly different from the way in which scenarios may be employed in a strict LCA for the entire building but since the use of rating tools in real construction projects is more common than LCA calculations it is important to say something about potential scenarios and scenario dimensions in such tools.

In cases where a specific environmental rating tool has been used, the extent to which scenarios/dimensions have been used depends specifically on the nature of the tools in question. If there is any way in which rating tools strictly do contain a scenario element, it is formally expressed in period of validity for the certificate in question. In the case of the Swedish rating tool Miljöbyggnad (Environmentally Rated Building), this is given as 10 years from the date of certification (unless the building is changed significantly before that period has elapsed).

A significant area where a scenario is implicitly assumed in the Swedish Miljöbyggnad tool is in calculation of the type of energy that is used. Here, a choice of 7 different electricity mixes can be chosen from, and district heating, as of time of writing is assessed according to 2008 statistics for fuel and heat supplied to each specific district heating grid. In the case of district heating, even if we assume that the building in question affects the district heating network in such a way that it draws heat equally from the average historical fuel and heat mix, there is considerable uncertainty here with respect to the future mix on the system. The question of how the demand of the building in question may affect heat production on the system (with respect to the way that different hourly load profiles will affect the production system differently) is a further complication.

Given that the electricity market in Sweden allows for individual subscribers to choose electricity from specific generation sources, in cases where building owners have chosen to do this, it may be considered that the future scenario dimension has been *constrained* by this choice. Having said that, in cases where the average historical mix for Sweden has been assumed, the case is not so clear, and is affected by the future development of the network as well as the related but nonetheless distinct question of how the specific building affects the generation profile in question.

The most well-known rating tools like LEED and BREEAM also contain elements which can be seen as related to life cycle thinking in scenario dimensions. Such issues include extra credits given for e.g. cleanability, flexibility, recyclability of construction materials, etc. which can be said to be related to maintenance and end-of-life scenario dimensions.

Some tools like DGNB, BREEAM and CASBEE cover some kind of LCA calculations.

8 Discussion

Table 10 summarizes the analysis of the different scenario aspect that have been considered in the report. For each aspect, the following questions have attempted to be answered:

- How important is an accurate definition of the aspect in question when scenario dimension for building alternatives includes 2 or more building alternatives that are to be compared with one another?
- How important is an accurate definition of the aspect in question in a absolute/normative scenario?
- In what way could the definition of the aspect in question be improved according to the work presented in this report?
- What features drive the improvement of the accuracy of description of the scenario aspect?

Table 10: Summary of analysis of scenario descriptions

Life-cycle scenario dimension	Importance of accurate definition in case of what-if type scenario dimension for building alternatives	Importance of accurate definition in absolute, normative type scenario dimension for building alternatives	Suggestions for improving accuracy of scenario dimension description	Drivers for improvement of scenario dimension description
Building Life	Analysis given in Section 0 suggests that an accurate specification is not important for considered cases, but this will vary from case to case	Undoubtedly. Since use-phase emissions are considered to be reduced in future, an accurate determination of building life will only get more important	Relate lifetime estimates to data and studies such as methods described in (van Nunen & Mooiman, 2011) Local planning authorities may contribute to this be discussing future aspects of existing areas and areas under development – specifically information about the time period for which the development in question is expected to “exist”.	Relative impacts of production in life-cycle will increase, and therefore greater accuracy required for building lifetime in assessing absolute impacts
Element Life	Only important if we	May change total	Application of	May increase in importance with the

	are interested in comparing different types of element (independent of “whole building” life above)	impacts on the order of magnitude of about 25 %	recommendations in ISO 15 686 Building and constructed assets, chiefly Part 2: Service life prediction procedures	increase in relative impacts of material production
Renovation	Again, only important if we are attempting to compare specific types of techniques	Comprehensive inclusion may increase impacts on the order of magnitude of 10 %	Possibility to take *retrofitting* as opposed to renovation into account based on previous data	May increase in importance for the reason that impacts for building materials will increase in importance
Energy Demand	Yes, clearly very important due to the high impacts that are associated with it, see analysis in Section 0	Yes, clearly very important due to the high impacts that are associated with it	Take into account nontechnical elements in modeling, such as occupant behavior.	Unclear extent to which models provide sufficiently accurate description of actual usage. The latest energy performance of buildings directive poses more stringent goals for buildings.
Type of Energy	Yes, clearly important, see analysis in Section 0	Yes, clearly important, see analysis in Section 0	There exists considerable uncertainty in long-term policy regimes for energy supply, not least in how CO_2 emissions from energy sources will affect type. This suggests that it	The magnitude of impacts that arise from energy varies greatly between energy type, and will vary considerably in the future compared to current production.

			may be interesting to use an explorative approach in definition of type of energy Involvement of decision makers beyond the building level may be useful here – e.g. on a local level municipal environmental goals, and on a higher level national and international environmental policies and goals. Possibly the local planning authority can be a point of contact between decision makers on building level and the wider (local, national and international) context in which the building exists	
Occupant related impacts	More research is needed to determine whether it is important or not in	Importance arises from the effect that occupant behavior may have on energy	Exploit literature sources on user behavior, and follow up real cases	Better descriptions of user behavior will facilitate better description of energy demand during construction, furthermore there may be interest in evaluating how a different ICT

		aspects		solutions may be used to facilitate more energy efficient occupant behavior.
End-of-life	Seemingly low impacts currently, more research is needed to determine if it is important or not	Impacts currently appear small, but may increase in the future	It may be interesting to develop explorative scenarios for how end-of-life processes may be at the end of a building's lifetime	The impacts arising from end-of-life treatment will grow in significance as material impacts in general from construction grows.

The method used in this report has been to identify and isolate in a reductionist way so-called scenario dimensions that have been shown to have important impacts on life-cycle impacts from buildings. While this has facilitated the analysis shown in Table 10, it should be pointed out that this methodology implies a limitation in interpretation of the results. Namely that scenario dimensions that we have analyzed in isolation are in reality but part of a system of interconnected variables in the form of the whole scenario considered. As such, for any given case where a life-cycle method is applied, the recommendations established and shown in Table 10 will only apply to a greater or lesser degree. Therefore it is still necessary to analyse on a case by case basis whether or not such recommendations are significant.

The examples considered in the LoRe-LCA project suggest that in carrying out inventory work for life-cycle methods, building design, materials (including impacts) and to a certain extent energy demand are well-described. This is in contrast to some of the aspects considered in this report and shown in Table 10. It seems that life-cycle methods in building projects may benefit from a more systematic and consistent work with *scenarios* describing future states and by extention scenario dimensions of which these scenarios are composed.

An interesting example here is the type of energy that is assumed for the building over the building’s lifetime. It is overwhelmingly popular to use current average mix for the network-based average mix (e.g. electricity, district heating or even gas) as the basis for calculating life-cycle impacts over the entire life of the building (at least 50 years into the future). Given the preponderance of factors (to a great extent external to decision makers on building projects) that will influence the environmental impact of the network-based energy supply over the building’s lifetime, it seems that such an assumption remains relatively crude. The strength of such an assumption seems to be the possibility to point to empirical data that supports the statement and a simple application of the principle of induction. Having said that, it seems nevertheless possible (and advantageous) to employ the deductive principle in establishing scenario dimensions for type of energy that are different to the current energy mix, by basing the dimensions and related inductions on empirical data other than the current energy mix, such as policy goals or institutional trends.

One of the strategies for dealing with uncertainties with a significant influence on impacts is sensitivity analysis. These are without doubt useful to a certain extent, however, to provide a better basis for decision making, such analyses should optimally be performed within the context of *an internally consistent scenario.* This is an argument presented originally in (Van der Heijden 2005). Following on from the discussion on energy mix scenario dimensions above, in a sensitivity analysis, the content of total renewables on an electricity grid may be assumed to be higher in some hypothetical sensitivity analysis than in a given base alternative. It may also be stated that this is due to political initiative and higher societal environmental goals. However, in order for such a sensitivity analysis to constitute part of an internally consistent scenario dimension, the question as to how the political initiative that was assumed to have caused the increase in renewables content on the grid may have changed other scenario dimensions of the future scenario. It is for example very plausible that such a political initiative for example mandate a decrease in energy demand for consumers in general, and specifically for the building for which the life-cycle method and sensitivity analyses are carried out. Such discussion of more well-founded scenarios for life-cycle methods in building projects always takes place against the backdrop that the complexity of the building process demands simple and convenient methods (see for example (Malmqvist, Glaumann et al. 2011)), and that a time-consuming scenario generation process for each and every project on top of already established life-cycle procedures would not be workable in practice. One suggestion for overcoming this barrier may be to integrate in national, municipal and local planning processes the generation of scenarios that can be used specifically in building projects. Examples of this as they pertain to scenario dimensions for building lifetime and type of energy are given in Table 10 above. Though this may involve significant work for scenario generation, in this way it may be possible to use the same scenarios for multiple building projects.

9 Conclusions

To model more detailed scenarios in LCA is time-consuming and it can thus be discussed how much effort to put in this issue. It is of primary importance that the scenario/dimensions be related to the goal and scope of the LCA study in question. For example if comparing alternatives which can be expected to encompass different maintenance and renovation processes, such scenario dimension descriptions should naturally be included to study the potential impacts related to this difference. For simplified LCA studies, for example related to early design, many processes and even life cycle stages may be omitted, thus also omitting the time spent on modeling scenario and constituent scenario dimensions.

With reference to the life-cycle variables identified in this report, below recommendations for scenario use in life-cycle work is summarized:

Dependant on the relative magnitudes of the impacts arising from material production and construction stages and the yearly impacts from the use stage, the relevance of an accurate building lifetime seems to vary (considering the aggregated yearly impacts). In some cases where the use-stage impacts are relatively high it has been shown that total impacts are not very sensitive at all. This is contrasted with other cases where a change in building life between 50 and 10 years has been shown to change the total GWP impact by up to 40 %. In light of policy intentions to reduce energy demand in buildings and increase share of renewable energy, it is considered that the effect accurate specification of building lifetime is only set to increase. Predictive methods that may be employed with advantage are those that have been applied in (van Nunen & Mooiman A, 2011).

A similar argument may be applied to separate exchangeable elements, although conditioned with the proviso that the total impacts from exchangeable elements seems according to evaluated cases to be less than for the lifetime of the building as a whole.

Energy demand may be able to be modeled with some accuracy with advanced modeling tools using a predictive scenario dimension technique. Better scenarios including dimensions taking into account behavioural studies may be necessary to better account for the effect of non-technical aspects, particularly user behavior, but also the development of process energy demand over the lifetime of the building.

Type of energy is very significant when considering impacts such as global warming potential. Here (as cited in the discussion above) it has been noted that the use of explorative scenario dimensions related to policy goals or institutional trends may be interesting, as long as such scenario dimensions can be established in a way that is suited to the building project e.g. where whole scenarios or scenario dimensions are generated on a regional basis and that these scenarios/dimensions can be used for each and every building project in a given region.

Finally, end-of-life is a life-cycle stage that is associated with the most uncertainty, and here it is useful to use explorative scenario dimensions also to describe possible outcomes in the light of this uncertainty.

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