LoRe-LCA

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

Methods and guidelines for sensitivity analysis, including results for analysis on case studies

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Definitions and Abbreviations

AP	Acidification Potential
CALCAS	Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability
CED	Cumulative Energy Demand
DHW	Domestic Hot Water
EP	Eutrophication Potential
GWP	Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
MVA	Multivariate Analysis
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
RES	Renewable Energy Sources
WP	Work Package

1 Introduction

"Low Resource consumption buildings and construction by use of LCA in design and decision making (LoRe-LCA)" is a project within the EU-FP 7.

LoRe-LCA aims to coordinate activities regarding the application of LCA in the European construction sector, focusing on comparing and improving the functional units used for LCA for whole buildings, improving the possibilities to compare results for different alternatives during design stage, and for comparison of results for different buildings. The project focuses on harmonisation and use of LCA-methods in design and decision-making for reaching overall goals of reduced resource consumption.

The main objectives of WP5 are to collect and analyse information on how LCA results are or could be interpreted including analysis of several indicators, normalisation and weigthing systems and sensitivity of the results.

2 Purpose and scope

The main purpose of this report is to collect information on different methods for sensitivity analyis and give some guidance on how sensitivity analysis can be carried out including the results of the case studies.

In accordance with ISO 14040 standard sensitivy analysis is a systematic procedure for estimating the effects of the choices made regarding methods and data on the outcome of a study. The same standard defines uncertainty analyisis as a systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability.
Although the ISO standard recommends the sensitivity and uncertainty analysis as part of an LCA study, guidence is not given for a systematic approach and a standard practice is still missing.

In LCA assessments for buildings, uncertainty can be due to differences in the conditions and assumptions, such as:

- data quality,
- building description,
- lifetime of the building,
- maintenance intervals,
- user behaviour,
- transport distance,
- system boundaries,
- electricity mix.

3 Sensitivity and uncertainty analysis methods

3.1 Types and sources of uncertainty

In accordance with Björklund (2002), uncertainty is due to lack of knowledge about the true value of a quantity. It should be distinguished from variability, which is attributable to the natural heterogeneity of values. Uncertainty can be reduced by more accurate and precise measurements. Variability cannot be reduced by further measurement, although better sampling can improve knowledge about variability.

Björklund (2002) lists the following types and sources of uncertainty:
- data inaccuracy: concerns the empirical accuracy of measurements that are used to derive the numerical parameter values
- data gaps: missing parameter values may leave the model with data gaps
- model uncertainty: model uncertainty is due to simplifications of aspects that cannot be modelled within the LCA structure
- uncertainty due to choices: for instance, choice of allocation rules, functional unit, system boundaries, characterisation method, weighting method
- spatial variability: variability stems from inherent fluctuations in the real world
- temporal variability: variations over time are relevant in both the inventory and impact assessment, or another aspect is the chosen time horizon to integrate potential effects, which, for instance, applies to global warming potentials (GWP)
- variability between sources and objects
- epistemological uncertainty: is due to the lack of knowledge on system behaviour, e.g a certain type of epistemological uncertainty arises when future systems are modelled, because the future is inherently uncertain
- mistakes: difficult to assess
- estimatimation of uncertainty: in itself a source of uncertainty

In the framework of CALCAS project, a survey on uncertainty aspects in LCA was carried out. The following classification of uncertainties was considered:
- parameter uncertainty: comes out from our incomplete knowledge about the true value of a parameter and it is generally due to measurement errors in input data
- model uncertainty: e.g. temporal and spatial characteristics lost by aggregation; linear instead non-linear models: derivation of characterisation factors.; lack of characterisation factors.
- scenario uncertainty: possible sources are represented by choices regarding functional unit, system boundaries, allocation procedures, how to asses future situations expected technology trends, weighting factors.

Uncertainty should be considered for an LCA inventory as well which is illustrated in Figure 1.
Mean values and standard deviation in the form of the 95% confidence interval are shown in relation to the POCP of ten different wall alternatives. Clear ranking between the options can be indentified if we consider the mean values only. However, if we take into consideration the confidence intervals as well, due to the overlapping of these intervals, the ranking becomes ambiguous.

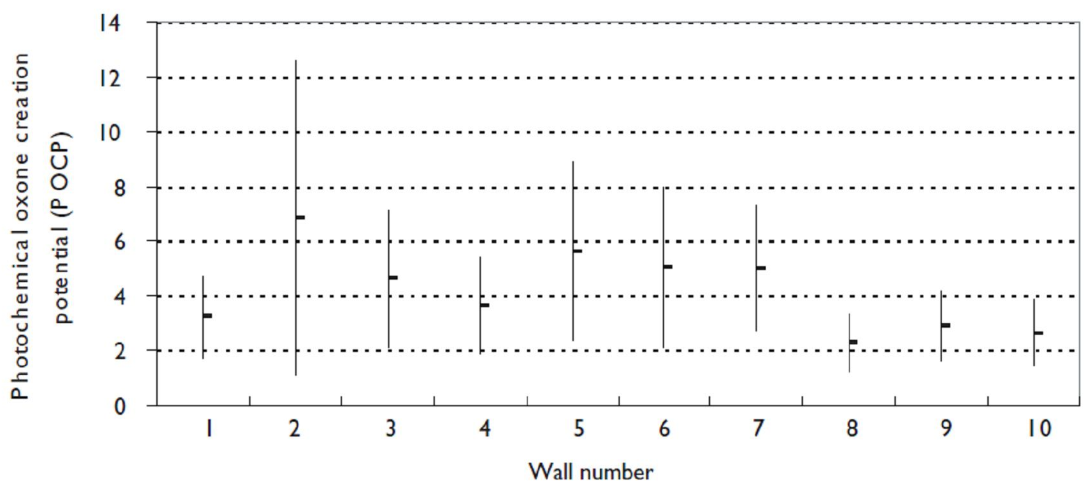


Figure 1
Source: Sensitivity and uncertainty,
Annex 31, Energy related environmental impact of buildings

3.2 Tools for sensitivity analysis

Björklund (2002) introduces different tools for sensitivity analysis, uncertainty importance analysis and uncertainty analysis.

Sensitivity is the influence that one parameter (the independent variable) has on the value of another (the dependent variable), both of which may be either continuous or discrete.
Uncertainty importance analysis focuses on how the uncertainty of different parameters contributes to the total uncertainty of the result.
Uncertainty analysis is a systematic procedure to ascertain and quantify the uncertainty introduced into the results of a life cycle inventory analysis due to the cumulative effects of input uncertainty and data variability.

Tools for sensitivity analysis

- One-way sensitivity analysis: determines the amount of an individual input parameter value needs to change, all other parameters held constant, in order for output parameter values to change by a certain percentage.
- Scenario analysis: involves calculating different scenarios, to analyse the influence of discrete input parameters on either output parameter values or priorities.
- Factorial design and multivariate analysis (MVA): changes in the discrete input variables are represented by the high and low levels in factorial design.
- Ratio sensitivity analysis: in ratio sensitivity analysis, which is applicable only in comparative studies, a ratio is calculated to determine the percentage an input parameter value needs to change in order to reverse rankings between two alternatives.
- Critical error factor: is a measure of the sensitivity of a priority between two alternatives to an input parameter value x.
- Tornado diagrams: illustrate the change in output parameter values for equal levels of change in input parameters.

Tools for uncertainty importance analysis

- Quantitative uncertainty importance analysis: can be performed
    - in the same manner as a sensitivity analysis by Tornado diagrams, but using known uncertainty ranges of input variables rather than the same variation for each input variable,
    - by calculating the correlation between model input and total model input, this is done by calculating the total model uncertainty with Monte Carlo simulation,
    - calculating relative sensitivity, the ratio of the standard deviation of a parameter over the critical error.

The table below shows the different tools for different combinations on input and output variables in LCA sensitivity analysis.

Input variable	**Output variable**	
	Parameter value	**Priority**
Paramater value	Tornado diagrams One-way sensitivity analysis	Ratio sensitivity analysis Critical error factor
Allocation rule	Scenario analysis Factorial design + MVA	Scenario analysis
Boundary	Scenario analysis Factorial design + MVA	Scenario analysis
Model	Scenario analysis Factorial design + MVA	Scenario analysis
Process	Scenario analysis Factorial design + MVA	Scenario analysis

Table 1

Source: BJÖRKLUND A.E (2002) Survey to improve reliability in LCA

In the *LCA Operational guide to ISO standards* (Guinée, 2001) the following three methods are discussed:

- Calculation of extreme values
  In this calculation the upper and lower values of each paramter are combined to find the upper and lower values of the end result, which seems to be a simple approach. However, Heijungs (1996) shows that testing of every combinatin of upper and lower values would take a very long time, therefore this kind of uncertainty analysis is not of much use in most LCAs.
- Formal statistics – uncertainty propagation
  Heijungs (1996) proposes that in this case one starts not by determining the upper and lower values of a given paramter but by assuming a particular distribution of the paramter values.
- Empirical statistics – Monte Carlo simulation
  Another technique to avoid the large number of combination of extreme values is stochastic modeling. This can be done with the aid of a Monte Carlo or Latin Hypercube simulation (Huijbregts, 1998a and 1998b). In the simulations a predefined, limited number of combinations (typically 10,000) of random parameters is used to calculate the results. In stochastic modeling, as opposed to formal statistic methods, is relatively easy to employ a variety of parameter distributions. The result of this tpye of analysis is a frequency chart of posssible outcomes.

4 Sensitivity results from the case studies

4.1 Case study in France

The building under study is a group of two attached houses built in 2007 in Picardy region, France (see Figure hereunder). These houses are the first certified "Passive-House" buildings in France.

Figure 2 General view of the two houses (Arch.: En Act architecture, contractor: les Airelles)

Each house is two-storied, with an inhabitable area of 132 m^2, a garage, a terrace, a balcony and a garden. Both include a hall, an office, a living-room and a kitchen downstairs, and a sitting room, a bathroom and three bedrooms upstairs. Only the situation of the garage differs. These dwellings are designed for a family of four persons. Wooden frame external walls are insulated by cellulose (22 cm) and polystyrene (15 cm), the slab by polystyrene (20 cm) and the attic by cellulose (40 cm). Triple-glazed windows and insulated external doors provide high insulation and air-tightness[1]. External venetian blinds provide solar protection during summer and mid-season. Thermal bridges are very low, supposed to be limited to 0,1 $W.m^{-1}.K^{-1}$ around the slab and the attic.

Both houses are equipped with a 30 m-long earth-to-air heat exchanger for summer cooling, with a heat recovery ventilation (average efficiency: 70%), with 5 m^2 of solar panels for solar water heating (solar fraction: 50%), and with a compact electric heat pump for the air heating and the water heating backup (average annual coefficient of performance: 3).

[1] The houses fulfill the Passivhaus label criterion: the air infiltration rate is inferior to 0,6 $vol.h^{-1}$ at 50 Pa pressure difference between inside and outside.

In order to evaluate the energy and environmental benefit of the passive house concept, a reference house has been defined, keeping the same geometry but considering technologies corresponding to the French thermal regulation level: 13 cm insulation in the walls, 14 cm in the ground slab and 22,5 cm in the roof, low emissivity double glazed windows, no heat recovery on ventilation, standard air tightness (total 0.6 ach ventilation + infiltration), no earth-to-air heat exchanger, no solar hot water system, standard boiler (87% annual efficiency) instead of a heat pump.

The sensitivity study concern two aspects inducing a high uncertainty on LCA results : the life span of the building, and occupants' behaviour.
The meteorological data used for the simulation correspond to the local climatic zone (oceanic climate). Ventilation, occupancy and internal heat gains are modelled by scenarios, considering two types of occupants' behaviour: economical, and spendthrift (see Table hereunder).

Table 2 Assumption regarding two types of occupants' behaviour

	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

Thanks to the implemented energy saving solutions described above, the heating load is very low if the occupants' behaviour is reasonable, see Table hereunder. The DHW load is also limited due to the solar system. On the other hand a spendthrift behaviour, increasing the temperature set point, hot water consumption and air exchange rate, reduces the performance of the house. The heat recovery and earth-air heat exchanger increase the electricity consumption for ventilation compared to the reference house.

Table 3 Calculated energy use of the houses

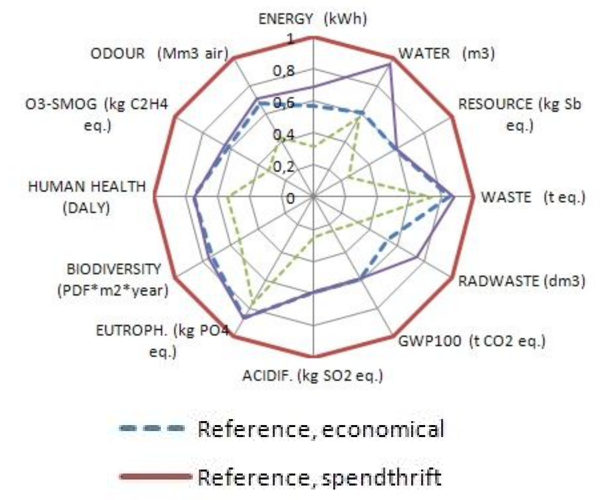
Energy use, kWh/m^2/yr	**Economical**		**Spendthrift**	
	passive house	reference house	passive house	reference house
Heating load	5	59	51	116

Energy use, kWh/m²/yr	**Economical**		**Spendthrift**	
Domestic Hot Water load	5	10	12	23
Cooking, Lighting, other Appliances	11	11	20	20
Ventilation	7	3	7	3
Total	28	83	*90*	*162*

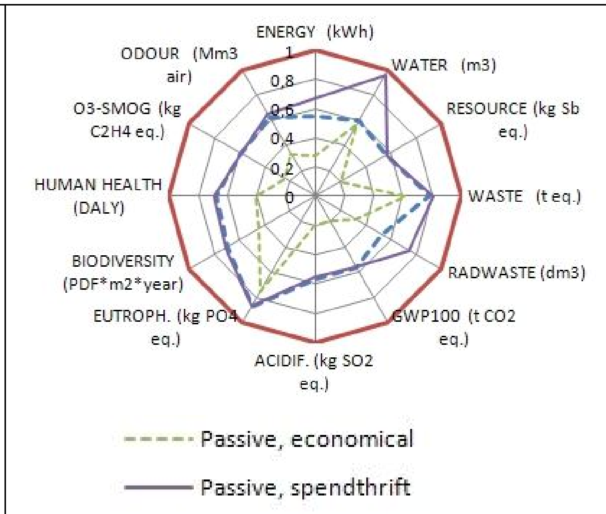
Regarding life cycle assessment, the material quantities have been derived from the 3D geometric model and wall composition data used for thermal simulation. A 5% surplus is added in order to account for on-site processes, broken elements and purchased quantities. An average 100 km transport distance (by truck) is considered from the factories to the building site, 20 km from the building site to incineration, and 2 km to landfill. The life span is 10 years for building finishes (painting), 30 years for windows and doors, and 50 years for the other elements and the whole building. End of life is modelled here very simply, assuming landfill for all demolition waste.

The French electricity production mix is the following: 78% nuclear, 14% hydro-electricity, 4% gas and 4% coal thermal plants. Using electricity for heating induces a high peak demand during cold days, e.g. 94,000 MW compared to around 60,000 MW in summer. This requires a larger use of thermal plants and imported electricity. For this reason, the European electricity production mix has been considered for the electricity consumed by the heat pump for space heating: 37% nuclear, 15% hydro-electricity, 10% gas, 28% coal and 10% fuel thermal plants. 9% losses are considered in the electricity grid, and 20% losses in the water mains.

The following Figure presents the comparative results for both occupancy scenarios (economical and spendthrift) and both performance levels (reference and passive houses). Each axis corresponds to an environmental impact indicator. The indicators are represented in relative values related to the worst case (reference house and spendthrift scenario) used as a reference. For instance, the CO_2 emissions are reduced by 40% thanks to a more appropriate behaviour, by 80% in the best case corresponding to the passive house and an economical behaviour. A sensitivity study has been performed regarding the building life span, considering 100 years instead of 50. This parameter is very uncertain, but the trend is very similar regarding the impact reduction obtained by higher construction quality and responsible behaviour.



Impacts over 50 years



Impacts over 100 years

Figure 3 LCA results from EQUER, comparison of occupants' behaviours

It is also useful to identify the source of the impacts in order to find ways to reduce them. The following graph shows the contribution of different life cycle stages in the global primary energy balance, assuming a 50 years life span. The indicator is expressed per m^2 inhabitable area and per year. Similar graphs could be drawn for other impacts. Construction related impacts are higher for the passive house due to increased insulation thickness, triple glazing and solar system, but impacts are reduced during the operation stage, see Figure hereunder.

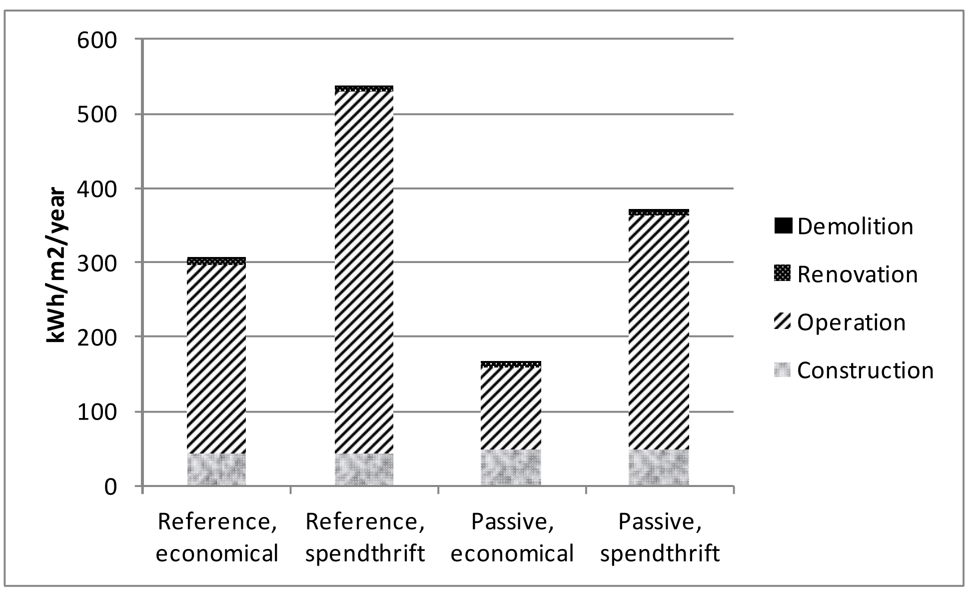


Figure 4 LCA results from EQUER, contribution of the life cycle stages

The table hereunder shows the sensitivity of each indicator to the life span, for each alternative (construction and occupancy). If only the operation phase was accounted for, the ratio between one indicator over 50 years and over 100 years would be 50%. The difference is higher due to the construction and end of life stages. It is near 50% for water consumption and radioactive waste (related to electricity consumption) due to the important contribution of the operation phase on these issues. On the other hand, inert waste is more influenced by the end of life of the building, so that the ratio is higher than 50%. The ratio is higher for a passive house and an economical behaviour, for which the energy and water consumption in the operation stage is lower.

50 years / 100 years (%)	Reference, economical	Reference, spendthrift	Passive, economical	Passive, spendthrift
ENERGY (kWh)	54%	52%	59%	54%
WATER (m3)	51%	50%	51%	51%
RESOURCE (kg Sb eq.)	56%	53%	69%	56%
WASTE (t eq.)	79%	73%	86%	79%
RADWASTE (dm3)	51%	50%	52%	51%
GWP100 (t CO2 eq.)	55%	53%	67%	56%
ACIDIF. (kg SO2 eq.)	55%	53%	66%	56%
EUTROPH. (kg PO4 eq.)	52%	52%	52%	52%
BIODIVERSITY (PDF*m2*year)	62%	58%	70%	63%
HUMAN HEALTH (DALY)	69%	62%	84%	68%
O3-SMOG (kg C2H4 eq.)	57%	54%	72%	59%
ODOUR (Mm3 air)	63%	58%	75%	63%

Table 4

These results show the possibility to reduce dramatically most environmental impacts by combining efforts made by professionals in the design and construction of low impact buildings, and made by inhabitants to adopt a more sustainable behaviour. The life span does not influence the ranking of the different alternatives, so that the results can be considered robust.

4.2 Case study in Spain – Campus of the University of Zaragoza

The description of the building, the objectives of the case study, the input data, the entire LCA results and detailed sensitivity calculations can be found under deliverable D4.3.

4.2.1 System boundaries

4.2.1.1 Simplified LCA

This sensitivity analysis compares the results obtained in the entire LCA with those obtained by simplifying the analysis.

The calculations show that an error of 14% and 23% for embodied energy impact and GWP impact respectively is estimated for the simplified analysis.

4.2.1.2 Broadening the system boundaries: incorporating urban mobility

This analysis compares the results obtained in the entire LCA with those obtained by incorporating urban mobility needs into the limits of the building's use stage.

The calculations show that the impact in equivalent CO_2 emissions associated with mobility is 2.3 times greater than the impact in the use stage of the building accounting for water consumption, energy and maintenance.

Therefore, including mobility within the limits of the LCA of the CIRCE building, this would provide 48% of the building's GWP. Similar figures are obtained if we analyse in terms of embodied primary energy.

4.2.2 Lifetime of the building

In this sensitivity analysis different lifetimes of 25, 50, 75, 100 and 125 years have been considered. In order to achieve comparability of the results, the annualized impact (in terms of GWP) has been assessed keeping the maintenance intervals constant.

The impact reduction is very significant as building’s lifetime is increased. In fact if we compare a lifetime 25 years with a lifetime of 50 years, a total reduction of 36% in the annualized GWP impact is obtained. The reduction is particularly significant in the production stage.

Obviously the impact of the building operation (including the operational energy use and the operational water use and wastewater treatment) is the same for the different building lifetime values. Consequently only the maintenance impact is increased in the use stage.

4.2.3 Electricity mix

This sensitivity analysis evaluates the influence of electric mix considered in LCA calculations on the results of the impact indicators GWP and Total score – Eco-indicator 99.

To this end, 4 different electricity mixes are compared: Spanish electricity mix, the average electricity mix in Europe estimated according to the statistics of UCTE-Union for the Co-ordination of Transmission of Electricity member countries -actually ENTSO-E European Network of Transmission System Operators for Electricity-, and 2 electricity mix scenarios. The first scenario considers a share of RES of 40% in the electricity mix, whereas the second scenario considers a share of RES of 80%.

Considering the average European electricity mix instead of the Spanish electricity mix, there is virtually no variation in the total GWP of the building (the increase of the impact is less than 1%).

Considering scenario 1, the decrease in total GWP is 8.1%. This decrease is greater in the use stage, where the reduction is 15%. In the production stage, the reduction is 5%, whereas in the other stages is virtually no variation.

Moreover, considering the scenario 2, the total GWP reduction is 15%. Again, in the use stage, the decrease obtained is higher (29%). While the decrease in the production stage is 9%, and in the other stages there is no variation.

Similar conclusions can be obtained by analyzing the influence of the electric mix on the Total Score – Eco-indicator 99.

4.2.4 Eco-indicator 99 - normalization and weighting factors

This sensitivity analysis evaluates the results obtained when considering the use of the three perspectives in the Eco-indicator 99 method: egalitarian, individualist and hierarchist.

The difference in the Total Score obtained with the different approaches is much higher in the production stage, with a rate of 73% (comparing the H/A approach with the I/I approach).

The difference between the H/A approach and the E/E approach in the Total Score is 11%, whereas between the H/A approach and the I/I approach, the difference stands as high as 42%. In the I/I approach, the most significant change is in the "minerals" assessment. Also "resp. organics", "climate change" and "ozone layer" present values higher than 100% compared to the figures for H/A approach. In addition, "fossil fuels" is not considered in the I/I approach. Regarding the E/E approach, the most important difference in is in the "carcinogens" assessment.

When analyzing the damage categories, in the I/I approach, the most important difference is in the "resources" assessment, which present a value higher than 80% in comparison with the H/A approach value. Regarding the E/E approach, the main change (+25%) is in the "ecosystem quality" assessment.

4.2.5 GWP time horizon

Commonly, a time horizon of 100 years is used by regulators. However, other time interval (e.g. 20 years, 500 years) can also be considered.
In this analysis, the results of the GWP impact of the building, considering a time horizon of 20, 100, and 500 years, are assessed.

Assuming a time horizon of 20 years, the GWP is increased by 10% compared to the common approach (100 years). However, if a time horizon of 500 years, the GWP is decreased by 4% compared to the common approach.

4.2.6 Transport distance from the factory gate to the building site

Regarding transport from the factory gate to the building site, a 20-28 t lorry at half load covering an average distance of 100 km (except for the graded aggregate, for which a distance of 15 km was taken into account) was considered as default.

This sensitivity analysis considers other means of transport and different distances.

The building's life cycle impact is evaluated in terms of GWP, assuming that all the building materials (except for the graded aggregate) and energy equipment are transported by a 20-28 t lorry at half load covering different distances from the factory gate to the building site: 50 km, 100 km, 200 km, 500 km, 1,000 km, 2,000 km and 5,000 km. For the graded aggregate, a distance of 15 km has been maintained.

The calculation shows that if the transport distance from the factory gate to the building site is lower than 200 km, the construction process stage involves an impact less than 10% of the total life cycle impact.

4.3 Case study in Spain – New dwelling in Zaragoza

The description of the building, the objectives of the case study, the input data, the entire LCA results and detailed sensitivity calculations can be found under deliverable D4.3.

4.3.1 System boundaries

4.3.1.1 Simplified LCA

This sensitivity analysis compares the results obtained in the entire LCA with those obtained by simplifying the analysis.

The calculations show that an error of 15% for both embodied energy impact and GWP impact is estimated for the simplified analysis. However, when considering the Total Score – Eco-indicator 99 impact, the error is higher (27%). Therefore, a greater number of studies would be required to draw relevant conclusions about this simplification proposal.

4.3.2 Cut-off rules

According to the system of the German Sustainable Building Council, all the building materials which have less than 1% of the total weight (inputs) of the building and the impact in the life cycle (outputs) due to the fact, that these materials make up less than 1% of the entire energy demand, GWP, or other impacts categories e.g. AP and EP can be neglected. An additional rule sets, that the sum of the neglected materials shall not be larger than 5% of the total weight and impacts of the building.

This section analyzes the results of applying this cut-off rule. Applying this cut-off rule, only doors and windowpanes could be negligible.

As a conclusion, in order to justify adequate cut off rules, it is essential to identify correctly the influent material flows in the building.

4.3.3 Lifetime of the building

In this sensitivity analysis different lifetimes of 25, 50, 75, 100 and 125 years have been considered. In order to achieve comparability of the results, the annualized impact (in terms of GWP) has been assessed keeping the maintenance intervals constant.

The impact reduction is very significant (particularly in the production stage) as building's lifetime is increased. For instance, when comparing a lifetime of 50 years with a lifetime of 100 years, a total reduction of 16% in the annualized GWP impact is obtained.

The impact of the building operation is not affected by the building lifetime. However, the impact of the maintenance on the use stage is slightly higher as the building lifetime is greater.

4.3.4 Maintenance intervals

This sensitivity analysis considers different maintenance intervals of 15, 25, 35 years.
Only the replacement of some building elements (materials and energy equipment) is taken into account. In all cases, a static LCA approach is considered, that it is to say the overall standard of the building is maintained as when it was built (but not improved).

Due to the static LCA approach considered, the impact obviously decreases as maintenance interval is greater. In fact, if we compare a maintenance interval of 15 years with an interval of 35 years, a total reduction of 13% in the GWP impact is obtained. Logically there are no changes in the impact of the production, construction and end-of-life stages.

As the impact of the building operation is not affected by the frequency of the maintenance, the impact of the maintenance on the use stage is higher as the maintenance interval is greater. For instance, if an interval of 15 years is considered, the maintenance impact represents 25% of the impact of the use stage. However, assuming an interval of 35 years, the maintenance impact reaches only 5% of the impact of the use stage.

4.3.5 CML2 normalization factors

This section evaluates the results obtained when considering the use of four different normalization factors in the CML2 method.

- W90: World (1990).
- W95: World (1995).
- WE95: West Europe (1995).
- NL97: The Netherlands (1997).

Results show that there are not significant differences between the impacts considering the normalization factors “World (1990)” and “World (1995)”. However, when selecting the normalization factors “West Europe (1995)”, the impacts are increased significantly, and the largest increase is found in the impacts obtained with the normalization factors “The Netherlands (1997)”. CML suggests choosing the whole world or an average world citizen for one year as reference system for all impact categories.

4.3.6 Transport distance from the factory gate to the building site

This sensitivity analysis considers other means of transport and different distances.

The building’s life cycle impact is evaluated in terms of GWP, assuming that all the building materials and energy equipment are transported by a 20-28 t lorry at half load covering different distances from the factory gate to the building site: 50 km, 100 km, 200 km, 500 km, 1,000 km, 2,000 km and 5,000 km.

The calculation shows that if the transport distance from the factory gate to the building site is lower than 200 km, the construction process stage involves an impact less than 6% of the total life cycle impact.

4.4 Case study in Hungary – New family house, Szombathely

The description of the building, the aim of the case study, the methodology, the input data and the results can be found under deliverable D4.3.

4.4.1 Lifetime of the building

A sensitivity analysis has been carried considering lifetimes of 50, 75 and 100 years for all the three different design options. The results are summarised and shown in the tables and charts below.

Option 1

Lifetime (years)	CED (MJ-Eq/m^2/year)	GWPa 100 (kg CO_2-Eq/m^2/year)	AP (kg SO_2-Eq/m^2/year)	ODP (kg CFC-11-Eq/m^2/year)	POCP (kg ethylene-Eq/m^2/year)	EP (kg PO_4-Eq/m^2/year)
50	701,34	40,27	7,57E-02	6,62E-06	6,29E-03	6,45E-03
75	685,44	39,16	7,17E-02	6,52E-06	6,02E-03	5,93E-03
100	682,68	38,94	7,12E-02	6,50E-06	5,98E-03	5,83E-03

Table 5 Total impact considering all phases for Option 1

Lifetime (years)	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
50	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
75	97,73%	97,24%	94,82%	98,58%	95,71%	91,89%
100	97,34%	96,70%	94,12%	98,21%	95,18%	90,37%

Table 6 Ratio of results relative to results for 50 years

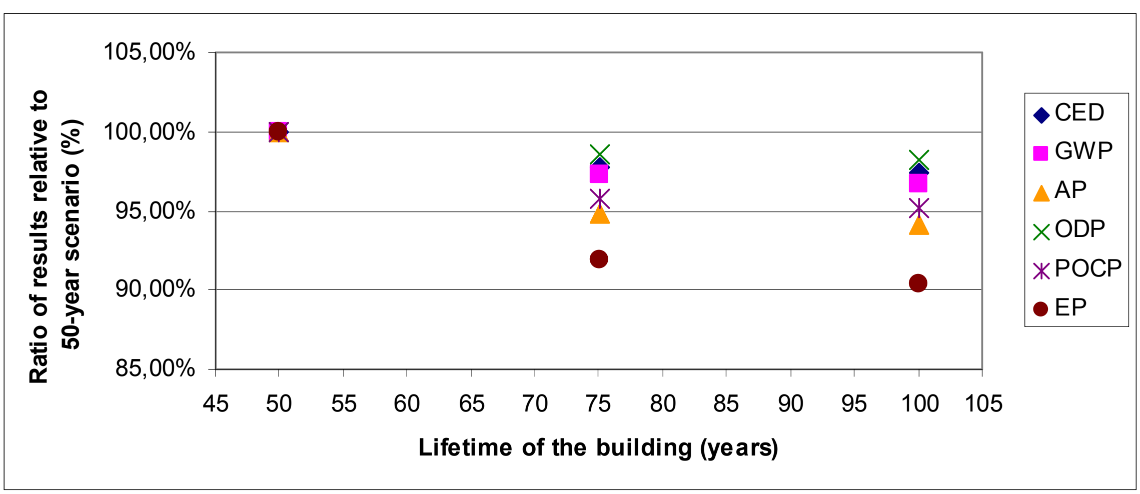


Figure 5

Option 2

Lifetime (years)	CED (MJ-Eq/m^2/year)	GWPa 100 (kg CO_2-Eq/m^2/year)	AP (kg SO_2-Eq/m^2/year)	ODP (kg CFC-11-Eq/m^2/year)	POCP (kg ethylene-Eq/m^2/year)	EP (kg PO_4-Eq/m^2/year)
50	537,85	30,22	7,41E-02	4,05E-06	5,98E-03	6,69E-03
75	516,23	28,74	6,94E-02	3,95E-06	5,54E-03	6,05E-03
100	513,73	28,53	6,87E-02	3,92E-06	5,53E-03	5,92E-03

Table 7 Total impact considering all phases for Option 2

Lifetime (years)	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
50	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
75	95,98%	95,10%	93,62%	97,45%	92,73%	90,40%
100	95,52%	94,41%	92,65%	96,83%	92,47%	88,44%

Table 8 Ratio of results relative to results for 50 years

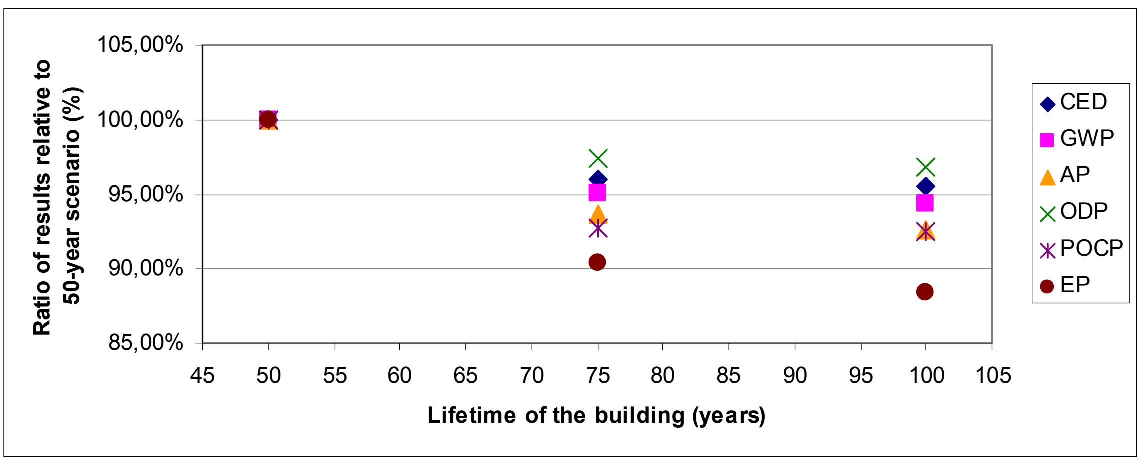


Figure 6

Option 3

Lifetime (years)	CED (MJ-Eq/m^2/year)	GWPa 100 (kg CO_2-Eq/m^2/year)	AP (kg SO_2-Eq/m^2/year)	ODP (kg CFC-11-Eq/m^2/year)	POCP (kg ethylene-Eq/m^2/year)	EP (kg PO_4-Eq/m^2/year)
50	336,34	20,22	5,05E-02	2,70E-06	4,71E-03	5,36E-03
75	314,55	18,72	4,56E-02	2,60E-06	4,27E-03	4,71E-03
100	312,1	18,52	4,49E-02	2,57E-06	4,26E-03	4,58E-03

Table 9 Total impact considering all phases for Option 3

Lifetime (years)	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
50	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
75	93,52%	92,59%	90,45%	96,16%	90,61%	87,91%
100	92,79%	91,59%	89,07%	95,22%	90,33%	85,48%

Table 10 Ratio of results relative to results for 50 years

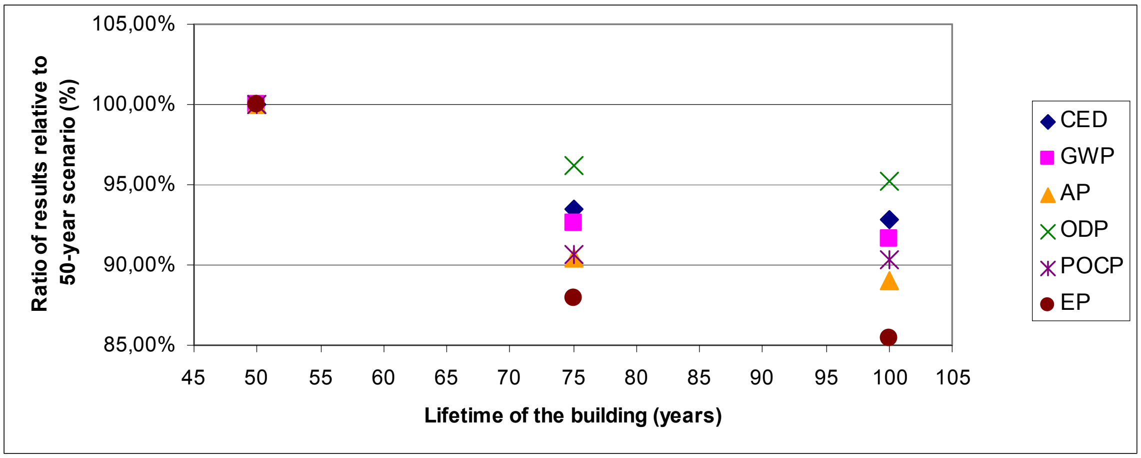


Figure 7

It has also been investigated whether the different lifetimes change the ranking between the different options. The tables and diagrams below show the results of this investigation.

Indicator	Option 1	Option 2	Option 3
50-year lifetime			
CED	100,0%	76,7%	48,0%
GWPa 100	100,0%	75,0%	50,2%
AP	100,0%	98,0%	66,7%
ODP	100,0%	61,2%	40,9%
POCP	100,0%	95,1%	75,0%
EP	96,4%	100,0%	80,1%
75-year lifetime			
CED	100,0%	75,3%	45,9%
GWPa 100	100,0%	73,4%	47,8%
AP	100,0%	96,4%	63,4%
ODP	100,0%	60,5%	39,9%
POCP	100,0%	92,1%	71,0%
EP	98,0%	100,0%	77,9%

Indicator	Option 1	Option 2	Option 3
100-year lifetime			
CED	100,0%	75,3%	45,7%
GWPa 100	100,0%	73,3%	47,6%
AP	100,0%	96,4%	63,1%
ODP	100,0%	60,3%	39,6%
POCP	100,0%	92,4%	71,1%
EP	98,5%	100,0%	77,4%

Table 11

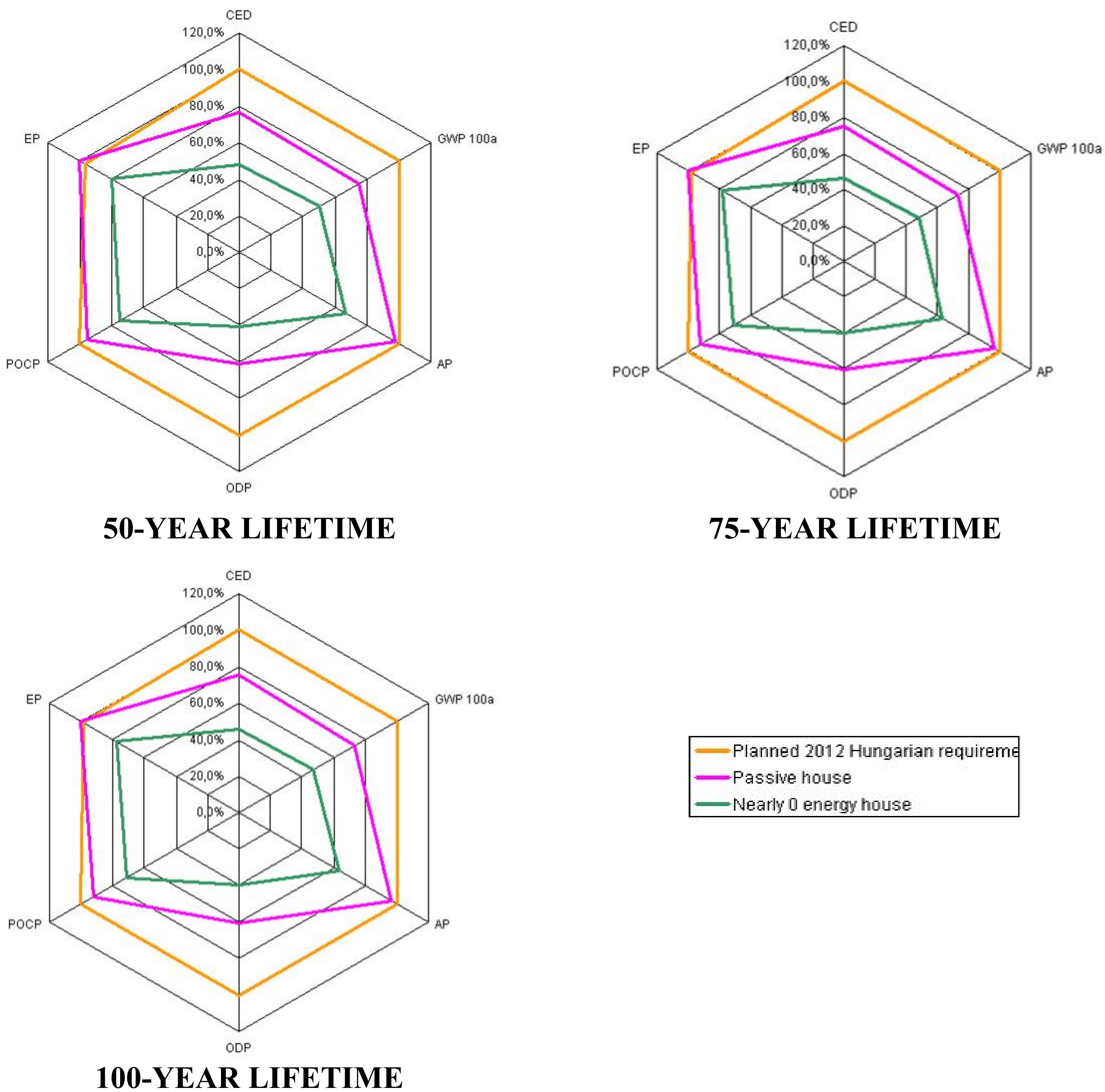


Figure 8

Sensitivity on the Eco-indicator 99 scores

The tables and chart below show the total Eco-indicator scores for different building lifetimes for all the three options.

Lifetime (years)	Option 1	Option 2	Option 3
50	36954	27218	20252
75	53555	38497	28019
100	71065	50963	37002

Table 12 Total scores

Lifetime (years)	Option 1	Option 2	Option 3
50	100,00%	73,65%	54,80%
75	100,00%	71,88%	52,32%
100	100,00%	71,71%	52,07%

Table 13 Total scores relative to Option 1

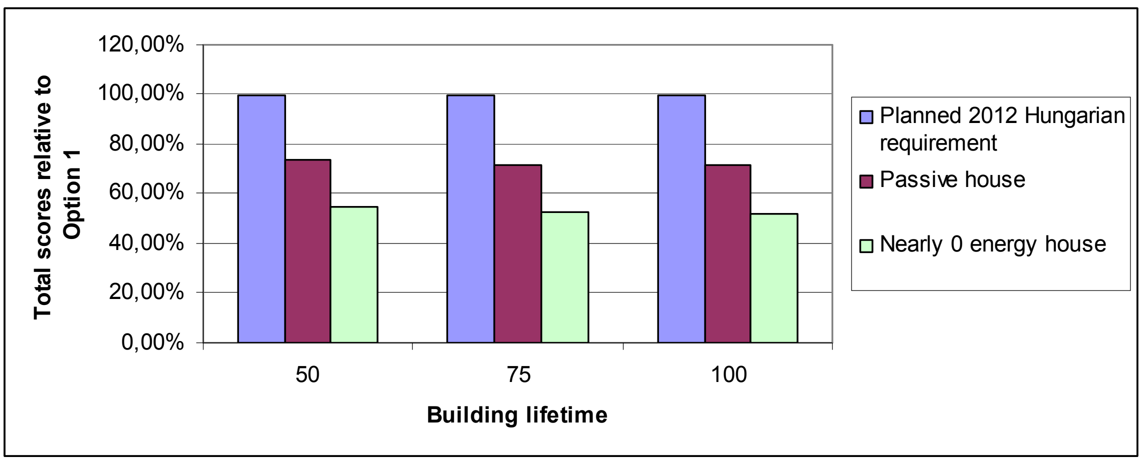


Figure 9

Conclusion

It can be concluded that different lifetime scenarios can have a significant effect on the final results when they are expressed in the form of annual values.
The reduction in the results for higher lifetimes is mainly due to the fact that the initial construction phase is divided by a larger number while the annual operation impact remains the same. However, this reduction slows down and compensated by the maintenance which increases with time.

For all the three options the lowest and highest reduction can be seen for ODP and EP respectively.

It can also be noticed that the lower the consumption of the building, i.e. the environmental impact during the operation phase, the final result is more sensitive. E.g. the reduction is 97,34%, 95,52% and 92,79% for Option 1, Option 2 and Option 3 respectively in the case of CED. The situation is the same for each indicator. The reason of this that the part of the operation phase from the total impact (e.g. 91%, 81% and 65% for Option 1, Option 2 and Option 3 respectively for CED) is different for each option and the less of this part the more reduction can be seen.

On the other hand, when the different options were compared to each other considering 50, 75 and 100 years lifetime, the result of the comparison remained the same, i.e. for each indicator no changes occurred in the ranking. The same was observed for the Eco-indicator scores.
It means, that the different lifetimes did not have any effect on the comparison exercise, which was the main aim of the study.

4.4.2 Maintenance intervals

Sensitivitiy analysis with average, high and low maintenance intervals was carried out for each option considering a building lifetime of 75 years.

The average, high and low maintenance intervarls for different materials are summarised in the table below.

Enclosure	Material	High		Average		Low	
		Lifetime	Replace-ments needed	Lifetime	Replace-ments needed	Lifetime	Replace-ments needed
Exterior Walls	Painting	6	12	8	9	10	7
	Plaster (inside)	30	2	40	1	60	1
	Ceramic masonry block	100	0	100	0	100	0
	Adhesive mortar	25	2	30	2	45	1
	Polystyrene foam	25	2	30	2	45	1
	Adhesive mortar	25	2	30	2	45	1
	Plaster (outside)	25	2	30	2	45	1
Garage Wall	Painting	6	12	8	9	10	7
	Plaster	30	2	40	1	60	1
	Ceramic masonry block	100	0	100	0	100	0
	Adhesive mortar	30	2	40	1	60	1
	Polystyrene foam	30	2	40	1	60	1
	Adhesive mortar	30	2	40	1	60	1
	Plaster	30	2	40	1	60	1
Floor above garage	Wooden parquet	15	4	20	3	30	2
	Polyethylene fleece	15	4	20	3	30	2
	Concrete screed and RC slab	100	0	100	0	100	0
	Polystyrene foam	30	2	40	1	60	1
	Adhesive mortar	30	2	40	1	60	1
	Plaster (inside)	30	2	40	1	60	1
	Painting	6	12	8	9	10	7
Slab on ground floor	Ceramic tiles	25	2	30	2	50	1
	Adhesive mortar	25	2	30	2	50	1
	Wooden parquet	15	4	20	3	30	2
	Concrete screed	100	0	100	0	100	0
	Polyurethane rigid foam	100	0	100	0	100	0
	1 layer of bituminous sheet DPC	100	0	100	0	100	0
	Sand	100	0	100	0	100	0
	Gravel	100	0	100	0	100	0

Enclosure	Material	High		Average		Low	
		Lifetime	Replace-ments needed	Lifetime	Replace-ments needed	Lifetime	Replace-ments needed
Roof (without tile)	Timber rafter	100	0	100	0	100	0
	Mineral wool	30	2	40	1	50	1
	PE foil	30	2	40	1	50	1
	Gypsum plaster board	30	2	40	1	50	1
	Painting	6	12	8	9	10	7
Wooden window with double/triple glazing and wooden entrance door		30	2	40	1	50	1
Gas boiler		15	4	20	3	25	2
Solar collector		15	4	25	2	30	2
Solar cells		20	3	30	2	40	1

Table 14

The results of the analysis are shown in the tables and charts below.

Option 1

Maintenance intervals	CED (MJ-Eq/m^2/year)	GWPa 100 (kg CO_2-Eq/m^2/year)	AP (kg SO_2-Eq/m^2/year)	ODP (kg CFC-11-Eq/m^2/year)	POCP (kg ethylene-Eq/m^2/year)	EP (kg PO_4-Eq/m^2/year)
High	697,40	39,89	7,51E-02	6,58E-06	6,22E-03	6,32E-03
Average	685,44	39,17	7,20E-02	6,52E-06	6,02E-03	5,93E-03
Low	677,25	38,73	6,98E-02	6,48E-06	5,84E-03	5,71E-03

Table 15 Total impact considering all phases for Option 1

Maintenance intervals	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
High	101,74%	101,85%	104,28%	100,88%	103,46%	106,64%
Average	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Low	98,81%	98,89%	96,98%	99,31%	97,15%	96,41%

Table 16 Ratio of results relative to average results

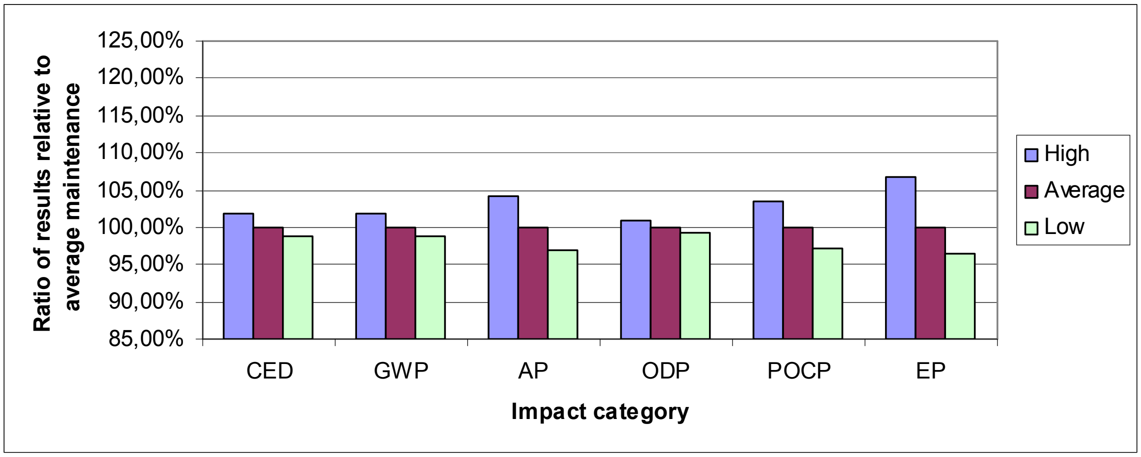


Figure 10

Option 2

Maintenance intervals	CED (MJ-Eq/m²/year)	GWPa 100 (kg CO_2-Eq/m²/year)	AP (kg SO_2-Eq/m²/year)	ODP (kg CFC-11-Eq/m²/year)	POCP (kg ethylene-Eq/m²/year)	EP (kg PO_4-Eq/m²/year)
High	539,05	30,13	7,57E-02	4,03E-06	5,99E-03	6,85E-03
Average	516,23	28,74	6,94E-02	3,95E-06	5,54E-03	6,05E-03
Low	499,89	27,80	6,51E-02	3,88E-06	5,07E-03	5,56E-03

Table 17 Total impact considering all phases for Option 2

Maintenance intervals	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
High	104,42%	104,83%	109,16%	102,25%	108,10%	113,14%
Average	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Low	96,83%	96,73%	93,82%	98,29%	91,40%	91,92%

Table 18 Ratio of results relative to average results

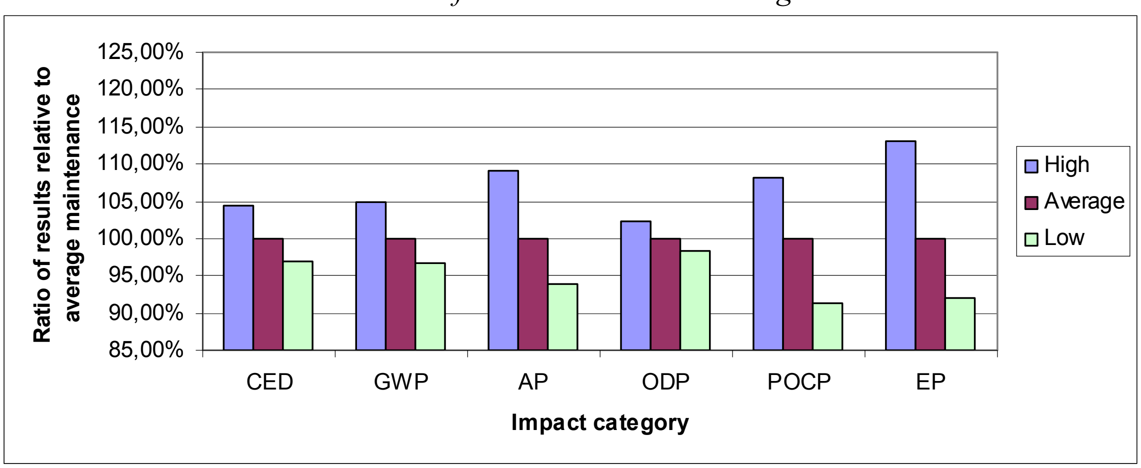


Figure 11

Option 3

Maintenance intervals	CED (MJ-Eq/m^2/year)	GWPa 100 (kg CO_2-Eq/m^2/year)	AP (kg SO_2-Eq/m^2/year)	ODP (kg CFC-11-Eq/m^2/year)	POCP (kg ethylene-Eq/m^2/year)	EP (kg PO_4-Eq/m^2/year)
High	344,42	20,54	5,46E-02	2,71E-06	4,87E-03	5,77E-03
Average	314,55	18,72	4,56E-02	2,60E-06	4,27E-03	4,71E-03
Low	294,69	17,57	4,03E-02	2,53E-06	3,74E-03	4,11E-03

Table 19 Total impact considering all phases for Option 3

Maintenance intervals	CED (%)	GWPa 100 (%)	AP (%)	ODP (%)	POCP (%)	EP (%)
High	109,49%	109,72%	119,66%	104,26%	114,16%	122,52%
Average	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Low	93,68%	93,84%	88,39%	97,38%	87,58%	87,20%

Table 20 Ratio of results relative to average results

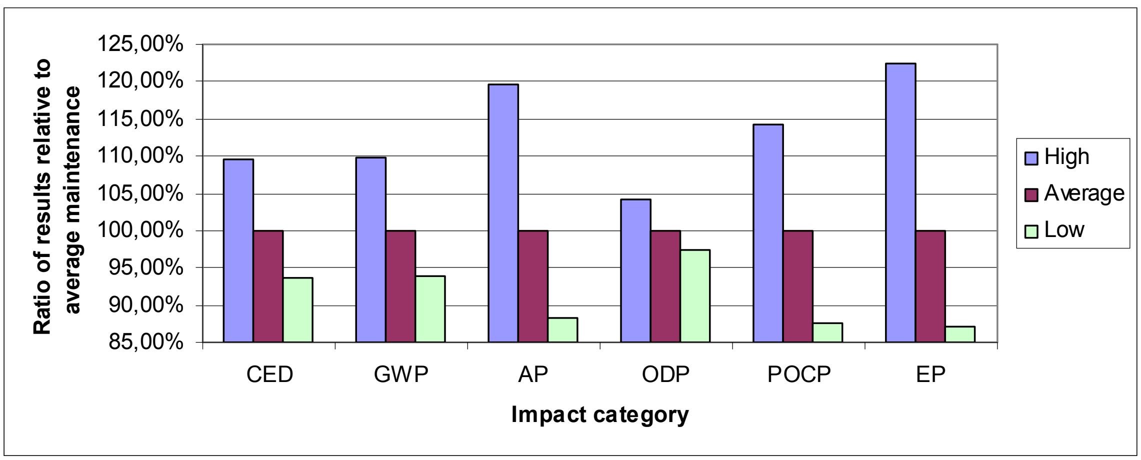
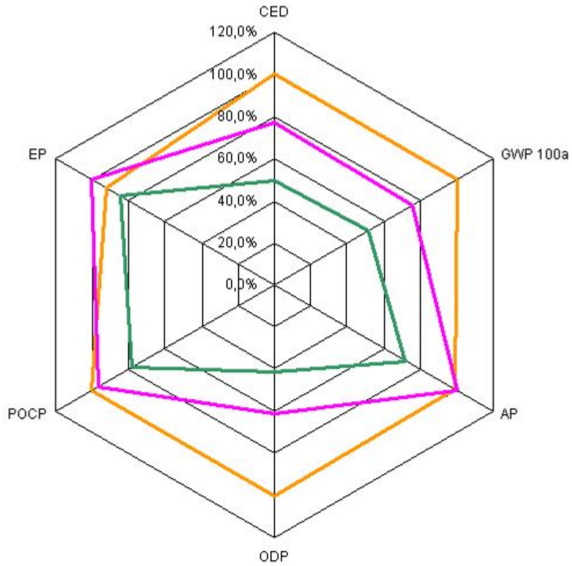


Figure 12

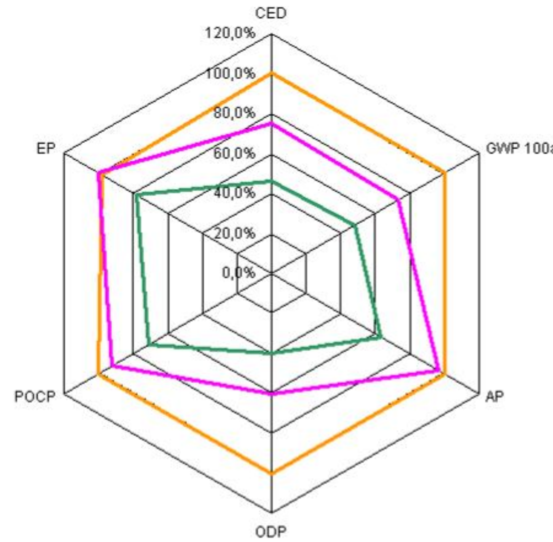
It has also been investigated whether the different maintenance intervals change the ranking between the different options considering a building lifetime of 75 years. The tables and diagrams below show the results of this investigation.

Indicator	Option 1	Option 2	Option 3
High maintenance intervals			
CED	100,0%	77,3%	49,4%
GWPa 100	100,0%	75,5%	51,5%
AP	**99,1%**	**100,0%**	**72,1%**
ODP	100,0%	61,3%	41,2%
POCP	100,0%	96,3%	78,3%
EP	92,3%	100,0%	84,3%
Average maintenance intervals			
CED	100,0%	75,3%	45,9%
GWPa 100	100,0%	73,4%	47,8%
AP	**100,0%**	**96,4%**	**63,4%**
ODP	100,0%	60,5%	39,9%
POCP	100,0%	92,1%	71,0%
EP	**98,0%**	**100,0%**	**77,9%**
Low maintencance intervals			
CED	100,0%	73,8%	43,5%
GWPa 100	100,0%	71,8%	45,4%
AP	100,0%	93,2%	57,8%
ODP	100,0%	59,9%	39,1%
POCP	100,0%	86,7%	64,0%
EP	**100,0%**	**97,3%**	**71,9%**

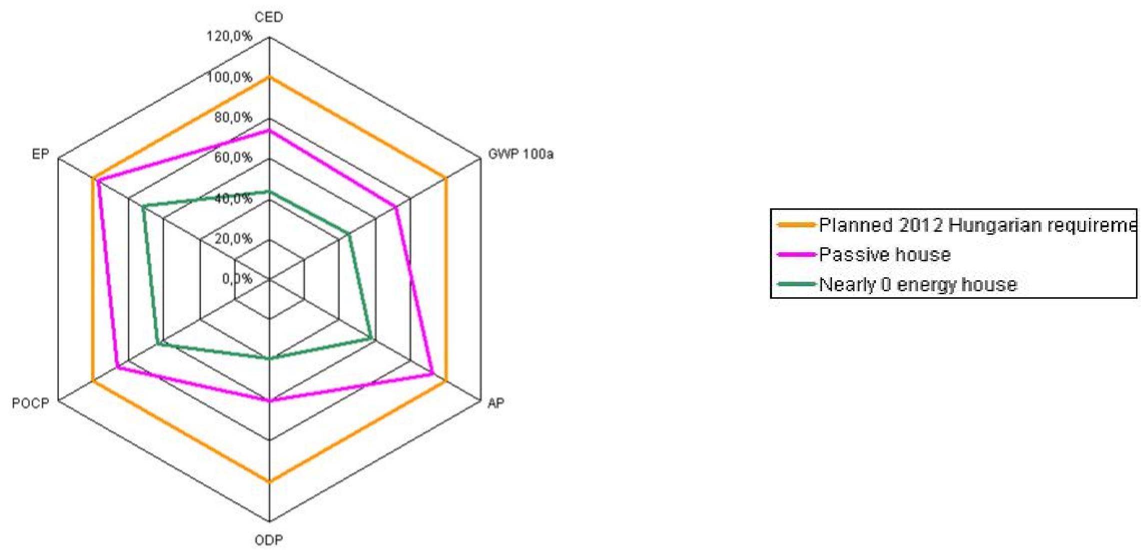
Table 21



HIGH MAINTENCANCE INTERVALS



AVERAGE MAINTENANCE INTERVALS



LOW MAINTENANCE INTERVALS

Figure 13

Sensitivity on the Eco-indicator 99 scores

The tables and chart below show the total Eco-indicator scores for different maintenance intervals for all the three options for a building lifetime of 75 years.

Maintenance intervals	Option 1	Option 2	Option 3
High	54943 (102,6%)	40888 (106,2%)	31466 (112,3%)
Average	53555 (100,0%)	38497 (100,0%)	28019 (100%)
Low	52603 (98,2%)	36769 (95,5%)	25937 (92,6%)

Table 22 Total scores

Maintenance intervals	Option 1	Option 2	Option 3
High	100,00%	74,42%	57,27%
Average	100,00%	71,88%	52,32%
Low	100,00%	69,90%	49,31%

Table 23 Total scores relative to Option 1

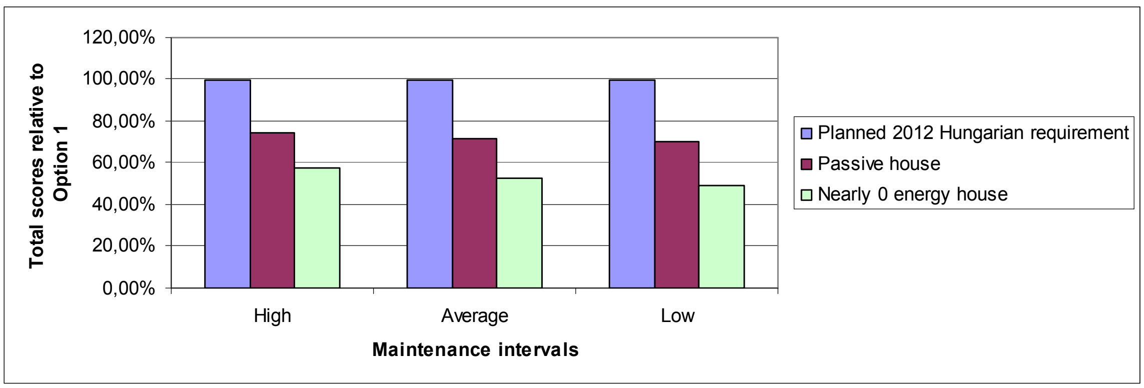


Figure 14

Conclusion

It can be concluded that different maintenance intervals scenarios can have an effect on the final results.

For all the three options the lowest and highest changes can be seen for ODP and EP respectively.

It can also be noticed that the lower the consumption of the building, i.e. the environmental impact during the operation phase, the final result is more sensitive. E.g. the ratio of the results for the high and low maintenance intervals relative to the average maintenance ranges from 98,81% to 101,74%, from 96,83% to 104,42% and from 93,68% to 109,49% for Option 1, Option 2 and Option 3 respectively in the case of CED. The situation is the same for each indicator and it is also the same for the Eco-indicator 99 scores. The reason of this that the part of the operation phase from the total impact (e.g. 91%, 81% and 65% for Option 1, Option 2 and Option 3 respectively for CED) is different for each option and the less of this part the more change can be seen.

On the other hand, when the different options were compared to each other considering high, average and low maintenance intervals, the result of the comparison almost remained the same.

Those cases where the ranking changed are in red in the tables above. It means, that in some cases the different maintenance intervals had an effect on the comparison exercise, which was the main aim of the study. However, this effect was quite slight as it limited to one indicator only and might be considered negligible. This can be supported by the comparison of the single value Eco-indicator scores where no changes occurred in the ranking.

4.5 Case study in Sweden – New Multifamily Buildings

The description of the building, the aim of the case study, the methodology, the input data and the results can be found under deliverable D4.3.

4.5.1 Scope, input data and results

The sensitivity analyses carried out here are carried out with respect to two key variables in the above study, namely lifetime of the building and specific global warming potential of energy mix. The values that are used for energy mix are shown in the table below. Each energy mix that is used in the analysis is named low Swedish, medium Swedish and high Swedish. This nomenclature refers to the fact that electricity and to a large extent district heating production in Sweden has a very low GWP in general compared to other countries internationally.

Name of energy mix scenario dimension	District heating		Electricity	
	GWP, g CO_2-e/kWh	Justification	GWP, g CO_2-e/kWh	Justification
Low Swedish Impact	5.2	This is the value used by the local municipality for their work with climate change	5.2	This local distribution network uses only Swedish hydroelectricity, based on (Vattenfall, 2005)
Medium Swedish Impact	30	This GWP is a reasonable (but low) figure for district heating in Sweden, based on (SABO, 2010)	20	This is an average GWP for Sweden electricity production (SABO, 2010)
High Swedish Impact	106	This is average GWP for Stockholm district heating from (SABO, 2010)	85	This is an average GWP for Nordic electricity production from (SABO, 2010)

Table 24 Values for Global Warming Potential (GWP) that are used in this sensitivity analysis, and their relation to the Swedish energy infrastructure.

Results for the sensitivity analyses are shown in the table and figures below.

	Wooden frame			Solid wood			Concrete		
	Low	Med.	High	Low	Med.	High	Low	Med.	High
Common input data									
Bought energy during the use phase, (kWh/m2 (HFA), year)									
District heating	38,3	38,3	38,3	35,4	35,4	35,4	41,3	41,3	41,3
Electricity	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0	35,0
Specific GWP for types of energy, g CO2 -e/kWh									
Electricity	5,2	20	85	5,2	20	85	5,2	20	85
District heating	5,2	30	106,5	5,2	30	106,5	5,2	30	106,5
Cases with 50 year lifetime									
GWP for material production, kg CO2 -e/m^2 (HFA), year	1,43	1,43	1,43	1,56	1,56	1,56	4,50	4,50	4,50
GWP for bought energy demand during use phase, kg CO2 /m2 (HFA), year	0,38	1,85	7,05	0,37	1,76	6,75	0,40	1,94	7,38
Total GWP, kg CO2 -e/m2 (HFA), year	1,81	3,28	8,49	1,93	3,32	8,31	4,89	6,44	11,88
GWP impacts relative to 50 year lifetime	100%	100%	100%	100%	100%	100%	100%	100%	100%
GWP impacts relative to base case energy mix	100%	181%	468%	100%	172%	431%	100%	132%	243%
GWP impacts relative to other building alternatives	100%	100%	100%	106%	101%	98%	270%	196%	140%
Cases with 100 year lifetime									
GWP for material produktion, kg CO2 -e/m2 (HFA), year	0,72	0,72	0,72	0,78	0,78	0,78	2,25	2,25	2,25
GWP for bought energy demand during use phase, kg CO2 /m2 (HFA), year	0,38	1,85	7,05	0,37	1,76	6,75	0,40	1,94	7,38
Total GWP, kg CO2 -e/m2 (HFA), year	1,10	2,56	7,77	1,15	2,54	7,53	2,64	4,19	9,63
GWP impacts relative to 50 year lifetime	61%	78%	92%	59%	77%	91%	54%	65%	81%
GWP impacts relative to base case energy mix	100%	234%	708%	100%	222%	656%	100%	158%	364%
GWP impacts relative to other building alternatives	100%	100%	100%	105%	99%	97%	241%	163%	124%

Table 25 Results for Swedish sensitivity analyses (results also shown in the following charts)

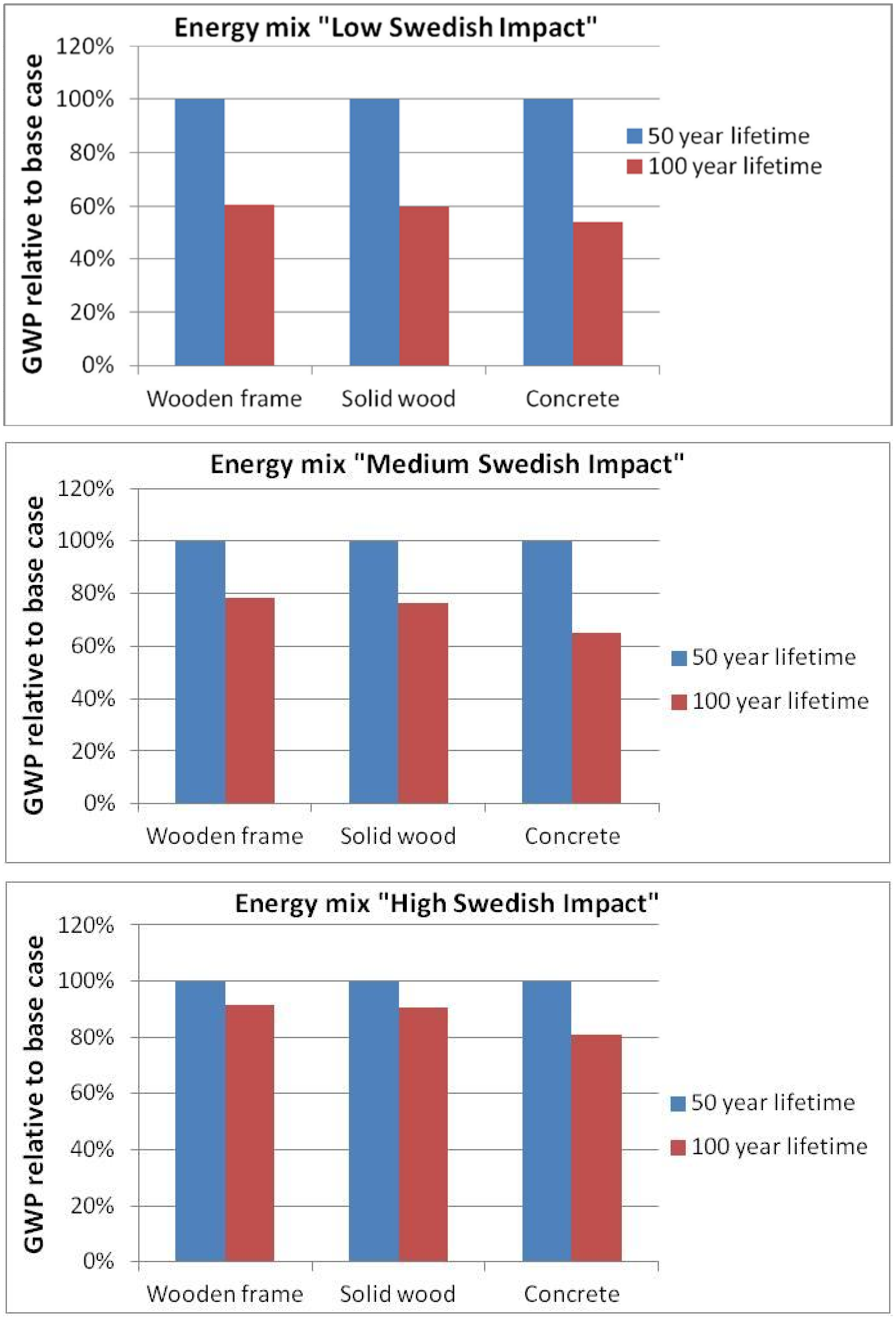
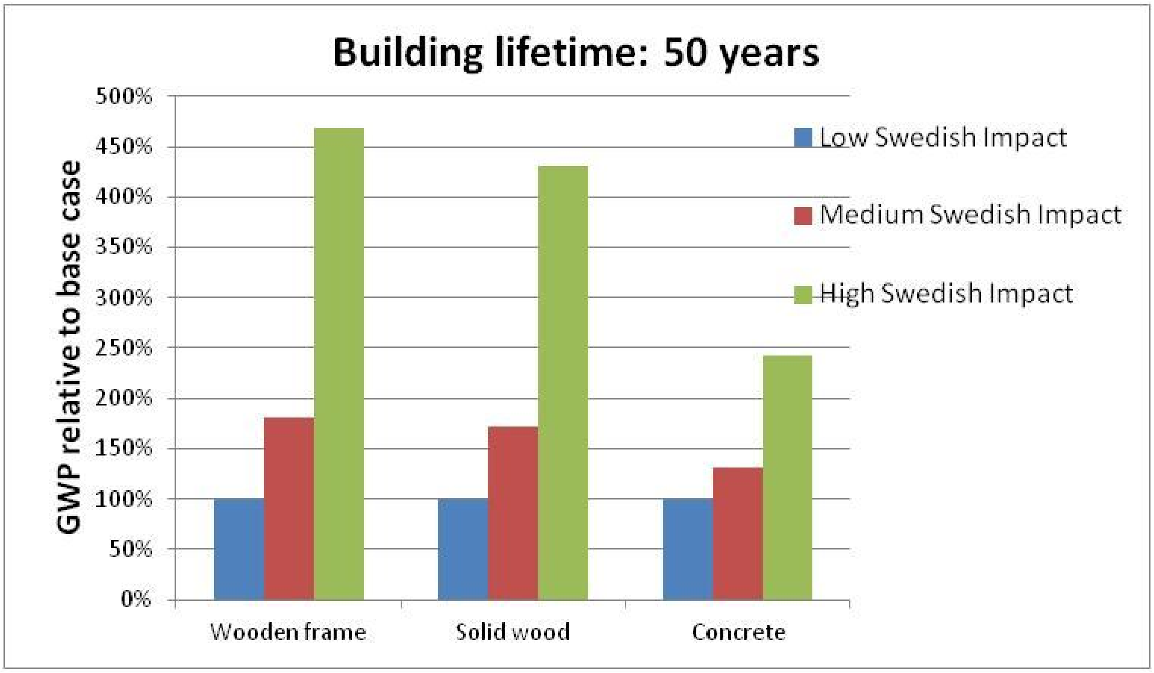


Figure 15 Results of sensitivity analyses varying building lifetime between 50 and 100 years



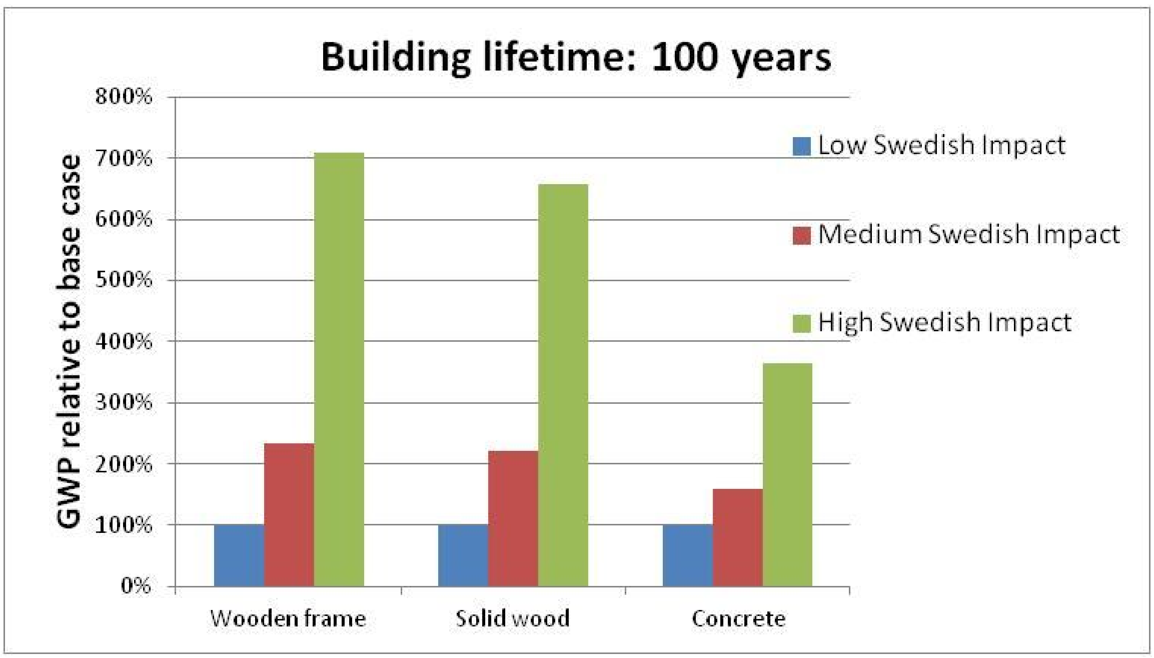


Figure 16 Results of sensitivity analyses varying energy mix

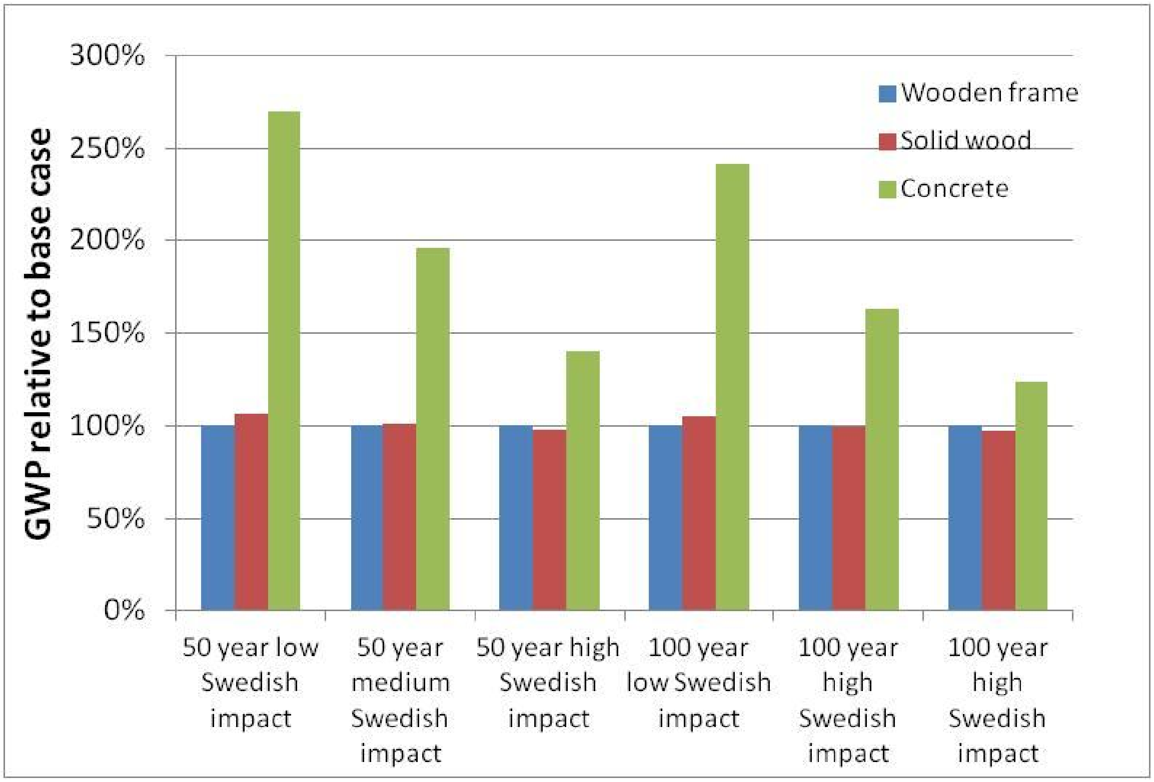


Figure 17 Results of sensitivity analyses comparing different building alternatives

4.5.2 Sensitivity analysis of building lifetime

Figure 15 shows that compared to the relevant base case alternative, the total GWP impact of the construction changes by between 46 % and 8 % depending on which energy mix and building type. That such a large variation as 46 % is observed is due to the very large proportion of total impacts that are due to material production in the low Swedish impact energy mix. That this variation is larger than in other sensitivity analyses in this report is due to the fact that low Swedish impact is low both compared to general Swedish energy mix impacts and particularly to international energy mix impacts.

4.5.3 Sensitivity analysis of energy mix

Figure 16 shows the energy mix has a very large effect on the total GWP impacts, with increases in impacts of up to 700 %. Inspection of Table 24 reveals that the reason for such a large variation is due to the fact that low Swedish impact energy mix has such a low impact by Swedish and particularly international standards. A connection should be drawn between Figures 15 and 16, where the large increase in relative impacts for higher impact energy mixes (shown in Figure 16) reflects the relative decrease in sensitivity to building lifetime that is observed for higher impact energy mixes seen from top to bottom in Figure 15.

4.5.4 Comparison of building alternatives in light of sensitivity analyses

As seen in Figure 17, when lifetime and energy mix are specified, the two wood alternatives are very close to one another in all cases. A dramatic difference between the comparison between the wood and the concrete alternatives can be seen however: For 50 year lifetime and low impact energy mix, total impacts are fully 270 % higher than the reference wood frame alternative. This compares with 124 % of total impacts compared to the reference wood frame alternative for the high impact mix and 100 year lifetime. It seems that in both of the cases mentioned, the analysis would still recommend a wood alternative. Having said that, there is a large relative difference in these comparisons, and for slightly higher impact energy mixes than the high Swedish impact alternative, the difference between the reference wood frame alternative and the concrete alternative would be so small that (in light of the uncertainties implicit in the LCA) the analysis could not rationally recommend a wood alternative over the concrete.

4.6 Case study in Austria – Biogenic CO_2

The complete case study can be found under deliverable D4.3.

In this case study different end-of-life scenarios including the cut-off method and several substituion options have been compared for 1 kg timber material.

In the substitution options the burdens caused by waste incineration operated with a electricity co-generation is assigned to the timber battens whereas the burdens caused by energy production at that time is subtracted.

The four substitution options considered different energy mixes as follows:

1 Substitution with IEA Baseline 2050 world energy mix.
2 Substitution with IEA Tech Plus 2050 world energy mix.
3 Substitution with Greenpeace / EREC energy (r)evolution mix 2050.
4 Substitution with Austrian Energy mix 2050 (forecast of IBO/Austrian Institute for healthy buildings).

The results of the study can be seen in the figure below.

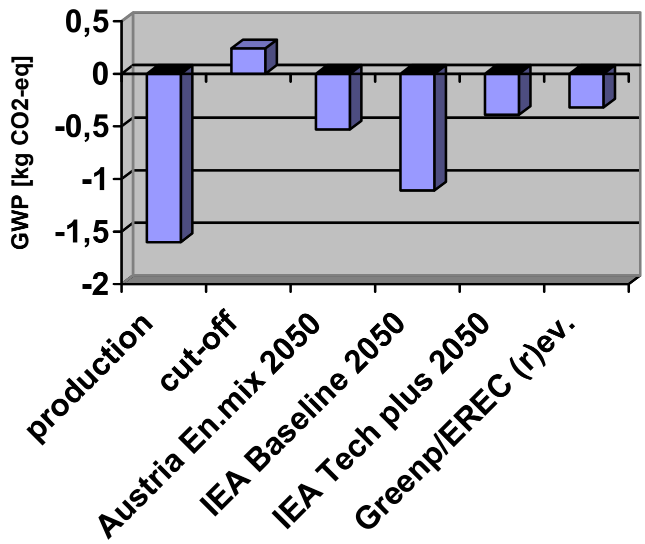


Figure 18

In the graph the "production" of the material results in a negative GWP which is due to the uptake of CO_2 during the growth of the tree.
The "cut-off" furthermore has all emissions from burning the material and re-emitting the incorporated biogenic carbon. The positive GWP is owed to the energy consumed during forestry, transport, production and demolishing processes.
Substitution models give a negative GWP since the recovered energy leads to a bonus that is subtracted. The bonus is bigger if the substituted energy has more burdens, e.g. has a large fossil fraction.

It can be seen that the substitution method is extremely sensitive regarding the subsituted energy carrier considered.
The ratio of the results relative to the Austrian Energy mix 2050 is given in the table below.

Energy mix	Ratio
Austrian Energy mix 2050	100 %
IEA Baseline 2050 world energy mix	209 %
IEA Tech Plus 2050 world energy mix	74 %
Greenpeace / EREC energy (r)evolution mix 2050	60 %

Table 26

In addition to the above, there are also uncertainties relating to the waste incineration, as the efficiency of co-generation can vary to a great degree.

5 Synthesis of sensitivity results from the case studies

In the case studies two different types of LCA assessements and sensitivity analysis can be seen.

The first type is when there is no comparison between design alternatives and only the sensitivity of final result of one alternative is investigated.
The aim of such an LCA study could be to determine the environmental impact of an existing or new building and, for instance, get a single value for each indicator or an aggregated weighted value which could be used for ranking a building in accordance with a predetermined ranking system or calculating whether a building meets a particular requirement.
In that case the aim of the sensitivity analysis was to find out how big was the effect on the final result due to using various input data for one variable, while all other variables remained constant, comparing it to a base scenario and expressing it in percentage relative to the base scenario. This is similar to scenario analysis as described in section 3.2.

The second type is when design alternatives for the same building are compared to each other. The aim of such an LCA study could be to help decision making by choosing the alternative which has less environmental impact.
In that case the aim of the sensitivity analysis was to identify whether the different input data for one variable, while all other variables remained constant, changed the ranking between the different options or not. Getting the same ranking means that the variable investigated does not affect the aim of the LCA study and make its result more robust. This is similar to ratio sensitivity analysis as described in section 3.2, however a ratio was not calculated to determine the percentage of the input parameter value needs to change in order to reverse rankings between the two alternatives.

The table below shows some of the outcome of the first type sensitivity analysis where the reduction in percentages compared to the base scenario can be seen. In the first column the variable parameter and the indicator investigated is given with the base and changed scenario.

Variable parameter and indicator	Reduction in the final result							
	Case Study – Spain Zaragoza University	Case Study – Spain Zaragoza Dwelling	Case Study - Hungary Option 1	Case Study - Hungary Option 2	Case Study - Hungary Option 3	Case study – Sweden Wooden fram	Case study – Sweden Solid wood	Case study – Sweden Concrete
Building lifetime – GWP 100a [kg CO_2-Eq/m^2/year] 50 years → 100 years*	18%	16%	3%	6%	8%	22%	23%	35%
Building lifetime – EP [kg PO_4-Eq/m^2/year] 50 years → 100 years	-	-	10%	12%	15%	-	-	-
Maintenance intervals – GWP 100a [kg CO_2-Eq/m^2/year] High maint. → Low maint.**	-	13%	3%	8%	16%	-	-	-
Maintenance intervals – EP [kg PO_4-Eq/m^2/year] High maint. → Low maint.**	-	-	10%	21%	35%	-	-	-
System boundary – GWP 100a [kg CO_2-Eq] Complete LCA → Simplified LCA	23%	15%	-	-	-	-	-	-
Electricity mix – GWP 100a [kg CO_2-Eq] Spanish mix → 80% RES	15%	-	-	-	-	-	-	-
Electricity mix – GWP 100a [kg CO_2-Eq/m^2/year], (50 years) High Swedish Impact → Medium Swedish Impact	-	-	-	-	-	61%	60%	46%
GWP time horizon [kg CO_2-Eq] GWP 20ys → GWP 100ys	9%	-	-	-	-	-	-	-
Transport distance – GWP 100a [kg CO_2-Eq] 500 km → 100 km	11%	11%	-	-	-	-	-	-

Table 27

* Considering the “Medium Swedish Impact” in the Swedish case study

** In the Spanish case studies high maintenance is 15 years and low maintenance is 35 years. In the Hungarian case studies maintenance intervals for different materials are given in section 4.4.2.

The next table below shows the outcome of the second type sensitivity analysis indicating whether the ranking between two design options changes or not due to difference scenarios considered. In this comparison exercise confidence intervals of the results were not taken into consideration.

Variable parameter	Indicator	Ranking changed				
		Hungarian case study		French case study	Swedish case study	
		Option 1 ↔ Option 2	Option 2 ↔ Option 3	Reference ↔ Passive	Wooden frame ↔ Solid wood	Solid wood ↔ Concrete
Building lifetime 50 ↔ 100 years	CED	No	No	-	-	-
	GWP100	No	No	No	No*	No*
	AP	No	No	No	-	-
	ODP	No	No		-	-
	POCP	No	No	No	-	-
	EP	No	No	No	-	-
	ENERGY	-	-	No	-	-
	WATER	-	-	No	-	-
	RESOURCE	-	-	No	-	-
	WASTE	-	-	No	-	-
	RADWASTE	-	-	No	-	-
	BIODIVERSITY	-	-	No	-	-
	HUMAN HEALTH	-	-	No	-	-
	ODOUR	-	-	No	-	-
	ECO-INDICATOR 99	No	No	-	-	-
User's behaviour Economical ↔ Spendthrift	ENERGY	-	-	No	-	-
	WATER	-	-	No	-	-
	RESOURCE	-	-	No	-	-
	WASTE	-	-	No	-	-
	RADWASTE	-	-	No	-	-
	GWP100	-	-	No	-	-
	ACIDIF.	-	-	No	-	-
	EUTROPH.	-	-	No	-	-
	BIODIVERSITY	-	-	No	-	-
	HUMAN HEALTH	-	-	No	-	-
	O3-SMOG	-	-	No	-	-
	ODOUR	-	-	No	-	-
Maintenance intervals High ↔ Average / Average ↔ Low	CED	No / No	No / No	-	-	-
	GWP100	No / No	No / No	-	-	-
	AP	Yes / No	No / No	-	-	-
	ODP	No / No	No / No	-	-	-
	POCP	No / No	No / No	-	-	-
	EP	No / Yes	No / No	-	-	-
	ECO-INDICATOR 99	No / No	No / No	-	-	-

Table 28

* For all the three electricity mix options.

6 Conclusion and recommendations

It can be seen from the percentages of the first table in section 5, that considering different scenarios for a given building, the final result can vary quite a lot and the reduction can easily reach 10% or higher.
It was noticed, that for building lifetimes and maintenance intervals, the better the building, i.e. the less the total impact, this reduction is getting higher.
Huge differences can be seen in the Swedish case study when different electricity mixes are compared.

This investigation confirms that a single data for a building (e.g. kg CO_2-Eq/m^2/year) must be accompanied by all the input information relating to the scenario used otherwise the interpretation can be misleading.
This is the same when we set a particular requirement for a building, e.g. the cumulative energy demand/m^2/year for the whole life cycle must be below a certain level. When an LCA assessment is carried out for such a purpose, sensitivity analysis might be neglected provided the scenario to be used for a given requirement is adequately defined.

The second table of section 5 shows that the building lifetime range chosen and the different user's behaviour did not affect the ranking between the different options, which made the result more robust from these points of view. The result of this comparison might have been different if the difference between the total impact of options in the base scneario had been smaller.
In addition, we should not forget about the uncertainty in the results when we compare two mean values in order to make a ranking between two alternatives since confidence intervals can overlap and make the ranking ambiguous as described in section 3.1.

In the case studies investigated different maintenance intervals for some indicators changed the ranking, but this effect was considered minor which was confirmed by comparing single weighted Eco-indicator 99 points.

For both types of sensitivity analysis discussed in section 5, scenario analysis can be considered as a simple an adequate tool to deal with uncertainty. However, all important variable paramaters need to be investigated considering a real and sensible range in the input data. More work could be done to compile and harmonise such input ranges.

Further investigation is also recommended to harmonise methods in relation to determinining uncertainty and confidence intervals of LCA inventories.

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