D6.1 Guidelines on Environmental and Cost Integrated Approach for Systemic Packages

Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

iNSPiRe

Project Title: Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

Project Acronym: iNSPiRe

Deliverable Title:

D6.1 Guidelines on Environmental and Cost Integrated Approach for Systemic Packages

Dissemination Level: PU

Lead beneficiary: CYCLECO

Marion Sié, CYCLECO

Jérôme Payet, CYCLECO

Date: September 30th, 2015

This document has been produced in the context of the iNSPiRe Project.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 314461. All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability. For the avoidance of all doubts, the European Commission has no liability in respect of this document, which is merely representing the authors view.

Table of Contents

1 Definitions ... 1
1.1 Glossary ... 1
1.2 Acronyms ... 1
2 Introduction ... 2
3 Life Cycle Assessment Method overview ... 2
3.1 Principle ... 2
3.2 Standards ... 2
3.3 Steps ... 2
3.4 Tools ... 4
4 Life Cycle Cost Method overview ... 5
4.1 Principle ... 5
4.2 Standards ... 5
4.3 Steps ... 5
4.4 Tools ... 6
5 Goal definition ... 7
5.1 Framework ... 7
5.2 Organisations involved ... 8
5.3 Period ... 8
5.4 Perspectives ... 9
5.5 Specific objectives ... 9
5.6 Decision context ... 10
5.7 Reporting ... 11
6 Scope definition ... 12
6.1 Functional unit ... 12
6.2 System boundaries ... 13
6.3 Economic boundaries ... 14
6.4 Management of multi-functionalities ... 14
7 Inventory elaboration ... 15
7.1 Background and foreground system ... 15
7.2 Data collection ... 15
7.3 Modelling method ... 16
7.4 Life cycle inventory calculation ... 16

8 Impacts assessment....18
8.1 Environmental impacts assessment....18
8.2 Global cost assessment....21
9 Interpretation....22
9.1 Hot spot analysis....22
9.2 Sensitivity analysis....22
10 References....23

1 Definitions

1.1 Glossary

Discount rate: It is a factor used to convert cash flows occurring at different times to a referential date – usually, it is the construction date – in order to allow aggregating or comparing them.

Elementary flows: These are the flows of pollutants and resources between the technosphere and nature. More specifically they describe (a) the material or energy entering the system being studied, which has been drawn from the environment without previous human transformation and (b) material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation.

Inventory: List of elementary flows entering or exiting the system under study.

Technosphere: The part of the physical environment affected through modification by humans.

1.2 Acronyms

CTUe: Comparative Toxic Unit for ecosystems

CTUh: Comparative Toxic Unit for humans

DHW: Domestic Hot Water

EDK: Energy Distribution Kit

EGK: Energy Generation Kit

FU: Functional Unit

H/C: Heating and Cooling

ILCD: International Life Cycle Data system

ISO: International Standard Organisation

LCA: Life Cycle Assessment (stand for environmental life cycle assessment)

LCC: Life Cycle Costing (stand for life cycle costs assessment)

LCI: Life Cycle Inventory (stand for environmental life cycle inventory)

LCIA: Life Cycle Impacts Assessment

PM: Particulate matter

PV: Present Value

SRP: Systemic Renovation Packages

WP: Work package

2 Introduction

The iNSPiRe project aims to design, develop and industrialize buildings components, kits and systemic packages for deep energy renovation of buildings, both in the residential and tertiary sectors. The sustainability of the solutions being developed, in particular their benefits on primary energy savings, is checked and assessed using Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methods.

This report presents the method implemented for LCA and LCC of materials and components developed in the framework of iNSPiRe project. Firstly an overview of both generic methods is provided (chapters 3 and 4). Secondly a detailed description of each step of the assessments is provided from the definition of goals to the results interpretation (chapters 5 to 9).

3 Life Cycle Assessment Method overview

3.1 Principle

LCA is an accounting method for environmental impacts of products, goods, and services. It is mainly used for comparison purposes between products fulfilling the same function. LCA assesses and sums up the environmental impacts of a product or a service over its whole life cycle, including manufacturing, use, and end of life. Partly terminated systems can also be assessed in case data on some life cycle steps are unavailable or present high uncertainties or are similar for each solutions compared, for instance the so-called “cradle to gate” assessments. It uses several indicators to express impacts. For instance, climate change, primary energy consumption, particulate matter formation, eco-toxicity.

3.2 Standards

In the framework of the iNSPiRe project, we used the LCA methodology to perform the environmental assessments of building materials and components. This methodology is described in standards and guides of best practices. The LCA made within iNSPiRe project relies on the following documents:

- ISO 14040-44 (ISO, 2006a, 2006b)
- ILCD Handbook (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010)
- EN 15978 (AFNOR, 2012)

3.3 Steps

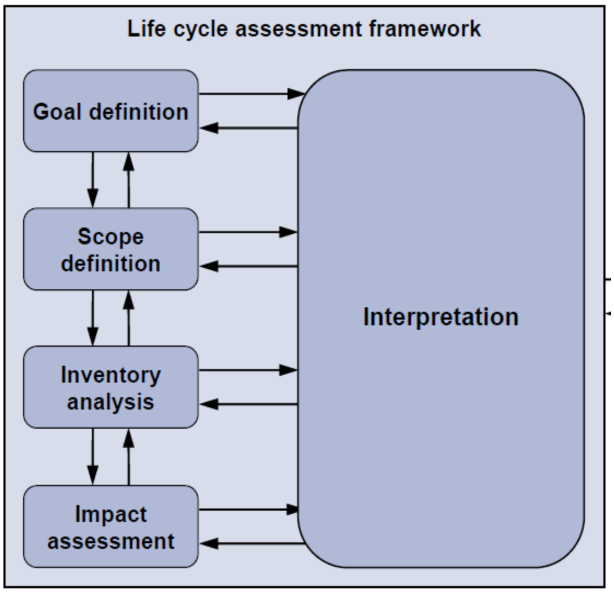

Figure 1: Life Cycle Assessment steps (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010)

Figure 1 shows the stages that compose an LCA study:

- In the first step of an LCA study, the analyst states all the objectives that the study aims to meet as well as the target audience to whom the results of the study will be communicated. The assumptions made all along the environmental assessment have to consider the objectives of the study.
- In the second phase, the LCA analyst will specify the functional units that will be investigated, the system boundaries (i.e., all the processes investigated in the environmental study), all the impact categories considered relevant for the study and all the limits of the study.
- Then, the analyst will realize an input and output inventory of the product under study. The inventory analysis includes all the materials, resources, and energy, necessary through the whole life cycle (i.e., extraction of the raw materials, manufacture, transport, use, and end-of-life) of a product. At this stage, it must be taken care of the coherence of the data and of their reliability.
- In the impact assessment, the potential environmental impacts of the inputs and outputs – as described above – are evaluated through the use of a methodology approved by an international consensus. At the end of this step some preliminary conclusions can be drawn. These conclusions need to be checked and validated during the interpretation step.
- In the interpretation phase, the LCA analyst checks and improves the assumptions and the data used along the study, while identifying the hotspots of the environmental analysis. At that point, the iteration of previous steps is done in order to improve the accuracy of data in particular the one corresponding to the hotspots. Then, the analyst studies the sensitivity of results and conclusions related to the pending assumptions and data uncertainties. This step takes place all along the study and at the very end, in a last

step, when the analyst validates the conclusions and the achievement of the objectives of the study.

3.4 Tools

We will use the following tools to perform an LCA study of the products and the components developed in the framework of the iNSPiRe project:

- Databases: In order to carry out the inventory, it is necessary to possess a reliable Life Cycle Inventory (LCI) database which links processes and services with emissions and extraction of substances to and from the ecosphere. To answer to this need, we will use three databases as a reference:
  - The European reference Life Cycle Database (ELCD) (Joint Research Centre, 2006). This database was released in 2006 and is freely available online. The development of this database is supported by the Joint Research Centre of the European Commission. It comprises LCI data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management. The respective data sets are officially provided and approved by the named industry association.
  - The ecoinvent 2.2 and 3 (ecoinvent Centre, 1998). This database was developed in Switzerland. It is considered a worldwide reference because of the consistency and transparency of its inventories with respect to the LCA methodology. It combines different existing databases and enhances them to obtain a unified and consistent set of LCI data particularly valid for western-Europe countries.
  - The C-BUILD e-LICCO database (Sié, Lautridou, Payet, Marie, & Combet, 2013) is composed of 1020 datasets of generic building products covering all building packages starting from structural work to finish to heating, ventilation, and air conditioning. This database has been built by Cycleco thanks to its own fund and Bourgogne district and the French Environmental and Energy Agency ADEME funding. Datasets are all based on the same background database (i.e., ecoinvent 2.2) and modelled following the same rules. This enhances the reliability of the results of the comparison among building variants. Every dataset is documented with details in French. In particular, allocation rules, representativeness and reference flows are specified.
- Software: SimaPro 8.0.X (PRé Consultants, 2014) Databases are utilized in the LCA software. The LCA software enables to quantify the environmental impacts associated to the system analysed. This software is the most widely used and the most appropriate to clearly present inventories and impact assessment results. It allows the analysis of the origin of the impacts related to the analysed products.

4 Life Cycle Cost Method overview

4.1 Principle

As explained by (A. Allacker, 2010), LCC is an economic accounting tool which is typically used to rank different investment alternatives in terms of cost reductions during life time. The approach was introduced in the British building industry during the 1950s, using the term 'cost-in-use' and replaced by the term LCC. The principle is to assess and sum up the costs of a product over its whole life cycle, including investment, operation, maintenance, and end-of-life disposal expenses. The main purpose of the process is to compare several product investment options, aiming at the same service, taking into account the present values of costs occurring during their life span. The integration of costs over the whole life cycle represents the main benefit of LCC, in particular when use costs are likely to represent a big share of the global life cycle cost. In consequence, the process is meaningful for products and systems having substantial operational and maintenance costs. In the case of building components, such as external walls, it is important to calculate the energy expense related to the use of one of the other technical solution in a building.

4.2 Standards

The method is mainly used for public procurement and more specifically for buildings and cars. Indeed, only these two sectors benefit from an international standard regarding the assessment of global cost: the ISO 15686-5 (International Standard Organisation, 2008) standard and the Clean Vehicle Directive (European Parliament & Council, 2009)

The methodology used for assessment of global cost within iNSPiRe is the LCC as described in the standard ISO 15686-5 (International Standard Organisation, 2008). This standard deals with assessment of global costs for buildings only, not for building products or for other sectors. The standard distinguishes two methods: the LCC (described above) and the whole LCC which accounts for environmental costs (also described as externalities) in addition to the ones already included in LCC. Environmental costs are not considered within iNSPiRe project.

4.3 Steps

The steps to perform the LCC are not clearly specified in the standard. In this study we follow the same procedure used for LCA:

- Goal definition: definition of the objectives of the study in terms of use and target public.
- Scope definition: definition of system boundaries, economic data and main assumptions.
- Costs inventory: cost data collection.
- Global cost assessment: cost actualisation and aggregation.
- Interpretation: result improvement and validation.

4.4 Tools

No specific database is used for LCC. When generic data will be needed, a bibliographic investigation will be performed to collect the most reliable estimates. Microsoft Excel software is used to perform LCC.

5 Goal definition

5.1 Framework

The assessment is performed in the framework of the collaborative project iNSPiRe involving 24 partners partly funded through the European Commission's Seventh Framework Programme (FP7). The project includes the design, the development and the industrialization of several components, kits and packages described in the following.

5.1.1 Products and kits description

Design and development of components by industrial partners:

- Tripan *Leichtbauteile Wimmer* GmbH (TRIP) ceiling heating and cooling panel
- Siko solar GmbH (SIKO) micro heat pump
- ClimateWell AB (CCT) solar thermal heating and cooling collector
- Bartenbach *Lichtlabor* GmbH (BLL) lights

Design and development of envelope and energy distribution / generation kits for renovation:

- 3 Wooden façade/roof kits
- 3 Metal façade/roof kits
- 2 Energy Distribution Kits (EDK)
- 1 Energy Generation Kit (EGK)

The façade/roof kits are based on build-ups manufactured by two partners of the project: Gumpp & Maier GmbH (G&M) and *Groupo Industriale* Tosoni (GIT) for wooden and metal systems respectively. They include in addition the products developed by the partners SIKO and CCT, as well as other products available on the market, sold by MANENS-TIFS SPA (MANENS) as far as energy generation systems are concerned.

The EDK include TRIP panels and BLL lights. The EGK consists of components available on the market.

The kits are not standards but tailor made to each renovation project. In contrast, the products developed by TRIP, SIKO and CCT aim to be standardized.

Products and kits are installed in three demonstration buildings according to their need for renovation:

- The Ludwigsburg case study, led by *Wohnungsbau Ludwigsburg* GmbH (WB-LB)
- The Madrid case study, led by *Empresa Municipal de la Vivienda y Suelo de Madrid* (EMVS)
- The Verona case study, led by GIT

5.1.2 Systemic Renovation Package (SRP) description

Eventually, the SRP are combinations of solutions developed within iNSPiRe or available on the market. They aim at improving the insulation and the air tightness of the envelope and the efficiency of heating and cooling. They are tailor-made for each building typology and localization and are composed of:

- An insulation (of varying thickness),
- Some windows (of varying glazing and frame types)
- A heating system including:
  - Solar collectors
  - Photovoltaic panels
  - Storage systems for Domestic Hot Water (DHW) and Heating and Cooling (H/C)
  - An energy generation system: gas boiler or heat pump water/water or water/air
  - A energy distribution system: radiators of fancoils or EDK
  - An EGK

5.2 Organisations involved

The author of the assessment is CYCLECO, a company specialized in LCA and LCC.

The client is the European Commission as it provides subsidies for the work.

The beneficiaries are:

- the industrial partners in charge of the development of the products, kits and SRP,
- the leader of the consortium : the *Accademia Europea Bolzano* EURAC,
- the leaders of the "Work package (WP) 3 Building Envelope's Solutions" : the *Fraunhofer-Gesellschaft zur foerderung der angewndten forschung* E.V (FhG-ISE); the "WP4 Energy Generation and Distribution Solutions" : *Fachhochschule stuttgart hochschulefur technik* (ZAFH) ; and the WP6: EURAC.

The beneficiaries are also the providers of the primary data used for the calculation.

5.3 Period

The assessment lasts from the beginning of the project M1 (October the 1st, 2012) to M42 (Mars the 31st, 2016), 6 months before the ending of the Project. During this period, partners design and develop the products, often on the basis of a product already existing on the market, the kits and the SRP. The Table 1 shows the approximate planning of components, kits and SRP design and development.

Table 1: Approximate planning of products, kits and SRP design and development

	M1–M6	M7-M12	M13-M18	M19-M24	M25-M36	M37-M48
Products						
Kits						
SRP						

Data collection and assessment have been performed in accordance to this planning.

5.4 Perspectives

In LCA the point of view implicitly taken into account is the "Environment" and the objective is to reduce impact from this point of view. In LCC, the point of view is not implicitly defined, but it has to be chosen by the analyst. Determining the point of view that has to be taken to perform the study is essential because it will determine what is considered as a cost or as a benefit during the project. In fact, costs and benefits are different depending on whether the analyst considers the owner of the building or a tenant of an apartment. The choice of the point of view to adopt determines also the data to be collected. Thus, it is essential that the point of view is relevant regarding the objectives of the study set with the client. Three examples are presented in the following table.

Table 2: Example of costs and benefits for distinct point of view in LCC

Point of view	Costs	Benefits
Building owner	Construction or purchase	Rents
Building users	Rents	Decrease of energy expenses
Owner and user of the building	Construction or purchase	Decrease of energy expenses

For the iNSPiRe project, it was decided to take the perspective – that may be theoretical – of the owner and the user of the building. This perspective shows the global cost of the construction or renovation as well as the decrease in energy consumption for the building users. LCC is performed to verify the economic effectiveness of the solutions being developed from the perspective of the owner and user of the building.

5.5 Specific objectives

The environmental and cost assessments have been realized in three steps:

- Environmental cradle to gate assessments of products and kits
- Integrated LCA & LCC of a demonstration building : the Madrid case study
- Integrated LCA & LCC of the SRP

The environmental cradle to gate assessments of products and kits aim at their environmental optimization, also called eco-design. Optimization occurs at the beginning of the project. It deals with improvement of production technologies and/or design of products and kits taking into account the environmental criteria over the whole production chain. For this purpose, comparisons are performed. The project partners will propose for each product/kit the use of different compositions and/or different technologies (i.e., variants) in order to obtain the product/kit with the best performances according to the goals of the project. According to the data availability and the number of variants per product/kit, comparisons are performed to determine the best environmentally option among the several variants of each product/kit and/or among the developed product/kit and the substitute currently available on the market. The comparison of the results help the project partners to define best actions for the reduction of the environmental impacts related to the products/kits.

The integrated LCA & LCC of the Madrid case study is performed in order to produce knowledge and lessons for future projects. The main objective is to compare a standard renovation with the renovation using iNSPiRe products in terms of environmental impacts and costs. This study shows the decomposition of environmental impacts and costs between renovation actions and building use for both scenarios. Beneficiaries better understand consequences of a change of the renovation actions on building use impacts and costs, and global environmental impacts and costs. In other words, the combined LCA & LCC allow to measure the internal and external costs' effectiveness of different renovation actions. Afterwards, beneficiaries will use conclusions of the assessment for internal awareness and communication in order to possibly eco-design future renovation project. In a second time, the results could also be the support of a public communication.

The integrated LCA & LCC of the SRP is also performed in order to produce knowledge and lessons for future projects. They aim at characterizing them on their life cycle performance, be they environmental or economic. These data are included in the database of SRP along with their other characteristics for further use by building professionals who will be able to compare them with each other.

5.6 Decision context

In LCA, the decision context is useful to choose between two modelling methods: attributional and the consequential modelling method. In attributional modelling, life cycle is modelled by depicting the existing supply-chain. It does not account for the indirect effects deriving by the change in the output of a product. Consequential modelling is a procedure oriented to the future. It identifies and takes into account the environmental consequences of a change in the outputs of a system and its indirect effects on the market. Table 3 presents the three situations which can occur in terms of decision context.

Table 3: Decision context situations (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010)

Situation A	"The study is a help to decision at a micro level which can engenders only small modifications of market mechanisms. Situation A refers to decision support directly or indirectly related to inform the purchase of products that are already offered in the market. Or to inform the design / development of products that are foreseen to entering the market."

	➔ Attributional modelling
Situation B	"The study is a help to decision at a macro level which can engenders large modifications of market mechanisms. Situation B refers to life cycle based decision support with consequences that are so extensive that they overcome thresholds and results in additionally installed or additionally decommissioned equipment / capacity somewhere in the life cycle of the system." ➔ Consequential modelling
Situation C	"The study is a purely descriptive accounting / documentation of the analysed system of the past, present or forecasted future, and without implying a decision-context that would account for potential additional consequences on other systems." ➔ Attributional modelling

It is worth mentioning that, even among the LCA community, identifying the decision context of the study is not straightforward as boundaries between situations are not clearly defined. Despite this fact, we would say that we are in situation A when the LCA is performed for eco-design and C when it is for producing knowledge and lessons for future projects. In consequence attributional modelling will be used, that is to say the life cycle is modelled by depicting the existing supply-chain. Thus, we will not take into account the indirect changes due to the product improvement itself.

5.7 Reporting

Several reports are made of this study as presented in Table 4.

Table 4: Reporting of LCA study within iNSPiRe Project

Report name	Dead line
DL 3.5: Assessment of the Embodied Energy, CO_2 and Cost for the Standardized Envelope RP	Mid-term : M15 and M24 (Dec. 2013 and Sept. 2014) Final: M42 (Mar. 2015)
DL 4.5: Assessment of the Embodied Energy, CO_2 and Cost for the Standardized Energy Generation and Distribution RP	Mid-term : M18 and M24 : (Mar. 2014 and Sept. 2014) Final : M42 (Mar. 2015)
DL 6.1: Guidelines on Environment and Cost Integrated Approach for Systemic Packages	M36 (Sept. 2015)
DL 6.2: LCA Results Communication Toolbox	M42 (Feb. 2016)

The present report is the deliverable 6.1.

6 Scope definition

6.1 Functional unit

6.1.1 Principle

The functional unit (FU) is the basis of the comparison. It is a statement describing the functions that must be fulfilled by all compared options.

6.1.2 Cradle to gate assessment

The functional unit for the cradle to gate assessment of products and kits is composed of:

- the unit of analysis, e.g. 1m^2 of wall,
- one or several quantitative parameters linked to the function fulfilled by the product, e.g. the thermal resistance R of the wall.

More details are provided in the deliverables 3.5 and 4.5.

6.1.3 Integrated LCA & LCC

The definition of the functional unit requires first an explanation of two concept: the starting and ending point and the reference period.

- Starting and ending point: The starting and ending point of a life cycle study of a building renovation is not the ecosphere, as it is the case for most common LCA studies, but an old building. This building includes old or none materials & equipment playing a direct or indirect role in building thermal performance, DHW supply and lighting: insulation, windows, H&C and DHW equipment, luminaires, etc. Only the potential substitution of these materials and equipment are of interest within iNSPiRe studies. As the building without these materials and equipment is and will be in place before and after the renovation, it is excluded from the system boundaries. It means that the construction and the demolition of the building excluding these materials and equipment is not part of system. Only the removal and disposal of the old equipment is taken into account, and of course the fabrication, installation, use and end of life of the new materials and equipment installed.
- Reference period: The reference period of the study should be chosen according to the building life span. The latter relies mainly on the building structure life span which is unknown, but still a reasonable assumption should be made based on the actual and most likely building life span. On the one hand, it is reasonable to think that if the renovation is conducted it means that the building structure has still several years to go. For that reason the reference period should not be inferior to 20 years. On the other hand, after a certain period of time the building, if not demolished, will be renovated again and the present study does not take into account these further renovations. In consequence, in order to not introduce a bias in the present study, we should define a reference period not superior to 40 years. A reference period of 30 years if taken into account. For the new products whose the life span is superior to the reference period, the impact of their fabrication and end of life is reduced proportionally to their contribution during the reference period. For the new products whose the life span is inferior to the

reference period, a replacement is included.

Thereafter the functional unit is defined as the following:

"Through the energetic renovation of a building whose characteristics are X, provide 1m^2 of living floor area of a thermal performance compliant to local standards, with Domestic Hot Water (DHW) and lighting, during 30 years."

In the case of the Madrid case study, X stands for the characteristics of the actual building; in the case of the SRP, X stands for the characteristics defined according to a local building stock analysis

6.2 System boundaries

The system has technological, spatial and temporal boundaries which need to be precisely defined. Every processes located inside the system boundaries must be taken into account. For combined LCA/LCC it is of main importance to check consistency of both modelling, in particular regarding system boundaries and inclusion or exclusion of processes accordingly.

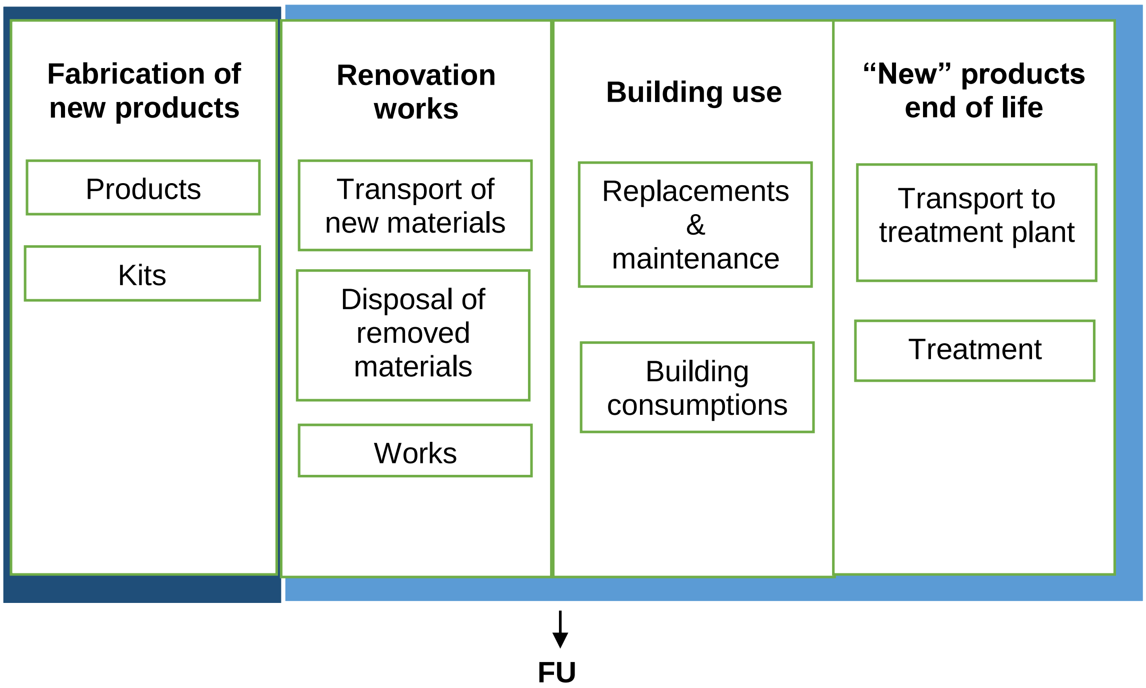

Figure 2: Technological boundaries of the system

- Technological boundaries: The life cycle assessment takes into account four steps:
    - Fabrication of news products: extraction of primary material, transformation of primary material, sub-part manufacture, component manufacture up to plant door, as well as every intermediary transports involved. The assessment of products and kits includes this step only.
    - Renovation works: transport to construction site, disposal of old products and

installation of new ones.

  - Building use: “new” products replacements and maintenance and building energy and hot water consumption.
  - “New” products end of life: transport to treatment plant, treatment.

The Figure 2 provides an illustration of the technological boundaries of the system. Only the dark blue is taken into account in the cradle to gate assessments of products and kits.

- Spatial boundaries: The assessment takes into account each parts of the product, kit or SRP. Every other parts of the building are not included.
- Temporal boundaries: The assessment goes from the first process occurring in the background system (e.g., extraction of energetic agents) to the last effect of the ultimate process occurring (e.g., landfill). Hence, the temporal boundaries go far beyond the products’ life span.

6.3 Economic boundaries

Economic boundaries are defined for LCC. They include:

- Lump-sum costs (from the building owner perspective):
  - costs of the components,
  - costs of the construction site (i.e., including labour, rent of building site machines, scaffoldings, etc.),
  - end of life costs (i.e., demolition/decommissioning costs, costs of disposal).
- Recurring costs (from the building user perspective):
  - maintenance costs (i.e., repairs, replacements),
  - energy costs.

6.4 Management of multi-functionalities

The management of multi-functionalities occurs when the product assessed – or some processes within the system boundaries – fulfil more functions than the one of interest. For instance, when the product is issued from a co-production process, management of multi-functionalities of the co-production process must be implemented.

In that case we resolve the multi-functionalities following ISO 14040-44 (ISO, 2006a, 2006b) recommendations:

- system expansion, if possible;
- allocation following physical rules, if possible;
- allocation following economic rules.

7 Inventory elaboration

7.1 Background and foreground system

In LCA the typology and quality of data to use rely on their belonging to the distinct grounds of the system. (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2010) distinguish two grounds, the fore and the back:

- The foreground includes the processes that are specific to the system studied. Project partners have a perfect command of the processes belonging to foreground system, can know entering and exiting flows of these processes and can take action to change the quantities or the nature of these flows;
- The background system includes the processes that are not specific to the system studied. Project partners do not have power on these processes and cannot optimize them.

The typology and quality of data to use rely on if they match with processes belonging to the foreground or the background system. For processes belonging to the foreground system, specific data from iNSPiRe partners and their supplier must be collected, whereas for processes belonging to the background system, generic data can be used.

7.2 Data collection

7.2.1 Generic data

The generic data are the data publically available and matching with average practices or technologies.

A first example of generic data are the inputs and outputs of the extraction and transformation processes of the primary materials. These processes belong to the background system and the data about themselves come from generic databases as ecoinvent (ecoinvent Centre, 1998), ELCD (Joint Research Centre, 2006) or C-BUILD e-LICCO database (Sié et al., 2013). They are valid for Europe or for a country depending on the level of detail of the database.

The electricity mix consumed for iNSPiRe products' manufacturing is also derived from generic database. In that case, Swedish, Austrian, German, Italian or European electricity mixes is chosen depending on the knowledge of the location of the process on the one hand and the availability of data in the databases on the other hand. If several locations are possible (e.g. the installation of building component can occur in distinct countries) either the impact with average European electricity mix is provided or one country is selected to be the reference.

Furthermore, the life cycle steps occurring after the product is out of the manufacturing plant are often described by generic data coming from internet. For instance, we found data on maintenance and end of life treatment processes on websites describing the most common practices.

No only inputs and outputs generic data have to be collected but also temporal data is needed as the life span of the different materials and components in order to plan their replacement along the life time horizon taken as reference for the study.

Eventually, generic costs variables have to be determined for the LCC: the discount rate and the growth rate of energy prices.

- Discount rate: it reflects the time value of money. It is used to convert cash flows occurring at different times to a referential date – usually, it is the construction date – in order to allow aggregating or comparing them. The discount is based on the preference for immediate enjoyment (i.e., the cost of time) and the risk aversion (i.e., the cost of risk). This means that one euro today worth more than one euro in the future due to inflation and the fact that today that one euro could be invested and lead to earn interests. For this study, we will use a discount rate called “real discount rate”, as opposed to “nominal discount rate”. The “real discount rate” considers a unique inflation rate applied to every deferred cost. It ranges from 1 to 4 % per year.
- Growth rate of energy prices: in the past, it has been observed that energy price increase more quickly than inflation rate (A. Allacker, 2010). This phenomenon is mainly due to changes in efficiency of production processes combined with more difficult access to energetic resources. Thus, it is appropriate to add a growth rate to the real discount rate for energy. (A. Allacker, 2010) suggests using a growth rate comprised between 1 and 6 % per year.

In any case, the generic data and its source is meticulously reported in the deliverable concerned.

7.2.2 Specific data

Data referring to processes belonging to the foreground system are provided by iNSPiRe partners and their suppliers. Data collection starts with the gathering of qualitative information from the partners of the project. Then quantitative data are collected and regularly updated. As for generic data, the specific data and its source is meticulously reported in the deliverable concerned.

7.3 Modelling method

Attributional modelling is used, that is to say the life cycle is modelled by depicting the existing supply-chain. Thus, we don’t take into account the indirect changes due to the product improvement itself.

7.4 Life cycle inventory calculation

7.4.1 Environmental inventory

The environmental Life Cycle Inventory (LCI) of a functional unit is the list of the substances released to the environment and the resources consumed from the environment that allow fulfilling the functional unit. Each substance released and resource consumed is an elementary flow. The inventory of elementary flow is generated in two steps:

- connection of either specific data from industrial partners and or generic data coming from public sources, to generic ones from generic databases in SimaPro software (PRé Consultants, 2014),
- generation of elementary flows inventory thanks to matrix operations achieved by the software.

7.4.2 Costs inventory

The costs life cycle inventory of a functional unit is the list of the actualised costs which should be spent (by the building owner and user as this perspective has been retained) at the time the study is done in order to fulfil the functional unit. Actualisation of future costs is performed using the discount rate.

8 Impacts assessment

8.1 Environmental impacts assessment

The purpose of impact calculation is to link inventory previously elaborated to impact indicators: effect indicators (or midpoints) and, eventually, damage indicators (or endpoints). There are around 30 effect indicators and no consensus on a short selection. On the other hand, there is a consensus on the division of damage in three categories – Human health, Biodiversity and Resources – but no reliable methods available to assess them.

The assessment of effect indicators is performed using characterisation factors which reflect the effect of each substance to a specific environmental mechanism. For instance, for climate change midpoint, the characterisation factor of each greenhouse gas is its global warming potential. Then, the assessment of damage indicators is performed using a damage factor which reflects the contribution of the impact on the damage.

As previously mentioned, there are numerous midpoints describing impacts on fauna, flora and human being of the present and the future generations. These indicators can overlap one over another, that is to say they address the same environmental mechanism (e.g. 'Non-renewable primary energy consumption' expressed in kWh and 'Resources depletion' expressed in kg Sb eq, i.e. mass antimony equivalent). In addition, there are several models available to assess one indicator. In general, most recent models are the most reliable ones. However, reliability is not the sole criteria. Some models are more or less optimistic regarding the future or have a distinct vision of what sustainability is.

Eventually, public or private organisations or group of people can propose LCIA methods which are a set of indicators assessed through selected models, for instance ReCiPe ('ReCiPe', 2014), ILCD Midpoints (European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2012) or IMPACT World + ('IMPACT World +', 2014). Although many efforts have been made to develop these methods, to date, none of them is fully satisfactory for decision making in the building sector because either there are too many indicators or there are too many uncertainties.

A selection of 7 environmental impact categories was made to be used for iNSPiRe based on (K. Allacker, Sié, Trigaux, Payet, & De Troyer, 2014). This selection is presented in the following.

Table 5: Selection of environmental impacts indicators for iNSPiRe project

Impact categories	Unit	Details	Models
Non-renewable primary energy consumption	kWh	It includes the non-renewable energy consumed, including losses during extraction, transport and transformation of energetic agents. It takes also into account the non-renewable energy contained in the materials. Non-renewable primary energy consumption of the unit of analysis “Fabrication of 1 unit of product” is usually called by building professionals the “Embodied energy”.	CED ecoinvent (Frischknecht et al., 2007)
Climate change	kg CO_2 eq	It characterizes the global warming potential taking into account the radiative forcing over a time horizon of 100 years. Biogenic carbon absorptions and emissions are taken into account as negative and positive values respectively (i.e. not neutral).	IPCC 2007 (Intergovernmental Panel on Climate Change (IPCC), 2007)
Water resource depletion	m^3 water eq	It represents the amount of water used adjusted according to the scarcity of water in the location of collection.	Swiss Ecoscarcity 2006 (Frischknecht, Steiner, & Jungbluth, 2009)
Acidification	molc H+ eq	It characterizes the increase in the amount of acidic substances in the lower atmosphere. These emissions are the cause of acid rain involving the decline of forests. The main compounds involved in this phenomenon are: SO_2, NOx, NH_3, HCl, HF. Acid deposition has effects on materials, forest ecosystems and freshwater ecosystems.	(Posch et al., 2008; Seppälä, Posch, Johansson, & Hettelingh, 2005)
Freshwater eutrophication	kg P eq	It is the excessive enrichment of a soil in nutrients. This causes asphyxiation of aquatic ecosystems.	ReCiPe 2008 (Struijs, Beusen, van Jaarsveld, & Huijbregts, 2009)
Freshwater ecotoxicity	Comparative Toxic Unit for ecosystems (CTUe)	It evaluates the toxicity of the emissions of substances on ecosystems, or more specifically the potential risks induced by the presence of chemical compounds in a specific ecological system.	USEtox (Rosenbaum et al., 2008)
Land use	kg C deficit	It quantifies the loss of Soil Organic Matter due to (1) the occupation of a certain area for a given time as well as (2) the change of the utilization of the soil.	(Canals et al., 2006)

Human toxicity - cancer effect	Comparative Toxic Unit for humans (CTUh)	It evaluates chronic toxicological effects on human health from emissions of carcinogens. It provides an estimate of the increase in morbidity throughout the human population.	USEtox (Rosenbaum et al., 2008)
Human toxicity - non cancer effect	CTUh	It evaluates chronic toxicological effects on human health from emissions of non-carcinogens. It provides an estimate of the increase in morbidity throughout the human population.	USEtox (Rosenbaum et al., 2008)
Particulate matter (PM)	kg PM2.5 eq	It quantifies the impact of premature death or disability that particulates/respiratory inorganics have on the population, in comparison to PM2.5. It includes the assessment of primary (PM10 and PM2.5) and secondary PM (incl. creation of secondary PM due to SOx, NOx and NH3 emissions) and CO.	(Spadaro & Rabl, 2004)

8.2 Global cost assessment

LCC results first in the evaluation of Present Values (PV) of lump sum and recurring costs. The PV is the value of a future cash flow discounted – through the discount rate – to reflect the value it would have at the date use as reference. The PV is calculated as follows (Equation 1):

$$\mathrm{PV} = \frac{\mathrm{Fx}}{(1+\mathrm{r})^{x}} \quad [1]$$

Where Fx is the future cost; x is the year of occurrence, and r is the discount rate.

Notice that long-term costs and benefits become much more apparent at a lower discount rate (e.g. for x = 10, the most r is small the higher PV is).

The PVs help knowing cost decomposition between investment and building use costs and understanding the consequences of a change of the investment on building use cost and global cost.

Secondly, LCC results in the evaluation of the net present value (NPV). The NPV is the sum of the discounted of PVs, for costs and benefits. It is the global cost over the whole life cycle of the building. The formula used to calculate the NPV is as follows (Equation 2):

$$NPV = \sum_{x=0}^{N} \frac{Fx}{(1+r)^{x}} \quad [2]$$

With N being the period of the analysis and the other parameters defined as above.

NPV is assessed and compared for different scenarios. For instance, it can be calculated to compare a building in which iNSPiRe components have been used and a building in which they have not been used.

9 Interpretation

The interpretation step consists in discussing the significance of the results deriving by the LCC and LCA analyses and how these results can be construed.

9.1 Hot spot analysis

The hot spot analysis aims to detect the main contributors to the impact or the global costs of the products/kits and SRP developed in the iNSPiRe project. Contributors can be products components, life cycle steps or sub-systems (cf. system boundaries). The hot spot analysis is the base to perform a sensitivity analysis.

9.2 Sensitivity analysis

The main goal of a sensitivity analysis is to provide insight about the variability of the results related to the change in the initial hypotheses. The goal is to study the consequences of the assumptions on the assessment results and conclusions. Assumptions can be due to uncertainty of data or methodological choices. Sensitivity analysis allows the validation or revision of first conclusions.

Choices of sensitivity analysis depend on results of hot spot analysis mainly and iNSPiRe partners:

- leeway for change (in the case the study is performed for ecodesign),
- specific questions for good understanding (in the case the study is performed to produce knowledge and lessons for future projects).

Hence, analyses to conduct are defined on a case-by-case basis.

Quantitative assessment of the uncertainties behind background processes modelling is not planned in the iNSPiRe project.

10 References

AFNOR. (2012). NF EN 15978 - Contribution des ouvrages de construction au développement durable - Évaluation de la performance environnementale des bâtiments - Méthode de calcul.

Allacker, A. (2010). *Sustainable building - The development of an evalution method*. PhD Thesis.

Allacker, K., Sié, M., Trigaux, D., Payet, J., & De Troyer, F. (2014). Search for the environmental indicators relevant for the building sector. In *Proceedings of SB14 conference*. Barcelona.

Canals, L. M. i, Bauer, C., Depestele, J., Dubreuil, A., Knuchel, R. F., Gaillard, G., … Rydgren, B. (2006). Key Elements in a Framework for Land Use Impact Assessment Within LCA (11 pp). *The International Journal of Life Cycle Assessment*, *12*(1), 5–15. http://doi.org/10.1065/lca2006.05.250

ecoinvent Centre. (1998). ecoinvent. Retrieved 15 July 2014, from http://www.ecoinvent.ch/

European Commission, Joint Research Centre, Institute for Environment and Sustainability. (2010). *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010* (No. EUR 24708 EN) (p. 417). Luxembourg: Publications Office of the European Union.

European Commission, Joint Research Centre, Institute for Environment and Sustainability. (2012). *Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods. Database and Supporting Information.* (No. EUR 25167). Office of the European Union.

European Parliament, & Council. Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehiclesText with EEA relevance, Pub. L. No. 2009/33/EC (2009).

Frischknecht, R., Jungbluth, N., Althaus, H.-J., Bauer, C., Doka, G., Dones, R., … Nemecek, T. (2007). *Implementation of Life Cycle Impact Assessment Methods* (No. ecoinvent report No 3, v2.0). Dübendorf: Swiss Centre for Life Cycle Inventories ecoinvent.

Frischknecht, R., Steiner, R., & Jungbluth, N. (2009). *The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA.* (No. Environmental studies no. 0906) (p. 188 pp.). Bern: Federal Office for the Environment.

IMPACT World +. (2014). Retrieved 15 July 2014, from http://www.impactworldplus.org/en/

Intergovernmental Panel on Climate Change (IPCC). (2007). *IPCC Fourth Assessment Report: Climate Change 2007. Working Group I: The Physical Science Basis. Technical Summary. TS.2.5 Net Global Radiative Forcing, Global Warming Potentials and Patterns of Forcing. Table TS.2*. Retrieved from http://www.ipcc.ch/publications_and_data/ar4/wg1/en/tssts-2-5.html

ISO. (2008). 15686 - Buildings and constructed assets -- Service-life planning -- Part 5: Life-cycle costing.

ISO. (2006a). 14040 - Environmental management -- Life cycle assessment -- Principles and framework.

ISO. (2006b). 14044 - Environmental management -- Life cycle assessment -- Requirements and guidelines.

Joint Research Centre. (2006). ELCD - European reference Life Cycle Database. Retrieved from http://eplca.jrc.ec.europa.eu/ELCD3/

Posch, M., Seppälä, J., Hettelingh, J.-P., Johansson, M., Margni, M., & Jolliet, O. (2008). The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. *The International Journal of Life Cycle Assessment*, *13*(6), 477–486. http://doi.org/10.1007/s11367-008-0025-9

PRé Consultants. (2014). SimaPro (Version 8). Retrieved from http://www.pre-sustainability.com/all-about-simapro

ReCiPe. (2014). Retrieved 15 July 2014, from http://www.lcia-recipe.net/

Rosenbaum, R. K., Bachmann, T. M., Gold, L. S., Huijbregts, M. A. J., Jolliet, O., Juraske, R., … Hauschild, M. Z. (2008). USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *The International Journal of Life Cycle Assessment*, *13*(7), 532–546. http://doi.org/10.1007/s11367-008-0038-4

Seppälä, J., Posch, M., Johansson, M., & Hettelingh, J.-P. (2005). Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator (14 pp). *The International Journal of Life Cycle Assessment*, *11*(6), 403–416. http://doi.org/10.1065/lca2005.06.215

Sié, M., Lautridou, P., Payet, J., Marie, D., & Combet, L. (2013). Development of an inventory database of materials products and equipment for the French construction sector. In *Proceedings of avniR conference*. Lille.

Spadaro, J. V., & Rabl, A. (2004). Pathway Analysis for Population-Total Health Impacts of Toxic Metal Emissions. *Risk Analysis*, *24*. http://doi.org/10.1111/j.0272-4332.2004.00514.x

Struijs, J., Beusen, A., van Jaarsveld, H., & Huijbregts, M. A. J. (2009). *Aquatic eutrophication. ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors.*