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PEF4Buildings

Study on the Application of the PEF Method and related guidance documents to a newly office building (ENV.B.1/ETU/2016/0052LV)

Deliverable D8: Final report and publishable executive summary

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ABSTRACT

The PEF4Buildings project is commissioned by the European Commission and is carried out by the Flemish Institute for Technological Research (VITO), KU Leuven and TU Graz. The aim of the project is to test the applicability of the PEF method Guide (Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations) and the latest versions available of the related guidance documents developed in the framework of the Environmental Footprint pilot test phase (European Commission (EC), 2017) to a new office building, and to provide an overview of pros and cons of alternative possible approaches to the definition of the benchmark and classes of performance for the typology of buildings within the scope of the study. The assessment and the overview will contribute to the development of a final approach to develop benchmark and classes of performance for different typologies of buildings.

As a first step (Task 1), a **PEF study on two new office buildings** is performed. The first building is the office building BelOrta of BelOrta CVBA, designed by the architectural firm ar-te and built in Belgium. The second building assessed in this study is the office BE2226 of Baumschlager & Eberle, Lustenau, Austria. The BelOrta building is a business-as-usual new office building, while the BE2226 building is a nearly-zero-energy building. These hence allow to test the PEF method to buildings located in different climatic contexts and varying in energy performance.

In a second step (Task 2), a **possible approach to benchmark office buildings and to define classes of performance for newly built office buildings** is developed. The approach is developed based on the findings of the PEF study on two new office buildings (from Task 1), the latest version of the PEF Guidance document available at the that time (v. 6.1 mainly and for limited aspects v. 6.2) (European Commission, 2017) and a dedicated desk research. It covers issues such as how to define the reference building, how to define system boundaries, how many reference buildings should be defined and how to handle this range of different options.

A third step of this study (Task 3) is devoted to the **assessment at the building level**, and more specifically how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method. The assessment starts from the results of the PEF study on the two new office buildings from Task 1, but is extended to other possible European building typologies.

Two 1-day **workshops with stakeholders** were organised (Task 4). At the first workshop (July 5th, 2017, Brussels) the draft results of the PEF study (Task 1) were presented. At the second workshop (January 29th, 2018, Brussels) the draft results of the desk research on benchmarking and performance classes of office buildings (Task 2) and of the assessment at the building level that links the environmental performance of construction products with the building assessment by using the PEF method (Task 3) were presented, followed by an interactive discussion with the stakeholders.

This report is the **final report** of this project (Task 5). It includes an executive summary of the activities carried out during the contract in English, French and German. All previous reports

prepared (of Tasks 1, 2 and 3) are annexes at the end of this report, including the minutes of the stakeholder workshops organised (Task 4).

CHAPTER 1 EXECUTIVE SUMMARY (ENGLISH)

1.1. INTRODUCTION

The aim of the PEF4Buildings project, carried out by the Flemish Institute for Technological Research (VITO), KU Leuven and TU Graz, is to test the applicability of the Product Environmental Footprint (PEF) method[1] to a new office building. The PEF method was developed by the European Commission as part of the Single Market for Green Products Initiative[2]. During several pilot projects[3], Product Environmental Footprint Category Rules (PEFCR) were developed for certain products. Among these products were the following construction products: thermal insulation, hot and cold water supply piping systems, photovoltaic modules, metal sheets and decorative paints. The PEF4Buildings project aims at testing the applicability of the PEF method, and the PEFCRs of these construction products, at the building level instead of the product level.

As a first step of the PEF4Buildings project, a **PEF study on two new office buildings** was performed. The first building is the office building BelOrta of BelOrta CVBA, designed by the architectural firm ar-te. The BelOrta building is an office building built in 2013-2015 in Belgium. It is a compact building with an inner patio around which the workspaces are organised. The architectural firm ar-te provided the necessary data and inputs for the PEF study of this building. We have chosen this building because (a) a BIM (Building Information Modelling) model was available which enhanced the inventory phase of the PEF study and (b) it is a business-as-usual building regarding typology, energy performance and technologies used. The second new office building assessed in this study is the office BE2226 of Baumschlager & Eberle, Lustenau, Austria. BE2226 is a nearly-zero-energy-building without active cooling and heating. Also for this building a BIM model was available. This second case study allowed to test the PEF method on a building with a very high energy performance located in a different geographical context.

In a second step, a **possible approach to benchmark office buildings and to define classes of performance** was developed. The approach that has been developed is based on the findings of the PEF study on two new office buildings, the latest version of the PEF Guidance documents available at that time (v. 6.1 mainly and for limited aspects v. 6.2) (European Commission, 2017) and a dedicated desk research on existing approaches. It covers issues like how to define the reference building, how to define system boundaries, how many reference buildings should be defined and how to handle this range of different options.

A third step of this study was devoted to the **assessment at the building level**. It gives guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method. The assessment started from the results of the

[1] Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations

[2] http://ec.europa.eu/environment/eussd/smgp/index.htm

[3] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

PEF study on two new office buildings, but has been extended to other possible European building typologies.

1.2. PEF STUDY ON TWO NEW OFFICE BUILDINGS

In order to test the applicability of the PEF method to a new office building, two case studies were selected, thereby ensuring the findings are not case specific or geographical context specific.

Case study 1: BelOrta building of ar-te in Belgium

Case study 2: BE2226 building of Baumschlager & Eberle, Lustenau in Austria

Figure 1: The two case studies that were selected for the PEF assessment

The system boundaries for the two PEF studies were defined from the perspective of the designer/architect. This means that everything that the designer/architect can influence has been included in the system boundaries, but everything the designer/architect does not control directly is excluded (e.g. paper, furniture, commuter transport). It was moreover chosen to exclude the parts of the office building which are not necessary for the functioning of the office building, such as kitchen/catering. This is seen as important to make fair comparisons of the environmental footprint of office buildings (i.e. benchmarking purposes) which not all comprise a kitchen. Furthermore, the PEF studies are limited to the building as such and exclude the surroundings (e.g. parking lot).

The following building elements were included in the reference flow:

- Foundation and sub-structure;
- The structural frame, including beams, columns and slabs;
- Staircases;
- External walls, cladding and insulation;
- Windows;
- Floors and ceilings;
- Internal walls;
- Doors;
- Roofs;
- Heating and cooling systems;
- Sanitary systems;
- Electrical systems.

Not included in the reference flow are:

- Consumables (e.g. IT equipment, paper, furniture);
- Surroundings (e.g. parking lot);
- Kitchen/catering;
- Commuter transport.

Based on a cross-analysis of the **life cycle stages** defined in the draft PEFCRs for the construction products within the PEF pilot phase and the EN norms related to construction products (EN 15978/EN15804) the life cycle stages presented in Table 1 have been defined for the PEF assessment of the two office buildings.

Table 1: Life cycle stages for the assessment at building level

LCS name	The following shall be included
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, End-of-Life (EoL) of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment
PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL
PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

Figure 2 presents the **system boundary diagram** for the assessment at the building level, where the life cycle stages are presented in a manner compatible with the one existing in EN 15804:2012+A1:2013 (Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products) and EN 15978:2011 (Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method).

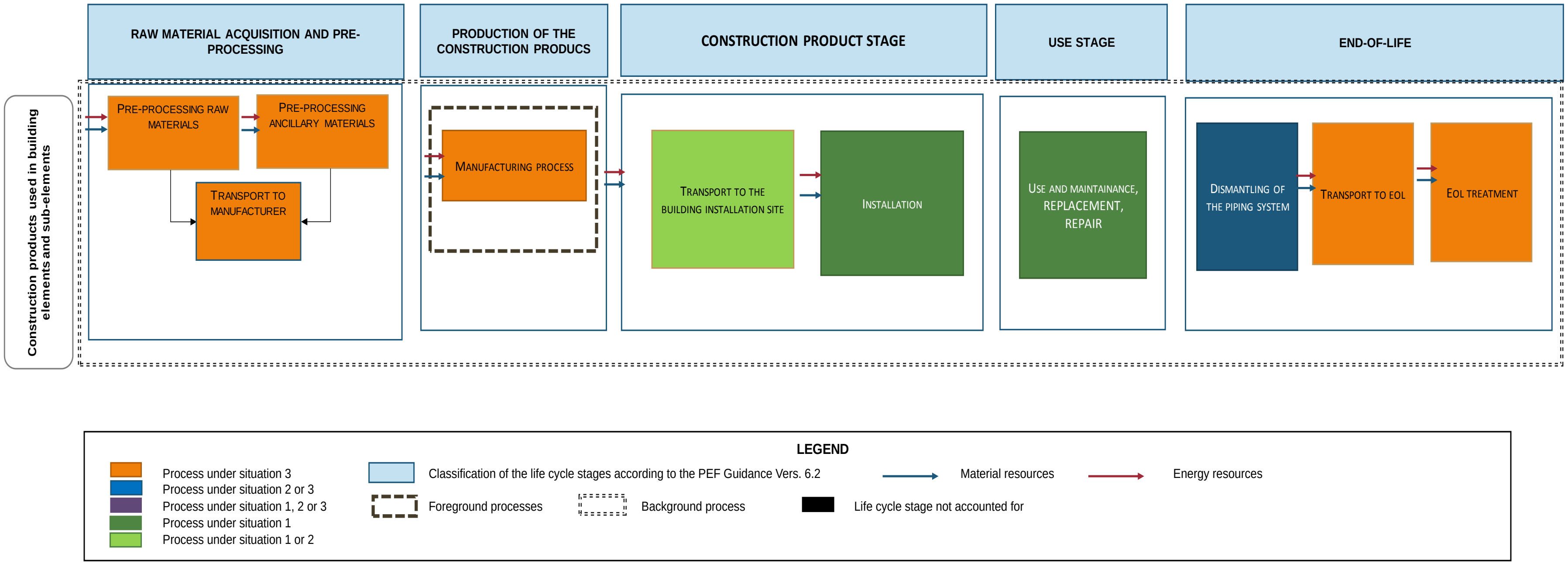


Figure 2: System boundary diagram for PEF assessment at building level

For each life cycle stage specific scenarios were developed for the assessment of the environmental impact at building level. These scenarios are mainly focusing on:

- *Assumptions related to construction process stage*: e.g. transportation of construction products from manufacturers to building construction site, but also the construction process;
- *Assumptions related to the use stage*: scenarios for the use of the installed construction products in the building, maintenance of the building, repair activities, replacement activities, refurbishment activities, operational energy use and operational water use;
- *Assumptions related to End of Life stage*: scenarios for the de-construction, reuse, demolition, recycling and disposal; including all transport.

In defining such scenarios, the PEF Guidance as well as the draft PEFCRs, EN norms and national norms have been used.

For the purpose of the PEF assessment rules for allocation at building level and at product level have been identified:

- At building level, the allocation of the impacts of re-used building elements could be discussed but was not part of this study as the focus was on new office buildings. Defining allocation rules related to the impacts shared between previous system boundaries and next system boundaries will be necessary when making a PEF study of renovated buildings;
- At product level the allocation follows the approach for the handling of multi-functional processes in the PEF Guidance 6.1 (European Commission, 2017).

The two PEF studies are set up similarly as a PEF screening study. Therefore no cut-offs are applied. All information that is not included in the studies is due to data gaps and not to cut-offs.

A hierarchical decomposition of the building (element method) was used in order to avoid data gaps as much as possible and in order to allow for inventory data of various sublevels to be used for the assessment of the building. The **model** structure is based on a hierarchical subdivision of the building in smaller entities: building elements, sub-elements and materials (Figure 3).

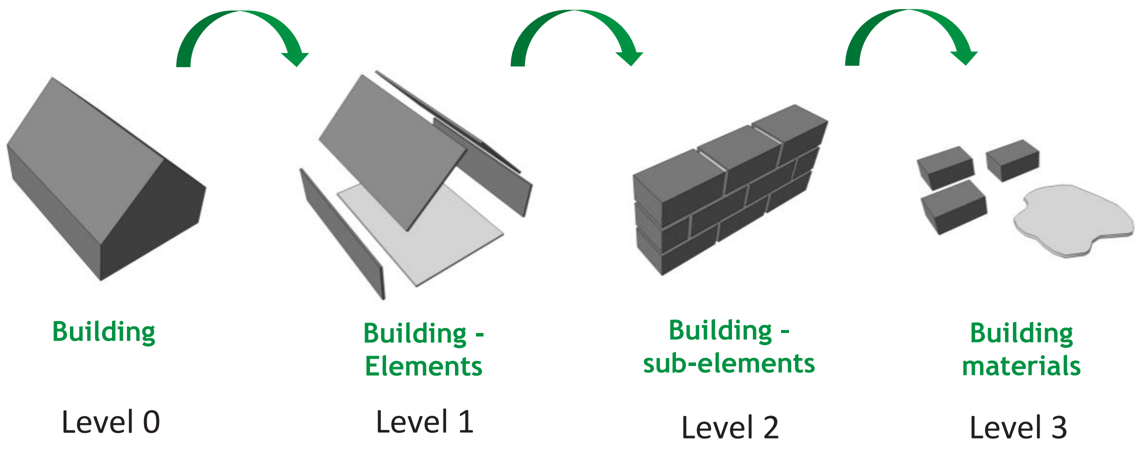
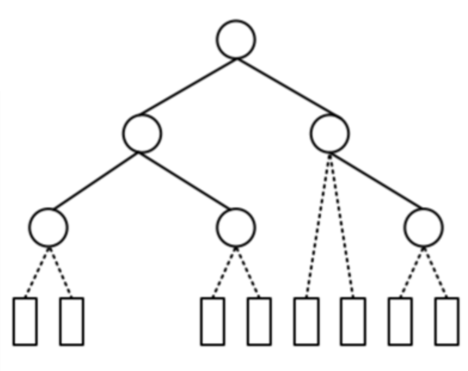


Figure 3: Hierarchical de-composition of the building (Trigaux et al., 2017)

For distinction and detailed analysis of the different building elements and sections of the building the tree-like building element classification system of OmniClass (2015) is used in compliance with ISO 12006-2 (International organization for Standardization, 2015).



- Level 0: Building
- Level 1: Building elements (e.g. external walls)
- Level 2: Building sub-elements (e.g. brick wall)
- Level 3: Building materials (e.g. bricks)

Figure 4: Adopted framework for classification according to ISO 12006-2 (ISO, 2015)

The process flow procedure as presented in Figure 5 elaborated for this project. First of all, sources to define the necessary information on building elements, building materials, scenarios, use phase were identified in the data gathering process. In a second step, a building element catalogue of the building components was developed in a spreadsheet (Excel) and are the main input for the life cycle impact assessment (LCIA) in the LCA software (SimaPro)[4].

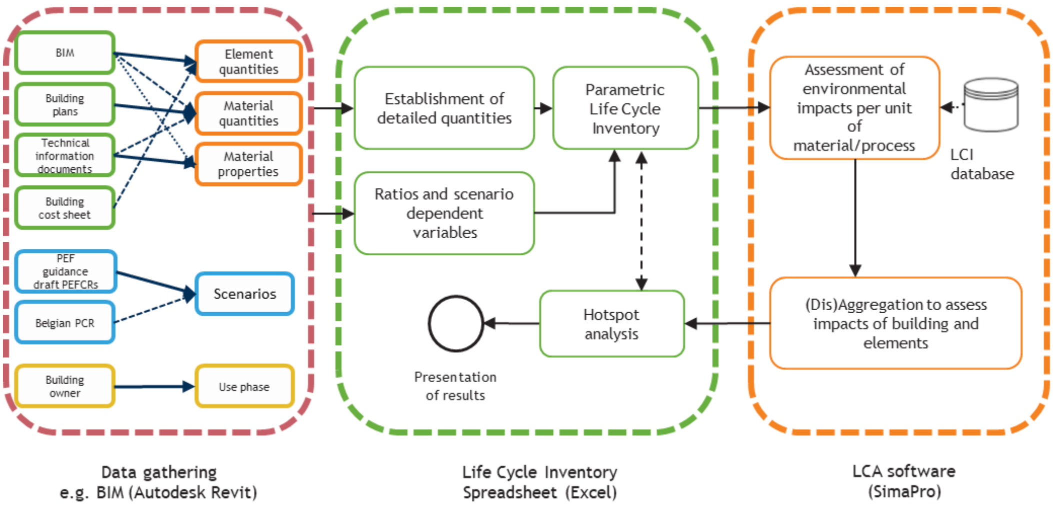


Figure 5: Data model development process

[4] The SimaPro LCA software was selected because the project team is used to work with it. It does not imply any preference in software to be used, neither by the EC or the project team.

The following learnings were gathered during the life cycle inventory phase:

- Datasets should allow the application of the CFF (Circular Formula Footprint) formula;
- Clear guidelines are needed to model the use phase;
- National scenarios are needed (e.g. for products for materials/building elements for which no draft PEFCR are available);
- During data gathering, the BIM model proved to be an important source with added value.

The **LCIA results** of both case studies were calculated according to the PEF Guide. It is important to note that two different modelling approaches were applied to the two case studies in order to learn from the differences. The BelOrta Simapro model follows strictly the hierarchical structure presented in Figure 3, while the BE2226 Simapro model is made on material level in order to test implications of different modelling approaches. The difference in modelling has mainly consequences during the interpretation of the results. More specifically, the BelOrta model allows to gain insight in the contribution of a material applied in a certain element to the total building impact, while the BE2226 model provides insight in the contribution of a certain material to the total building impact. For example, the BelOrta model gives the impact of concrete in inner walls and in outer walls separately, while the BE2226 model provides the impact of concrete (in all building elements aggregated).

As this project didn't intend to focus on the absolute values and results obtained, but aimed at understanding the methodological aspects of calculating a PEF of an office building, the numerical results of the study are not reported here. Although the intention of the two assessments of the two cases is not to compare their LCIA results in detail, some important outcomes can be highlighted:

- Firstly, the overall weighted score of the two buildings differ significantly: the BE2226 building clearly show a lower impact than the BelOrta building. This was expected as the second case (BE2226) is an advanced building (NZEB) while the first case (BelOrta) is a business-as-usual case. However, it should be noted that the building control system (including sensors, control panels…) and piping is not modelled for the second case because of lacking data. Furthermore, the two buildings have the same use and a similar size in terms of floor area but represent different building typologies;
- Secondly, the most relevant impact categories identified differ between the two cases. The most relevant impact categories hence clearly depend on the building (energy performance and materials used), but also on the location (electricity mix). This is important if the aim is to limit the impact categories of PEF4Buildings to the most relevant ones. We can furthermore conclude that several of the most relevant impact categories are 'additional' impact categories which are not included in the current version of the EN 15804 and EN 15978;
- Thirdly, for both buildings the operational energy use and the pre-processing of raw materials have been identified being amongst the most relevant life cycle stages. However, for the BelOrta building, the use phase contributes significantly more to the life cycle impact than for the BE2226 building. As the use phase in the BE2226 building causes lower impacts than in the BelOrta building, additional life cycle stages become more relevant;
- Fourthly, the identification of the most relevant processes leads to a different set of most relevant processes for both buildings. This was expected as both buildings consist of different materials and elements, but are also located in a different location and hence a different electricity mix is used during the important use phase of the building.
  Finally, the inclusion/exclusion of the toxicity impact categories clearly influences the results to a significant extent, especially for the second case study.

1.3. Proposal for approach for benchmark and classes of performance for office buildings

In order to propose a possible approach to benchmark and to define classes of performance for new office buildings, a dedicated desk research was performed, focusing on existing reports on building typologies, sustainability schemes, LCA guidelines (such as the EN 15978 norm and the draft PCR for buildings) and national methods or legal requirements (such as the E+C- method in France, DGNB and BNB in Germany, GWW in the Netherlands, MMG in Belgium). The researched methods are compared on different aspects: the meaning and approach of the benchmark that is defined, how reference buildings are defined, the considered system boundaries, functional unit and reference flow, and the approach used to define performance classes.

1.3.1. Overview of findings

Several important differences were identified in the **meaning and related approaches** used for defining the environmental benchmarks of buildings. The literature review revealed that various **meanings** of benchmarks of buildings are used, ranging from limit values (minimum acceptable performance), over a reference value (present state of the art, e.g. average) and best practice value (values reached in experimental or demonstration projects) to target values (values that can be reached in medium- or long-term perspective). Depending on the meaning chosen, different **approaches and sources** are used to calculate the benchmark values, ranging from laws prescriptions, standards (for limit values), over statistical values and reference buildings (for reference values) to political target values or economic and technical optima (for target values). Building certification schemes, such as BREEAM or DGNB, typically use various values, i.e. limit, reference and target values, to define their benchmark and classes of performance. Current national benchmarks mostly represent a level-playing-field with a lower limit as a starting point. Their goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behavior on the other hand. Nevertheless, benchmarks can evolve in time as technology advances and knowledge of the building stock grows.

Another differentiation noticed in approach followed in literature is the use of **external versus internal benchmarks**. The former is the most common and compares a certain building with a reference building differing in layout and material choice (sometimes also in energy performance). The inner benchmark is more rarely used (e.g. by LEED) and compares the impact of the design building with a reference building with only variation in materials (meaning that the propose-building is identical to the reference building in terms of layout, size and energy performance).

Some systems furthermore have defined a **benchmark for each environmental impact category** separately (e.g. DGNB), while others have defined a **benchmark for the aggregated single score** (e.g. The Netherlands). In the systems with benchmarks for each impact category separately, the final score is obtained by weighting the different scores on the different impact categories. The weighting of the different impact categories is then part of the methodology.

From the desk research we can conclude that **reference buildings** to determine the benchmark can either be real buildings representing the reference building, or can be virtual buildings (i.e. based on statistical analysis of a representative part of the national building stock). Such statistical analysis differentiates various building types, sizes, materials and energy performances.

“50 years” has been found as the most common reference study period for office buildings. A commonly used **reference flow** is “per floor area, per year”. Some studies suggest to take the function of the building into account, e.g. the number of work stations in the office building or the amount of people in full time employee equivalent. No relevant assumptions on cut-off rules or scenarios were found in the desk research.

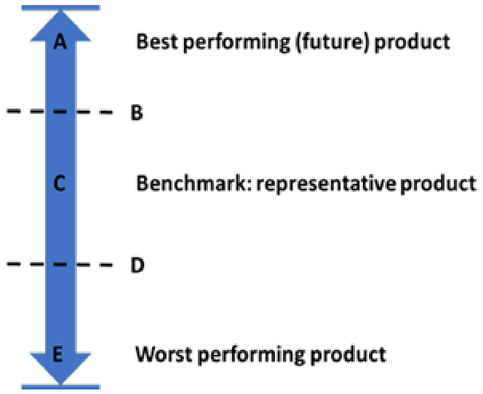


Figure 6: Performance levels according to PEF Guidance document (Technical Helpdesk PEF, 2016)

In an issue paper of the PEF Technical Helpdesk[5] guidance is giving on how to calculate **performance levels for products** (based on most relevant parameters and by determining market realistic minimum and maximum values). The desk research aimed at exploring if other methods are used to define performance classes for buildings in existing approaches. We can conclude that the **aim** of performance classes can be different and determines the approach to define performance classes. For the definition of performance classes, a lot of information is needed on the relevant buildings to be "represented" in different classes, to be able to set the desired thresholds. For that, just as for benchmarking, one needs to have an overview of the environmental impacts of the various buildings to be covered by the performance classes, which can be either **real buildings or virtual buildings**. In the case of performance classes, as the amount of data needed is large, generally virtual buildings are used. To set the thresholds between different performance classes, some systems rely purely on the relative improvement compared to the benchmark (e.g. 5%, 10% or 15% better than the benchmark). Other systems (such as in the report by W/E adviseurs[6]) are based upon the statistical spread of the analysed building stock. A general graph of the approach that was used in this background study is shown in Figure 7.

[5] Technical Helpdesk PEF. (2016). *Issue paper "Determining the EF benchmark and performance classes" - version 3*.

[6] W/E adviseurs. (2014). *Onderzoek "Bepaling kwaliteitsniveaus milieuprestatie van woonfuncties" - Eindrapport*. Retrieved from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2014/11/14/onderzoek-bepaling-kwaliteitsniveaus-milieuprestatie-van-woonfuncties/eindrapport-bepaling-kwaliteitsniveaus-milieuprestatie-we-adviseurs.pdf

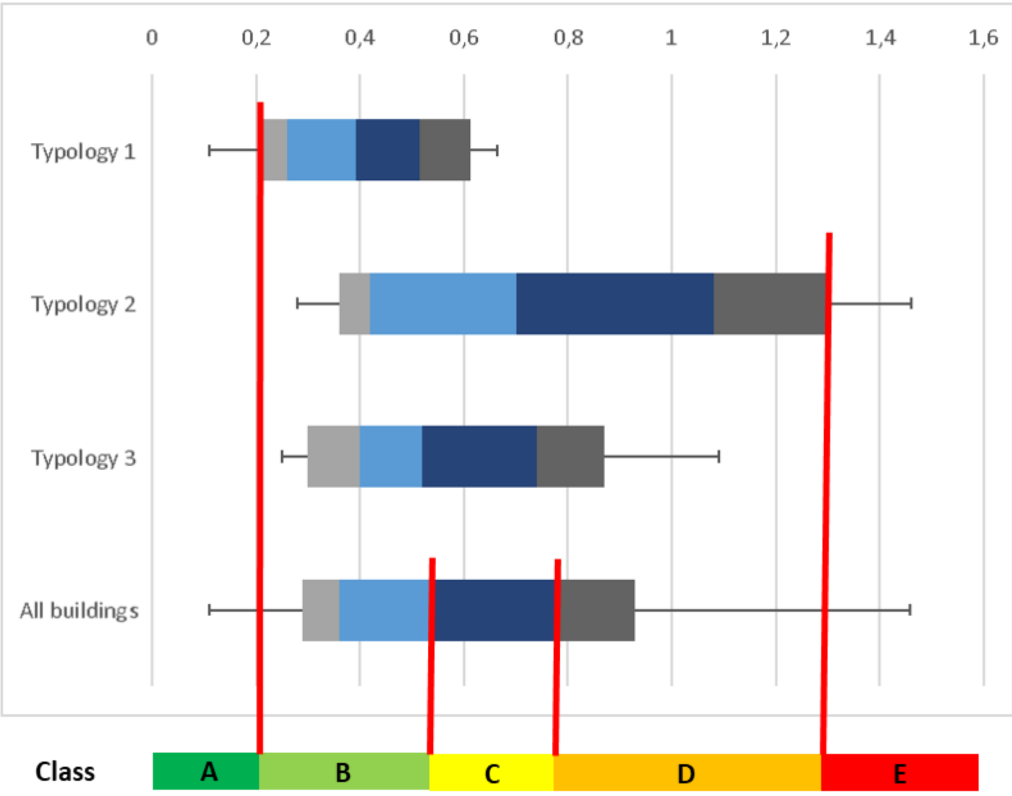


Figure 7: Statistical information as basis for performance classes

1.3.2. Recommendations

Recommendations are made based on the findings of the PEF study of two new office buildings, the PEF guide and related guidance documents, the desk research, the received feedback from the stakeholders and previous experiences of the project team. The recommendations are made with certain assumptions and goals in mind, so they cannot be generalised and applied to any situation.

The project team recommends to define a **common EU methodology** to calculate the environmental impact of buildings and a common EU methodology on how to define environmental benchmarks. This is needed in order to reach a harmonized approach in Europe. It is furthermore recommended to calculate the benchmark values at national level in order to take into account external factors such as climate, construction practice and culture influencing the environmental impact of a building. It is also recommended to use a **stepwise conservative approach**, meaning that initially benchmarks are defined representing lower limit values and which gradually become more severe in time. This allows all stakeholders to get used to the method first and to ensure that the full market is included in a transition to sustainable building.

In order to define an environmental benchmark for office buildings, insight is needed in the average environmental impact of office buildings in Europe and on the variation of it throughout the building stock. This insight can either be gained from **real cases or virtual cases**. The first conservative benchmark should be set to allow all office buildings that **fulfill minimum legal requirements** on energy, water, fire safety, etc. To define the environmental impact fulfilling the improvement or target value, this can be based on best-practice buildings (experimental or demonstration projects) or based on virtual buildings with for example 30% less impact than the reference value (i.e. representing business-as-usual). In the second approach, the percentage reduction could either be based on a statistical analysis of building practice in the specific Member State or based on political targets set.

For the definition of **reference buildings**, building typologies must be defined that represent the building practice in a specific Member State. To calculate the environmental impact of each of the building types, the influence of the market variations on the impact of the building needs to be identified per building type in a dedicated **statistical study**. Market variation in terms of size, materials used and technical solutions are to be considered.

The desk research revealed that benchmarks can be defined to cover both material and energy impact of the building, or a separate benchmark can be defined for each. Based on the PEF assessment of the two office buildings with a very different energy performance in Deliverable D3 (VITO et al., 2018a), the project team recommends to have one benchmark including both **material and energy impact**. However, taking practical implementations into account, it might be easier to separate both (in a first phase) because energy benchmarks are currently already established in the EU Member States. Although material and energy impact can be separated in a first implementation stage, it is recommended that the same environmental indicators are assessed in order to allow for a smooth aggregation in the second implementation stage.

The desk research provided an overview of insights gathered, but it is clear that **additional data is needed** at the national level in order to define explicit recommendations on certain aspects that are relevant to defining reference buildings. Most countries lack a large database on non-residential buildings, and therefore the gathering of more data and the **creation of databases** are recommended.

Providing a clear **reference flow** for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the **function of office buildings** into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends **m² floor area** per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the **complete building** and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishes as well as technical equipment. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEF method for buildings. PEF recommendations can be followed related to cut-off rules and scenarios.

Although a benchmark should not differentiate between **design** (for obtaining a building permit) **and post-construction phase** (e.g. when 2 years in use), we recommend to define clear and different calculation rules on how to calculate the impacts in the design and post-construction phase when comparing these to the benchmark:

- Design phase: impact of operational energy should be linked with the energy performance calculation methods already established in the member states;
- Post-construction: impact of operational energy should be based on primary data: measured data for at least two years (average yearly consumption).

To avoid burden shifting or trade-offs between impacts, the project team recommends to have a **benchmark for each impact category separately, as well as at the aggregated level**. Once the most relevant impact categories for buildings have been identified, the benchmarks could be limited to the relevant impact categories only.

As **data quality requirements** are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in the PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

Starting from the benchmarks defined at national level, **performance classes** can be defined. If environmental assessment data is available on a large amount of buildings representing the office building stock, data on existing buildings should be used. If such data is not available, few representative buildings should be chosen and virtual variations of these buildings analysed. **Market variations** in terms of size, materials used and technical solutions are to be considered.

When the legal requirements define the lower limit of the first performance classes, and a statistical analysis defines the upper limit of the best performance classes, this range can be divided in five performance classes, as defined in the PEF Guidance.

1.4. GUIDANCE DOCUMENT FOR THE ASSESSMENT AT THE BUILDING LEVEL

The project team investigated **how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method**.

Existing methods to assess the environmental performance at the building level were screened: the EN 15978 standard[7]; CEN/TC 350[8]; in Belgium the method Material based environmental profiles of building elements (MMG)[9] in combination with the Belgian EPD program (product environmental declarations) and the recently launched tool TOTEM[10]; in France the method positive energy low carbon (E+C-)[11] and different software linked to the French EPDs "Fiches de Données Environnementales et Sanitaires (FDES)"[12]; in Germany the DGNB[13] and BNB[14] system; and in the Netherlands the Assessment Method for the Environmental Performance of Construction and Civil

[7] Bureau for Standardisation (NBN). (2013). NEN-EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.
[8] http://portailgroupe.afnor.fr/public_espacenormalisation/centc350/index.html
[9] Openbare Vlaamse Afvalstoffenmaatschappij (OVAM). (2013). Environmental profile of building elements [update 2017]. Retrieved from http://www.ovam.be/sites/default/files/atoms/files/Environmental%20profile%20of%20building%20elements%20-%20update%202017.pdf
[10] https://www.totem-building.be/
[11] République française. (2017). Référentiel « Energie – Carbone » pour les bâtiments neufs – Méthode d'évaluation de la performance énergétique et environnementale des bâtiments neufs. Retrieved from http://www.batiment-energiecarbone.fr/wp-content/uploads/2017/06/referentiel-energie-carbone-methode-evaluation-2017-07-01.pdf
[12] http://www.inies.fr/accueil/
[13] http://www.dgnb.de/
[14] https://www.bnb-nachhaltigesbauen.de/

Engineering Works (GWW)[15] in combination with the Dutch EPD program and the tool GPR Gebouw[16].

It can be concluded that **national systems** are very valuable since they usually take national guidelines into account and therefore have the highest potential of complying with the local realistic situation. In case national Product Category Rules (PCRs) for construction products provide guidance on the definition of the functional unit, this results in an easy link between the Environmental Product Declarations (EPDs) of construction products and the LCA at the building level.

It is recommended to develop a **PEFCR(s) at building level** in the future, which forms the basis for all (new) PEFCRs for construction products and should be aligned to existing PEFCRs at the construction product level, for example by consistent definition of life cycle stages. Currently, the number of life cycle stages considered is different in the various construction PEFCRs. The project team recommends to consider the life cycle stages as described in section 1.2. A clear reference flow should be defined, as described in the previous section, and clear rules should be defined at the building level for what is included or excluded and on cut-offs. Different PEFCRs should be developed for different building typologies and include national scenarios, for example on the use phase and for the dismantling/demolishing of the building. A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear guidelines to model the use phase and the reference study period and related references service lives are crucial. At building level, the PEFCR(s) for building(s) shall be clear on the procedures related to the allocation of impacts of re-used building elements (mainly important during renovation projects) by setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building). At product level, the allocation should follow the approach for the handling of multi-functional processes in the latest version of the PEF Guidance document.

A more extended list of generic datasets is needed to model an entire building. It is therefore recommended to provide a common EF database for the most frequent processes, e.g. using PEF compliant datasets purchased by EC, with integration of the CFF formula in the datasets.

Another aspect that has the potential to increase the feasibility of an LCA at the building level, is creating a link with **design tools (CAD systems and BIM systems), assessment tools and PEF compliant databases**. This can make data gathering a lot easier and greatly reduce the time and effort spent by the LCA practitioner. As modelling a building is very complex, a more flexible parameter structure for the amounts of elements and materials has to be found to further support a parametric approach. We recommend a hierarchical decomposition of the building as shown in Figure 3.

A generic **template for the data collection** and modelling is recommended if PEF studies of buildings should become mainstream. This template can be annexed to the PEFCR(s) to be developed.

[15] Stichting Bouwkwaliteit. (2014). Assessment Method Environmental Performance Construction and Civil Engineering Works (GWW), (November), 89. Retrieved from https://www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf

[16] https://www.gprsoftware.nl/

Today only a few **assessment tools** can calculate all PEF-required environmental impacts. However, all PEF categories could be integrated into these tools in the future to avoid burden shifting. Most of the current assessment tools are focused on the construction phase because there is a lack of information from environmental profiles on building processes (maintenance, repair, refurbishment, etc.). All life cycle stages should be taken into account. It is recommended to use PEF/LCA software that allows to directly extract the LCIA results at the level of the building, at the level of the life cycle stages, at the level of the element in each life cycle stage, and at the level of the material/process. It would be helpful if in future the PEF/LCA software would allow to do the hotspot analysis (identification of the most relevant impact categories, life cycle stages and processes) directly in the software.

A critical review of all PEF studies of buildings is recommended to ensure that the assessment is fairly, completely and accurately reported and in line with the latest version of the PEF guidance document.

CHAPTER 2 NOTE DE SYNTHÈSE (FRANÇAIS)

2.1. INTRODUCTION

Le but du projet PEF4Buildings, réalisé par l'Institut flamand pour la recherche technologique (VITO), KU Leuven et TU Graz, est de tester l'applicabilité de la méthode PEF (Product Environmental Footprint / Empreinte environnementale des produits)[17] sur un nouvel immeuble de bureaux. La méthode PEF a été élaborée par la Commission européenne dans le cadre de l'initiative « Marché unique des produits verts »[18]. Pendant plusieurs projets pilotes[19], des règles de catégories d'empreinte environnementale des produits (Product Environmental Footprint Category Rules ou PEFCR) ont été élaborées pour certains produits. Parmi ces produits figuraient les produits de construction suivants : isolation thermique, systèmes de conduites d'alimentation en eau chaude et froide, modules photovoltaïques, plaques de métal et peintures décoratives. Le projet PEF4Buildings vise à tester l'applicabilité de la méthode PEF et des PEFCR de ces produits de construction, au niveau du bâtiment plutôt qu'au niveau du produit.

Dans un premier temps du projet PEF4Buildings, **une étude PEF sur deux nouveaux immeubles de bureaux** a été réalisée. Le premier immeuble est l'immeuble de bureaux BelOrta de BelOrta CVBA, conçu par le cabinet d'architectes ar-te. L'immeuble BelOrta est un immeuble de bureaux construit en 2013-2015 en Belgique. Il s'agit d'un immeuble compact doté d'une cour intérieure autour de laquelle les espaces de travail sont organisés. Le cabinet d'architectes ar-te a fourni les données et les contributions nécessaires à l'étude PEF de ce bâtiment. Nous avons choisi ce bâtiment parce que a) un modèle BIM (Building Information Modelling ou modélisation des données du bâtiment) était disponible qui renforçait la phase d'état des lieux de l'étude PEF et b) il s'agit d'un immeuble ordinaire en matière de typologie, de performance énergétique et de technologies employées. Le deuxième nouvel immeuble de bureaux évalué dans cette étude est le bureau BE2226 de Baumschlager & Eberle, à Lustenau, en Autriche. BE2226 est un immeuble à consommation énergétique quasi nulle sans refroidissement et chauffage actifs. Pour ce bâtiment aussi, un modèle BIM était disponible. Cette étude de seconde phase a permis de tester la méthode PEF sur un bâtiment ayant une performance énergétique très élevée et située dans un contexte géographique différent.

Dans un second temps, une **approche possible visant à comparer des immeubles de bureaux et à définir des classes de performance** a été élaborée. L'approche qui a été élaborée repose sur des conclusions de l'étude PEF sur deux nouveaux immeubles de bureaux, sur la version la plus récente des documents d'orientation PEF disponibles à l'époque (v. 6.1 essentiellement et pour des aspects limités v. 6.2) (Commission européenne, 2017) et sur une recherche documentaire spécialisée sur les approches existantes. Elle couvre des questions comme comment définir le bâtiment de

[17] Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations
[18] http://ec.europa.eu/environment/eussd/smgp/index.htm
[19] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

référence, comment définir les limites du système, combien de bâtiments de référence doivent être définis et comment traiter cette plage de différentes options.

Une troisième étape de cette étude a été consacrée au **bilan au niveau bâtiment**. Elle donne des conseils sur comment lier le bilan de la performance environnementale des produits de construction au bilan d'un bâtiment à l'aide de la méthode PEF. Le bilan est parti des résultats de l'étude PEF sur deux nouveaux immeubles de bureaux, mais a été étendu à d'autres typologies de bâtiments européens possibles.

2.2. ÉTUDE PEF SUR DEUX NOUVEAUX IMMEUBLES DE BUREAUX

Pour tester l'applicabilité de la méthode PEF à un nouvel immeuble de bureaux, deux études de cas ont été sélectionnées, assurant ainsi que les conclusions ne sont pas spécifiques des cas ou spécifiques du contexte géographique.

Étude de cas 1 : Immeuble BelOrta d'ar-te en Belgique

Étude de cas 2 : Immeuble BE2226 de Baumschlager & Eberle, à Lustenau en Autriche

Figure 8: Les deux études de cas qui ont été sélectionnées pour le bilan PEF

Les limites du système des deux études PEF ont été définies du point de vue du concepteur / de l'architecte. Cela signifie que tout ce sur quoi le concepteur / l'architecte peut avoir une influence a été inclus dans les limites du système, mais chaque chose sur laquelle le concepteur / l'architecte n'a pas de maîtrise directe est exclue (par ex. papier, mobilier, transports en commun). Il a, en outre, été décidé d'exclure les parties de l'immeuble de bureaux qui ne sont pas indispensables au fonctionnement de l'immeuble de bureaux, comme la cuisine/restauration. Cela est considéré comme important pour effectuer des comparaisons équitables de l'empreinte environnementale des immeubles de bureaux (c.-à-d. à des fins d'analyse comparative) qui ne comportent pas tous une cuisine. De plus, les études PEF sont limitées au bâtiment en tant que tel et excluent les alentours (par exemple, parking).

Les éléments de bâtiment suivants ont été inclus dans le flux de référence :

- Fondations et sous-structure ;
- Le cadre structurel, dont les poutres, colonnes et dalles ;
- Escaliers ;
- Murs externes, revêtement et isolation ;

- Fenêtres ;
- Sols et plafonds ;
- Parois internes ;
- Portes ;
- Toits ;
- Systèmes de chauffage et de refroidissement ;
- Systèmes sanitaires ;
- Systèmes électriques.

Ne sont pas inclus dans le flux de référence :
- Les consommables (par exemple, équipement informatique, papier, mobilier) ;
- Alentours (par exemple, parking) ;
- Cuisine/restauration ;
- Transports en commun.

Sur la base d'une analyse transversale des **étapes du cycle de vie** définies dans les PEFCR provisoires pour les produits de construction faisant partie de la phase PEF pilote et des normes EN relatives aux produits de construction (EN 15978/EN15804), les étapes du cycle de vie présentées au Table 2 ont été définies pour le bilan PEF des deux immeubles de bureaux.

Table 2: Étapes du cycle de vie pour le bilan au niveau bâtiment

Nom d'étape du cycle de vie	**Les suivantes seront incluses**
PEF_A1	Prétraitement et acquisition de matières premières et emballage de matières premières
PEF_A2	Transport des matières (de construction) premières vers le site de production
PEF_A3	Fabrication des produits de construction et des emballages afférents
PEF_A4	Transport vers le chantier
PEF_A5	Construction - processus nécessaires à la construction du bâtiment, y compris tous les matériaux connexes, fin de vie des matériaux d'emballage éliminés, toute perte pendant la construction)
PEF_B1	Étape d'utilisation
PEF_B2	Entretien
PEF_B3	Réparation
PEF_B4	Remplacement
PEF_B5	Rénovation
PEF_B6	Utilisation de l'énergie d'exploitation
PEF_B7	Utilisation de l'eau d'exploitation
PEF_C1	Démantèlement
PEF_C2	Transport vers le lieu de fin de vie
PEF_C3/C4	Mise au rebut en fin de vie (tri pour le traitement de fin de vie, recyclage, incinération et mise en décharge de tous les matériaux à la fin de la vie du bâtiment)

La Figure 9 présente le **schéma des limites du système** pour le bilan au niveau bâtiment, où les étapes du cycle de vie sont présentées d'une manière compatible avec celle qui existe dans la norme EN 15804:2012+A1:2013 (Contribution des ouvrages de construction au développement durable - Déclarations environnementales sur les produits - Règles régissant les catégories de produits de construction) et EN 15978:2011 (Contribution des ouvrages de construction au développement durable — Bilan de la performance environnementale des bâtiments — Méthode de calcul).

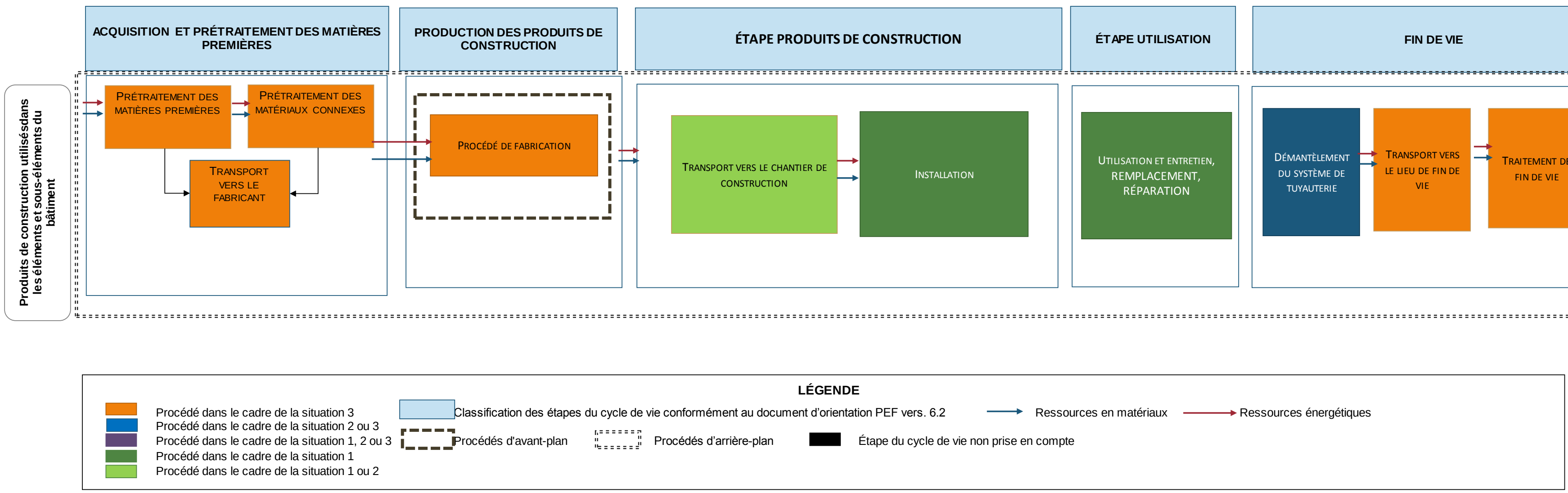


Figure 9: Schéma des limites du système pour le bilan PEF au niveau bâtiment

Pour chaque étape du cycle de vie, des scénarios spécifiques ont été élaborés pour le bilan de l'impact environnemental au niveau bâtiment. Ces scénarios portent essentiellement sur :

- *Des hypothèses liées à l'étape du processus de construction* : par exemple, le transport de produits de construction des fabricants au chantier, mais aussi le processus de construction ;
- *Des hypothèses liées à l'étape de l'utilisation* : hypothèses sur l'utilisation des produits de construction installés dans le bâtiment, entretien du bâtiment, activités de réparation, activités de remplacement, activités de rénovation, usage opérationnel de l'énergie et usage opérationnel de l'eau ;
- *Des hypothèses liées à l'étape de fin de vie* : hypothèses sur la déconstruction, la réutilisation, la démolition, le recyclage et la mise au rebut ; incluant l'ensemble du transport.

Pour la définition de ces scénarios, l'orientation PEF ainsi que les PEFCR provisoires, des normes EN et nationales ont été employées.

Aux fins du bilan PEF, des règles pour l'affectation au niveau bâtiment et au niveau produit ont été identifiées :

- Au niveau bâtiment, l'affectation des impacts des éléments de construction réutilisés pourrait être discutée, mais ne faisait pas partie de cette étude dans la mesure où l'accent était mis sur les nouveaux immeubles de bureaux. Définir les règles d'affectation liées aux impacts partagés entre des anciennes limites de systèmes et les prochaines limites de systèmes seront nécessaires lors de la conduite d'une étude PEF de bâtiments rénovés ;
- Au niveau produit, l'affectation suit l'approche relative au traitement des processus plurifonctionnels du document d'orientation PEF 6.1 (European Commission, 2017).

Les deux études PEF sont configurées de manière similaire à une étude de présélection PEF. Par conséquent, aucun seuil n'est appliqué. Toutes les informations qui ne sont pas incluses dans les études ne le sont pas en raison de déficits de données et non de seuils.

Une décomposition hiérarchique du bâtiment (méthode des éléments) a été utilisée pour éviter des déficits de données dans la mesure du possible et pour permettre d'utiliser des données d'inventaire de différents sous-niveaux pour le bilan du bâtiment. La structure du **modèle** repose sur une sous-division hiérarchique du bâtiment en éléments plus petits : éléments du bâtiment, sous-éléments et matériaux (Figure 10).

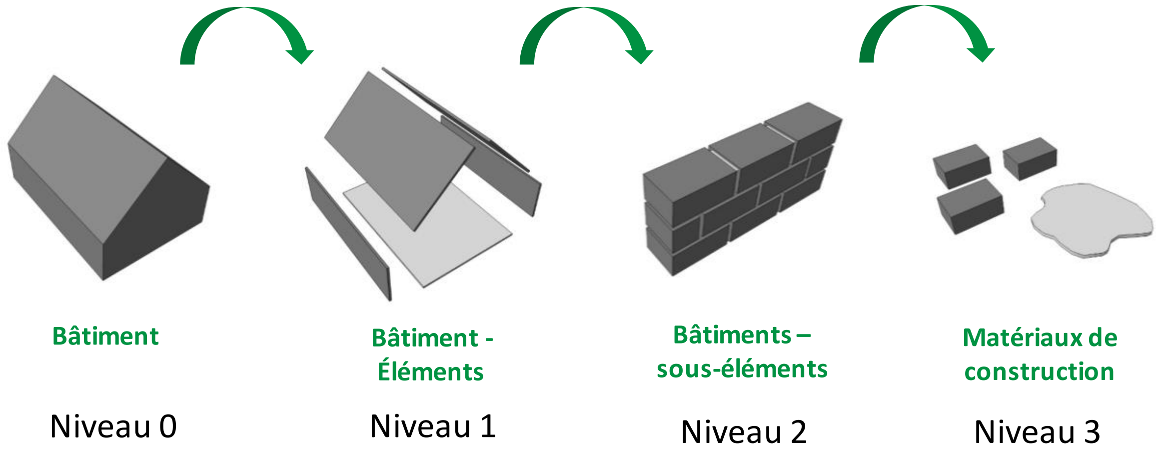
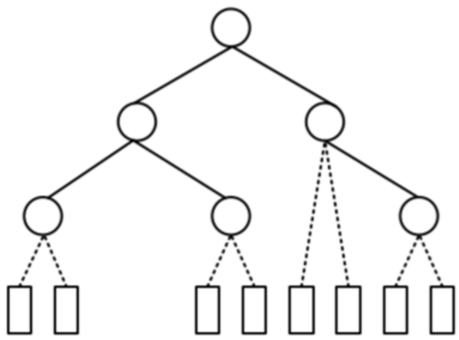


Figure 10: Décomposition hiérarchique du bâtiment (Trigaux et al., 2017)

Pour une distinction et une analyse détaillée des différents éléments du bâtiment et des sections du bâtiment, le système de classification en arborescence des éléments du bâtiment d'OmniClass (2015) est employé conformément à la norme ISO 12006-2 (International organization for Standardization, 2015) *(*Figure 11*).*



- Niveau 0 : Bâtiment
- Niveau 1 : Éléments du bâtiment (par exemple, murs externes)
- Niveau 2 : Sous-éléments du bâtiment (par exemple, mur de brique)
- Niveau 3 : Matériaux de construction (par exemple, briques)

Figure 11: Cadre adopté pour la classification conformément à la norme ISO 12006-2 (ISO, 2015)

La procédure de flux de processus telle que présentée à la Figure 12 a été élaborée pour ce projet. Tout d'abord, les sources destinées à identifier les informations nécessaires sur les éléments du bâtiment, les matériaux de construction, les scénarios, la phase d'utilisation ont été identifiées au cours du processus de recueil de données. Dans un second temps, un catalogue d'éléments de construction des composants de construction a été élaboré dans une feuille de calcul (Excel) et constituent les principaux apports pour le bilan de l'impact du cycle de vie (LCIA) dans le logiciel LCA (SimaPro)[20].

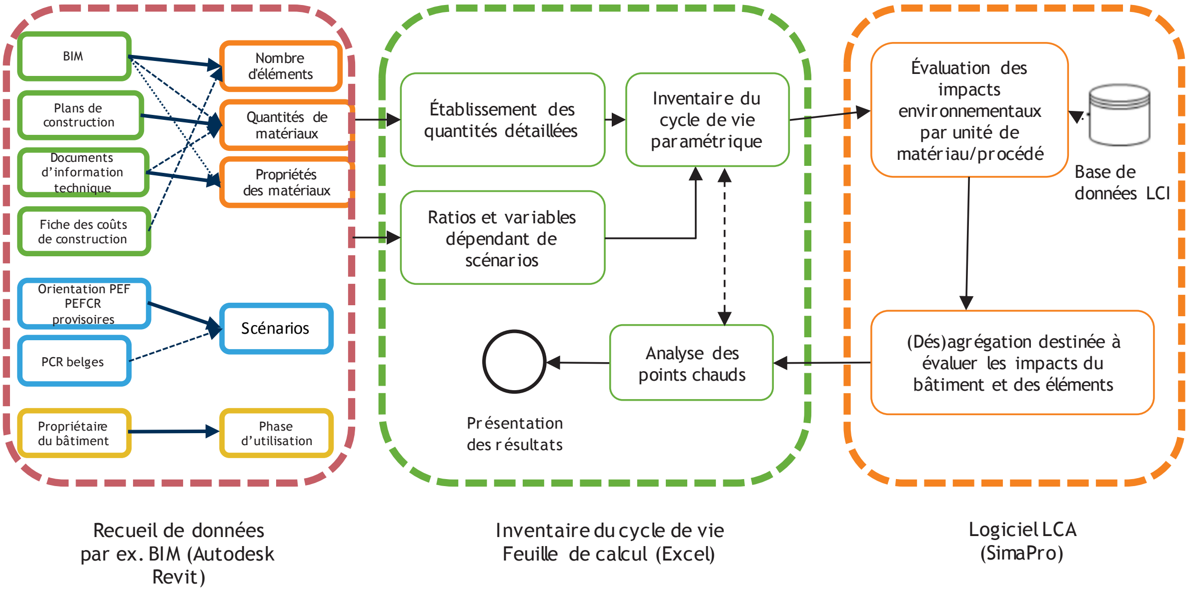


Figure 12: Processus de développement du modèle de données

Les enseignements suivants ont été tirés de la phase d'inventaire du cycle de vie :

- Les ensembles de données doivent permettre l'application de la formule CFF (Circular Formula Footprint - Empreinte de formule circulaire) ;
- Des principes directeurs clairs sont nécessaires pour modéliser la phase d'utilisation ;
- Des scénarios nationaux sont nécessaires (par exemple, pour les produits pour matériaux/éléments de construction pour lesquels aucune PEFCR provisoire n'est disponible) ;
- Pendant le recueil des données, le modèle BIM s'est révélé être une source importante apportant de la valeur ajoutée.

Étant donné que ce projet ne visait pas à s'attacher aux valeurs absolues et aux résultats obtenus, mais à comprendre les aspects méthodologiques du calcul d'une PEF d'immeuble de bureaux, les résultats numériques de l'étude ne sont pas rapportés ici. Bien que l'intention des deux bilans des deux cas ne soit pas de comparer leurs résultats LCIA en détail, certaines constatations importantes peuvent être soulignées :

- Tout d'abord, la note pondérée globale des deux bâtiments est sensiblement différente : le bâtiment BE2226 affiche clairement un impact inférieur à celui de l'immeuble BelOrta. Cela était prévu puisque le second cas (BE2226) est un bâtiment avancé (NZEB) tandis que le premier cas (BelOrta) est un cas ordinaire. Toutefois, il est utile de remarquer que le système de contrôle du bâtiment (dont les capteurs, armoires de commande...) et les

[20] Le logiciel LCA SimaPro a été choisi parce que l'équipe du projet a l'habitude de travailler avec. Cela n'implique pas une préférence quelconque pour le logiciel à utiliser, de la part de la Commission européenne ou de l'équipe du projet.

conduites ne sont pas modélisés pour le second cas en raison d'un manque de données. De plus, les deux bâtiments ont le même usage et une taille similaire en termes de surface de plancher, mais représentent des typologies de bâtiment différentes ;

- Ensuite, les catégories d'impact les plus pertinentes identifiées diffèrent d'un cas à l'autre. Les catégories d'impact les plus pertinentes dépendent donc clairement du bâtiment (performance énergétique et matériaux utilisés), mais aussi de l'emplacement (production d'électricité). Cela a de l'importance si l'objectif est de limiter les catégories d'impact du PEF4Buildings à celles qui sont les plus pertinentes. Nous pouvons en outre conclure que plusieurs des catégories d'impact les plus importantes sont des catégories d'impact « supplémentaires » qui ne sont pas incluses dans la version actuelle des normes EN 15804 et EN 15978 ;
- Troisièmement, pour les deux bâtiments, l'utilisation opérationnelle de l'énergie et le prétraitement des matières premières ont été identifiés comme figurant parmi les plus pertinentes des étapes du cycle de vie. Pour l'immeuble BelOrta, toutefois, la phase d'utilisation contribue nettement plus à l'impact du cycle de vie que pour le bâtiment BE2226. Étant donné que la phase d'utilisation du bâtiment BE2226 a des impacts moindres que l'immeuble BelOrta, des étapes supplémentaires au cycle de vie gagnent en pertinence ;
- Quatrièmement, l'identification des processus les plus pertinents mène à un ensemble différent des processus les plus pertinents pour les deux bâtiments. Cela était attendu puisque les deux bâtiments se composent de matériaux et d'éléments différents, mais sont également situés dans des lieux différents et donc une production d'électricité différente est utilisée pendant la phase importante de l'utilisation du bâtiment.

  Pour finir, l'inclusion/exclusion des catégories d'impact dans le domaine de la toxicité a une influence évidente sur les résultats dans une grande mesure, en particulier pour la deuxième étude de cas.

Il est en outre important de noter que deux démarches de modélisation différentes ont été appliquées aux deux études de cas pour apprendre des différences. Le modèle Simapro BelOrta suit strictement la structure hiérarchique présentée à la Figure 10, alors que le modèle Simapro BE2226 est réalisé au niveau matériaux pour déterminer les implications de différentes démarches de modélisation . L'écart de modélisation a principalement des conséquences pendant l'interprétation des résultats. Pour le bâtiment BelOrta, les résultats et l'analyse des points chauds pourraient être directement extraits du modèle SimaPro dans la mesure où le modèle SimaPro BelOrta permet d'extraire directement les résultats LCIA au niveau du bâtiment, au niveau de l'étape du cycle de vie, au niveau de l'élément de chaque étape du cycle de vie et au niveau du matériau/procédé. Pour le bâtiment BE2226, une étape intermédiaire via le modèle de feuille de calcul a été nécessaire pour agréger les matériaux comme requis en vue d'identifier les processus les plus pertinents.

Les recommandations sur la manière de surmonter les difficultés méthodologiques identifiées seront décrites à la section 2.4, où les conclusions de l'étude PEF sur deux immeubles de bureaux sont combinées avec les conclusions de la recherche documentaire de la section suivante.

2.3. PROPOSITION D'APPROCHE POUR UN RÉFÉRENTIEL ET DES CLASSES DE PERFORMANCE POUR LES IMMEUBLES DE BUREAUX

Pour proposer une approche possible pour étalonner et définir des classes de performance pour les nouveaux immeubles de bureaux, une recherche documentaire spécialisée a été menée, qui s'attachait aux rapports existants sur les typologies de bâtiments, aux plans de développement durable, aux principes directeurs LCA (comme la norme EN 15978 et les PCR provisoires pour les bâtiments) et aux méthodes nationales ou exigences légales (comme la méthode E+C- en France, DGNB et BNB en Allemagne, GWW aux Pays-Bas, MMG en Belgique). Les méthodes analysées sont comparées sur divers aspects : la signification et l'approche du référentiel qui est définie, comment les bâtiments de référence sont définis, les limites de système envisagées, l'unité fonctionnelle et le flux de référence, ainsi que l'approche employée pour définir des classes de performance.

2.3.1. Vue d'ensemble des conclusions

Plusieurs différences importantes ont été identifiées dans la **signification et les approches liées** utilisées pour définir les référentiels environnementaux des bâtiments. L'examen de la littérature a révélé que diverses **significations** de référentiels de bâtiments sont utilisées, allant de valeurs limites (performance minimale acceptable), par rapport à une valeur de référence (état de l'art actuel, par exemple moyenne) et une valeur de pratiques exemplaires (valeurs atteintes dans des projets expérimentaux ou de démonstration) jusqu'à des valeurs cibles (valeurs qui peuvent être atteintes dans une perspective de moyen terme ou de long terme). En fonction de la signification choisie, différentes **approches et sources** sont employées pour calculer les valeurs de référentiel, allant des prescriptions de lois, de normes (pour les valeurs limites), par rapport à des valeurs statistiques et des bâtiments de référence (pour les valeurs de référence) jusqu'à des valeurs cibles politiques ou des valeurs optimales économiques et techniques (pour les valeurs cibles). Les programmes de certification de bâtiments, comme BREEAM ou DGNB, utilisent en règle générale diverses valeurs, c.-à-d. des valeurs limites, de référence et cibles, pour définir leur référentiel et les classes de performance. Les référentiels nationaux actuels représentent essentiellement des règles de jeu équitables avec une limite basse comme point de départ. Leur objectif est d'autoriser les bâtiments avec une valeur plus basse d'une part, mais aussi d'éviter un comportement de cavalier seul d'autre part. Pour autant, les référentiels peuvent évoluer au fil du temps à mesure que la technologie avance et que la connaissance du parc de bâtiments se développe.

Une autre différenciation remarquée dans l'approche suivie en littérature est l'utilisation de **référentiels externes contre internes**. La première est la plus courante et compare un certain bâtiment à un bâtiment de référence différent par son agencement et le choix des matériaux (parfois aussi en matière de performance énergétique). Le référentiel interne est plus rarement utilisé (par exemple par LEED) et compare l'impact du bâtiment modèle avec un bâtiment de référence pour lequel seuls les matériaux varient (ce qui signifie que le bâtiment projeté est identique au bâtiment de référence en termes d'agencement, de taille et de performance énergétique).

Certains systèmes ont en outre défini un **référentiel pour chaque catégorie d'impact** séparément (par exemple, DGNB), tandis que d'autres ont défini un **référentiel pour la note unique agrégée** (par exemple, les Pays-Bas). Dans les systèmes ayant des référentiels pour chaque catégorie d'impact séparément, la note finale est obtenue en pondérant les différentes notes sur les différentes catégories d'impacts. La pondération des différentes catégories d'impacts fait ensuite partie de la méthodologie.

De la recherche documentaire, nous pouvons conclure que les **bâtiments de référence** pour déterminer le référentiel peuvent être soit de vrais bâtiments représentant le bâtiment de référence ou être des bâtiments virtuels (c.-à-d. basés sur une analyse statistique d'une partie représentative du parc immobilier national). Une telle analyse statistique différencie différents types de bâtiments, tailles, matériaux et performances énergétiques.

« 50 ans » a été découvert comme la période d'étude de référence la plus courante pour les immeubles de bureaux. Un **flux de référence** couramment utilisé est « par surface de plancher, par an ». Certaines études suggèrent de prendre la fonction du bâtiment en compte, par exemple le nombre de postes de travail dans l'immeuble de bureaux ou le nombre de personnes en équivalent temps plein. Aucune hypothèse utile sur des règles de seuil ou des scénarios n'est ressortie de la recherche documentaire.

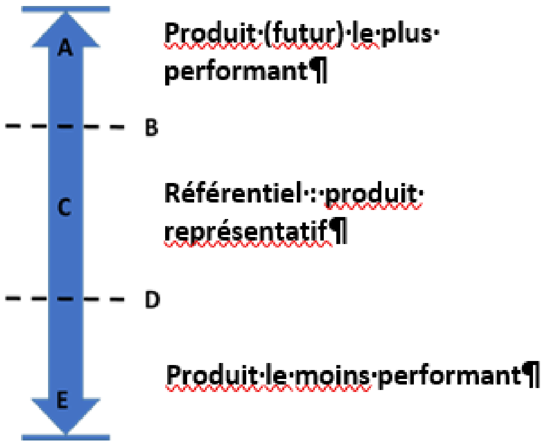


Figure 13: Niveaux de performance selon le document d'orientation PEF (Technical Helpdesk PEF, 2016)

Dans le document d'orientation PEF[21], des conseils sont donnés sur la manière de calculer les **niveaux de performance pour les produits** (basés sur les paramètres les plus pertinents et en déterminant des valeurs minimales et maximales de marché réalistes). La recherche documentaire visait à explorer si d'autres méthodes étaient utilisées pour définir des classes de performance pour les bâtiments dans les approches existantes. Nous pouvons conclure que l'**objectif** des classes de performance peut être différent et détermine l'approche à employer pour définir des classes de performance. Pour la définition des classes de performance, un grand nombre d'informations est nécessaire sur les bâtiments pertinents pour qu'ils soient « représentés » dans différentes classes, afin de pouvoir fixer les seuils désirés. Pour cela, tout comme pour les analyses comparatives, il est nécessaire d'avoir une vue d'ensemble des impacts environnementaux des différents bâtiments à couvrir par les classes de performance, qui peuvent être de **vrais bâtiments ou des bâtiments virtuels**. Dans le cas de classes de performance, étant donné que le volume de données nécessaires est important, ce sont généralement des bâtiments virtuels qui sont utilisés. Pour définir les seuils entre différentes classes de performance, certains systèmes s'appuient exclusivement sur l'amélioration relative par rapport au référentiel (par exemple, 5 %, 10 % ou 15 % supérieur au référentiel). D'autres systèmes (comme ceux figurant dans le rapport des conseillers W/E[22] – reposent sur la dispersion statistique du parc immobilier analysé. Un exemple de cette approche est illustré à la Figure 14.

[21] Technical Helpdesk PEF. (2016). Issue paper "Determining the EF benchmark and performance classes" - version 3.

[22] W/E adviseurs. (2014). Onderzoek "Bepaling kwaliteitsniveaus milieuprestatie van woonfuncties" - Eindrapport. Retrieved from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2014/11/14/onderzoek-bepaling-kwaliteitsniveaus-milieuprestatie-van-woonfuncties/eindrapport-bepaling-kwaliteitsniveaus-milieuprestatie-we-adviseurs.pdf

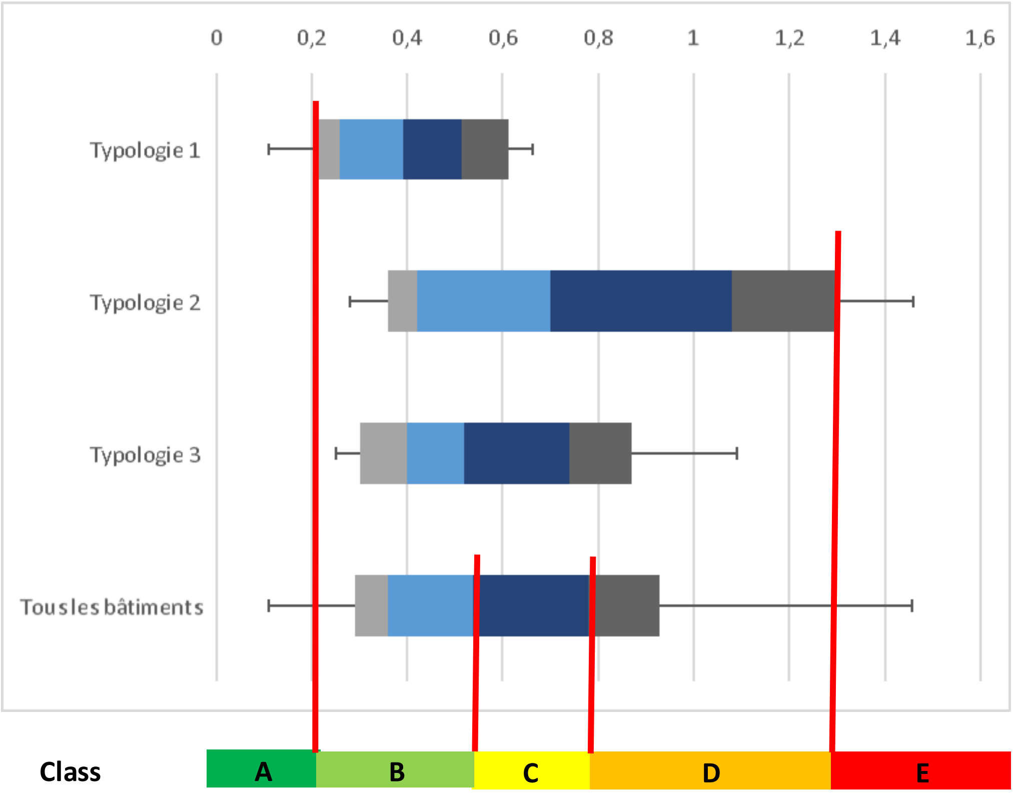


Figure 14: Informations statistiques comme base de classes de performance

2.3.2. Recommandations

Les recommandations sont faites en fonction des constatations de l'étude PEF sur deux nouveaux immeubles de bureaux, le guide PEF et les documents d'orientation afférents, la recherche documentaire, les commentaires reçus des parties prenantes et les expériences antérieures de l'équipe du projet.

L'équipe du projet recommande de définir une **méthodologie européenne commune** pour calculer l'impact environnemental des bâtiments et une méthodologie européenne commune sur comment définir des référentiels environnementaux. Cela est nécessaire pour atteindre une approche harmonisée en Europe. Il est en outre recommandé de calculer les valeurs de référentiel au niveau national pour prendre en compte des facteurs externes comme le climat, les pratiques de construction et la culture ayant une influence sur l'impact environnemental d'un bâtiment. Il est également recommandé d'employer une **approche prudente progressive**, ce qui signifie qu'initialement les référentiels sont définis en représentant les valeurs limites basses qui deviennent progressivement plus strictes au fil du temps. Cela permet à toutes les parties prenantes de s'habituer d'abord à la méthode et d'assurer que le marché complet est inclus dans une transition vers un bâtiment durable.

Pour définir un référentiel environnemental pour les immeubles de bureaux, un éclairage est nécessaire au sujet de l'impact environnemental moyen des immeubles de bureaux en Europe et sur leurs divergences dans l'ensemble du parc immobilier. Cet éclairage peut être tiré de **cas réels ou de cas virtuels**. Le premier référentiel prudent doit être défini pour autoriser tous les immeubles de bureaux qui **remplissent les exigences légales minimales** en matière d'énergie, d'eau, de sécurité incendie, etc. Pour définir l'impact environnemental respectant l'amélioration ou la valeur cible, celui-ci peut être fondé sur les bâtiments intégrant des pratiques exemplaires (projets expérimentaux ou de démonstration) ou fondé sur des bâtiments virtuels avec, par exemple, un impact inférieur de 30 % à celui de la valeur de référence (c.-à-d. représentant un bâtiment ordinaire). Dans la seconde approche, la réduction du pourcentage pourrait soit être fondée sur une analyse statistique des pratiques de construction dans l'État membre spécifique soit sur un ensemble de cibles politiques.

Pour la définition de **bâtiments de référence**, des typologies de bâtiment doivent être définies qui représentent les pratiques de construction dans un État membre précis. Pour calculer l'impact environnemental de chacun des types de bâtiments, l'influence des variations de marché sur l'impact du bâtiment a besoin d'être identifiée par type de bâtiment dans une **étude statistique** spécialisée. Les variations de marché en termes de taille, matériaux utilisés et solutions techniques doivent être prises en compte.

La recherche documentaire a révélé que les référentiels peuvent être définis pour couvrir à la fois l'impact matériel et énergétique du bâtiment ou qu'un référentiel séparé peut être défini pour chacun d'eux. Sur la base du bilan PEF des deux immeubles de bureaux avec une performance énergétique très différente dans le Livrable D3 (VITO et al., 2018a), l'équipe du projet préconise d'avoir un référentiel incluant à la fois l'**impact matériel et énergétique**. Pour autant, en prenant en compte les mises en œuvre pratiques, il pourrait être plus facile de séparer les deux (dans un premier temps) parce que les référentiels énergétiques sont actuellement déjà établis dans les États membres de l'UE. Bien que l'impact matériel et énergétique puisse être séparé dans une première étape de mise en œuvre, il est recommandé que les mêmes indicateurs environnementaux soient évalués pour permettre une agrégation harmonieuse lors de la seconde étape de mise en œuvre.

La recherche documentaire a offert un aperçu des éclairages recueillis, mais il est évident que des **données supplémentaires sont nécessaires** au niveau national pour définir des recommandations explicites sur certains aspects qui sont utiles à la définition de bâtiments de référence. La plupart des pays ne disposent pas d'une base de données de grande taille sur les bâtiments non résidentiels et, par conséquent, la collecte de données supplémentaires et la **création de bases de données** sont recommandées.

La fourniture d'un **flux de référence** clair pour le bilan de bâtiments améliorera grandement la comparabilité d'études futures. D'un point de vue scientifique, l'équipe du projet recommanderait de définir une unité fonctionnelle appropriée pour le référentiel qui prenne la **fonction des bâtiments de bureaux** en compte, par exemple des équivalents temps plein par an. Pour autant, les exigences en matière de performance énergétique des bâtiments déjà établies dans l'ensemble des États membres utilisent des surfaces de plancher en m² pour tous les référentiels définis dans les programmes de certification des bâtiments actuels. C'est pourquoi, en prenant en compte les implications pratiques et pour permettre des analyses cohérentes des bâtiments, l'équipe du projet recommande la **surface de plancher en m²** par an comme le flux de référence le plus approprié. Lorsque l'on opte pour la surface de plancher en m², il est recommandé de définir des règles claires et strictes sur la manière de définir la surface de plancher : par exemple brute, nette ou surface de plancher chauffée.

De plus, il est recommandé d'évaluer le bâtiment complet et ses éléments : fondations, enveloppe du bâtiment, parois intérieures et étages intermédiaires, en incluant toutes les finitions ainsi que les équipements techniques. Le mobilier, les bureaux, équipements informatiques, la cuisine et les espaces de stationnement doivent être exclus. Point le plus important, des règles claires doivent être définies dans une méthode PEF pour les bâtiments. Les recommandations PEF peuvent être suivies par rapport à des règles de seuil et des scénarios.

Même si un référentiel ne doit pas faire une différence entre la **phase de conception** (pour obtenir un permis de construire) **et la phase post-construction** (par exemple, après 2 ans d'utilisation), nous recommandons de définir des règles de calcul claires et différentes sur la manière de calculer les impacts à la phase de conception et à la phase post-construction lors de la comparaison de celles-ci au référentiel :

- Phase de conception : l'impact de l'énergie d'exploitation doit être liée aux méthodes de calcul de la performance énergétique déjà établies dans les États membres ;
- Post-construction : l'impact de l'énergie d'exploitation doit être fondé sur des données primaires : données mesurées pendant au moins deux ans (consommation annuelle moyenne).

Pour éviter un transfert de charges ou des compromis entre les impacts, l'équipe du projet recommande d'avoir un **référentiel pour chaque catégorie d'impact séparément, ainsi qu'au niveau agrégé**. Une fois que les catégories d'impact les plus pertinentes auront été identifiées, les référentiels pourront être limités exclusivement aux catégories d'impact pertinentes.

Étant donné que les **exigences de qualité de données** sont considérées comme cruciales à des fins de référentiel en LCA, il est recommandé de suivre la même approche que dans les PEFCR. Cela assure la qualité de données nécessaire et donc la représentativité des référentiels définis.

Avec les référentiels définis au niveau national comme point de départ, des **classes de performance** peuvent être définies. Si des données de bilan environnemental sont disponibles sur un grand nombre de bâtiments représentant le parc d'immeubles de bureaux, les données sur les bâtiments existants doivent être utilisées. Si ces données ne sont pas disponibles, quelques bâtiments représentatifs doivent être choisis et des variations virtuelles de ces bâtiments analysées. Les **variations de marché** en termes de taille, matériaux utilisés et solutions techniques doivent être prises en compte.

Lorsque les exigences légales définissent la limite basse des premières classes de performance et qu'une analyse statistique définit la limite haute des meilleures classes de performance, cette fourchette peut être divisée en cinq classes de performance, comme défini dans le document d'orientation PEF.

2.4. DOCUMENT D'ORIENTATION POUR LE BILAN AU NIVEAU BÂTIMENT

L'équipe du projet a fait des recherches sur **la manière de lier le bilan de la performance environnementale des produits de construction au bilan d'un bâtiment à l'aide de la méthode PEF**.

Des méthodes existantes pour évaluer la performance environnementale au niveau du bâtiment ont été examinées : la norme EN 15978 standard[23] ; CEN/TC 350[24] ; en Belgique, la méthode Profil

[23] Bureau for Standardisation (NBN). (2013). NEN-EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

environnemental des éléments de construction basée sur les matériaux (MMG)[25] en association avec le programme DEP (Déclarations Environnementales de Produits) et l'outil récemment lancé TOTEM[26] ; en France la méthode énergie positive - bilan carbone (E+C-)[27] et différents logiciels liés aux FDES (Fiches de Données Environnementales et Sanitaires)[28] ; en Allemagne le système DGNB[29] et BNB[30] ; et aux Pays-Bas, la Méthode d'évaluation du bilan environnemental des travaux de construction et de génie civil (GWW)[31] en association avec le programme DEP néerlandais et l'outil GPR Gebouw[32].

On peut conclure que les **systèmes nationaux** sont très précieux puisqu'ils prennent habituellement en compte les principes directeurs nationaux et ont donc le potentiel le plus élevé de conformité à la situation réaliste locale. Au cas où des règles de catégories de produits (PCR) pour les produits de construction fournissent des orientations sur la définition de l'unité fonctionnelle, cela aboutit à un lien facile entre les Déclarations Environnementales de Produits (DEP) des produits de construction et la LCA au niveau du bâtiment.
Il est recommandé de développer une/des **PEFCR au niveau bâtiment** à l'avenir, qui forme(nt) la base de toutes les (nouvelles) PEFCR pour les produits de construction et doi(ven)t être alignée(s) sur les PEFCR existantes au niveau produits de construction, par exemple par une définition cohérente des étapes du cycle de vie. Actuellement, le nombre d'étapes du cycle de vie envisagé est différent dans les diverses PEFCR de construction. L'équipe du projet recommande d'envisager les étapes de cycle de vie telles que décrites à la section 1.2. Un flux de référence clair doit être défini, comme décrit à la section précédente et des règles claires doivent être définies au niveau du bâtiment dans le domaine de ce qui doit être inclus ou exclu et sur les seuils. Des PEFCR différentes doivent être élaborées pour les différentes typologies de bâtiments et inclure des scénarios nationaux, à titre d'exemple sur la phase d'utilisation et pour le démantèlement / la démolition du bâtiment. Une différenciation entre les règles/principes directeurs est nécessaire pour les études PEF dans le domaine de l'aide à la conception / des permis de construire et ex-post construction. Des principes directeurs clairs pour modéliser la phase d'utilisation et la période de l'étude de référence et les durées de service de référence liées sont cruciaux. Au niveau bâtiment, la (les) PEFCR pour le(s) bâtiment(s) sera(ont) claire(s) au sujet des procédures liées à l'affectation des impacts des éléments de bâtiment réutilisés (essentiellement importants pendant les projets de rénovation) en énonçant les principes d'affectation des impacts entre les anciennes limites de

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[24] http://portailgroupe.afnor.fr/public_espacenormalisation/centc350/index.html
[25] Openbare Vlaamse Afvalstoffenmaatschappij (OVAM). (2013). Environmental profile of building elements [update 2017]. Retrieved from http://www.ovam.be/sites/default/files/atoms/files/Environmental%20profile%20of%20building%20elements%20-%20update%202017.pdfs
[26] https://www.totem-building.be/
[27] République française. (2017). Référentiel « Energie – Carbone » pour les bâtiments neufs – Méthode d'évaluation de la performance énergétique et environnementale des bâtiments neufs. Retrieved from http://www.batiment-energiecarbone.fr/wp-content/uploads/2017/06/referentiel-energie-carbone-methode-evaluation-2017-07-01.pdf
[28] http://www.inies.fr/accueil/
[29] http://www.dgnb.de/
[30] https://www.bnb-nachhaltigesbauen.de/
[31] Stichting Bouwkwaliteit. (2014). Assessment Method Environmental Performance Construction and Civil Engineering Works (GWW), (November), 89. Retrieved from https://www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf
[32] https://www.gprsoftware.nl/

système et les prochaines limites de système est (sont) nécessaire(s) (comme la réutilisation des fondations sur pieux de l'ancien bâtiment). Au niveau produit, l'affectation doit suivre l'approche relative au traitement des processus plurifonctionnels de la dernière version du document d'orientation PEF.

Une liste plus étendue de jeux de données génériques est nécessaire pour modéliser un bâtiment entier. Il est donc recommandé de fournir une base de données EF commune pour les processus les plus fréquents, par exemple à l'aide de jeux de données compatibles avec la PEF achetés par la Commission européenne avec intégration de la formule CFF dans les jeux de données.

Un autre aspect qui a le potentiel d'accroître la faisabilité d'un LCA au niveau bâtiment est la création d'un lien avec des **outils de conception (systèmes de CAO et systèmes BIM), des outils d'évaluation et des bases de données compatibles avec la PEF**. Cela peut grandement faciliter le recueil de données et fortement réduire le temps et les efforts consacrés par le professionnel LCA. La modélisation d'un bâtiment étant très complexe, il a été constaté qu'une structure de paramètres plus flexible pour les quantités d'éléments et de matériaux apportait un appui supplémentaire à une approche paramétrique. Nous recommandons une décomposition hiérarchique du bâtiment comme illustré à la Figure 10.

Un modèle générique pour le **recueil de données** et la modélisation est recommandé au cas où les études PEF de bâtiments devraient se généraliser. Ce modèle peut être mis en annexe à la (aux) règle(s) PEFCR à développer.

Aujourd'hui, seuls quelques **outils d'évaluation** peuvent calculer tous les impacts environnementaux requis pour les PEF. Toutes les catégories de PEF pourraient, toutefois, être intégrées à ces outils à l'avenir pour éviter un transfert de charges. La plupart des outils d'évaluation courants portent sur la phase de construction en raison de l'absence d'informations tirées de profils environnementaux sur les procédés de construction (entretien, réparation, rénovation, etc.). Toutes les étapes du cycle de vie doivent être prises en compte. Il est recommandé d'utiliser le logiciel PEF/LCA qui permet d'extraire directement les résultats LCIA au niveau du bâtiment, au niveau des étapes du cycle de vie, au niveau de l'élément de chaque étape du cycle de vie et au niveau du matériau/procédé. Il serait utile à l'avenir que le logiciel PEF/LCA permette une analyse des points chauds (identification des catégories d'impact les plus pertinentes, des étapes du cycle de vie et des procédés) directement dans le logiciel.

Un examen critique de toutes les études PEF de bâtiments est recommandée pour assurer que le bilan fait l'objet de comptes rendus équitables, exhaustifs et précis et correspond à la version la plus récente du document d'orientation PEF.

CHAPTER 3 ZUSAMMENFASSUNG (DEUTSCH)

3.1. EINFÜHRUNG

Ziel des PEF4Buildings-Projekts, ist es, die Anwendbarkeit der Product Environmental Footprint (PEF)-Methode[33] (Umweltfußabdruck von Produkten) auf neue Bürogebäude zu testen. Das PEF4Buildings Projekt wurde unter Leitung des flämischen Instituts für Technologieforschung (VITO), zusammen mit der Katholieke Universiteit Leuven (KU Leuven) und der Technischen Universität Graz (TU Graz) durchgeführt. Die PEF-Methode selbst wurde von der Europäischen Kommission (EC) im Rahmen der Initiative "Binnenmarkt für umweltfreundliche Produkte"[34] entwickelt. In mehreren Pilotprojekten[35] wurden für bestimmte Produkte sogenannte Product Environmental Footprint Category Rules (PEFCRs, dt. Kategorienregeln für den Umweltfußabdruck von Produkten) entwickelt, unter anderem bisher für folgende bauspezifische Produkte: Wärmedämmung, Warm- und Kaltwasserleitungen, Photovoltaikmodule, metallische Bleche und Dekorfarben. Im PEF4Buildings Projekt wurde die Anwendbarkeit der PEF-Methode und dieser Bauprodukt-PEFCRs auf Gebäudeebene untersucht.

Ein erster Schritt war die **Analyse von zwei Büro-Neubauten unter Anwendung der PEF-Methode**. Das erste Gebäude ist das Bürogebäude „BelOrta“ von BelOrta CVBA, entworfen vom Architekturbüro ar-te. Das BelOrta-Gebäude ist ein Bürogebäude, welches 2013-2015 in Belgien gebaut wurde. Es handelt sich um ein kompaktes Gebäude mit einem Innenhof, um den sich die Arbeitsräume gruppieren. Das Architekturbüro ar-te lieferte die notwendigen Daten und Inputs für die PEF-Studie dieses Gebäudes. Das Konsortium entschied sich für dieses Gebäude, weil (a) ein Building Information Model (BIM-Modell) verfügbar war, welches die Sachbilanz-Erstellung während der PEF4Buildings-Studie unterstützen sollte und (b) es sich um ein Business-as-usual-Gebäude in Bezug auf Typologie, Energieeffizienz und verwendete Technologien handelt. Das zweite in dieser Studie untersuchte neue Bürogebäude ist das „BE2226“ Gebäude der Architekten Baumschlager & Eberle, Lustenau, Österreich. BE2226 ist ein innovatives Nahezu-Null-Energie-Gebäude ohne aktive Kühl- und Heizsysteme. Auch für dieses Gebäude stand ein BIM-Modell (angefertigt von der TU Graz) zur Verfügung. Diese zweite Fallstudie ermöglichte es, die PEF-Methode an einem Gebäude mit einer sehr hohen Energieeffizienz in einem anderen geografischen Kontext zu evaluieren.

In einem zweiten Schritt wurde ein **möglicher Ansatz zum Benchmarking von Bürogebäuden und zur Definition von Leistungsklassen** entwickelt. Der entwickelte Ansatz basiert auf den Ergebnissen des ersten Teils, der PEF-Studie zu zwei neuen Bürogebäuden, der neuesten Version der damals verfügbaren PEF Guidance Dokumente (verwendet wurde hauptsächlich Version 6.1, für ausgewählte Aspekte Version 6.2) (Europäische Kommission, 2017) und einer themenspezifischen Literaturrecherche zu bestehenden Benchmarking-Ansätzen. Die Recherche sollte einen Überblick

[33] Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations
[34] http://ec.europa.eu/environment/eussd/smgp/index.htm
[35] http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

zu relevanten Fragestellungen ermitteln: Wie definiert man ein Referenzgebäude? Wie werden die Systemgrenzen festgelegt? Wie viele Referenzgebäude sollten herangezogenen werden? Und wie wird mit den verschiedenen möglichen Optionen in bestehenden Benchmarking-Ansätzen umgegangen?

Der dritte Schritt war der **Bewertungsmethodik auf Gebäudeebene** gewidmet. Dieser Teil bietet grundsätzliche Erkenntnisse, wie die Bewertung der umweltbezogenen Qualität von Bauprodukten mit der Bewertung eines Gebäudes nach der PEF-Methode verknüpft werden kann. Die Vorschläge basieren auf den Ergebnissen der PEF4Buildings-Studie an zwei neuen Bürogebäuden, wurden aber auf andere im europäischen Kontext relevante Gebäudetypologien ausgedehnt.

3.2. PEF-STUDIE ZU ZWEI NEUEN BÜROGEBÄUDEN

Um die Anwendbarkeit der PEF-Methode auf neue Bürogebäude zu testen und dabei sicherzustellen, dass die Ergebnisse nicht fall- oder geographisch-kontextspezifisch sind, wurden zwei Fallstudien für die Studie ausgewählt.

Fallstudie 1: BelOrta Gebäude von ar-te in Belgien

Fallstudie 2: BE2226 Gebäude von Baumschlager & Eberle, Lustenau in Österreich

Figure 15: Die beiden für die PEF-Bewertung ausgewählten Fallstudien

Die Systemgrenzen für die beiden PEF-Bewertungen wurden aus Sicht der Planenden/Architekten festgelegt. Dies bedeutet, dass möglichst alles, was die Planenden/Architekten beeinflussen können, in die Systemgrenzen aufgenommen wurde. Ausgeschlossen wurde demnach alles, was die Planenden/Architekten nicht direkt kontrollieren (z.B. Konsumgüter, Möbel, Pendlerverkehr). Darüber hinaus wurden jene Teile des Bürogebäudes, die für den Betrieb der Bürofunktion nicht unmittelbar erforderlich sind, wie z.B. Küche und Gastronomie, ausgeschlossen. Dies war unter anderem wichtig, um den Umweltfußabdruck von Bürogebäuden vergleichbar zu machen (z.B. in Hinblick auf Benchmarking). Die PEF-Bewertungen beschränkten sich auf das Gebäude als solches und schlossen die Gebäude-Umgebung (z.B. Parkplatz) aus.

Folgende Bauelemente wurden in den Referenzfluss aufgenommen:

- Fundament und Unterbau;
- Tragwerk, einschließlich Stützen, Balken und Decken;
- Treppen;

- Außenwände, inkl. Verkleidungen und Dämmung;
- Fenster;
- Böden und Decken;
- Innenwände;
- Türen;
- Dächer;
- Heiz- und Kühlsysteme;
- Sanitärsysteme;
- Elektrische Systeme.

Nicht im Referenzfluss enthalten sind:
- Konsumgüter (z.B. IT-Ausstattung, Papier, Möbel);
- Umgebung (z.B. Parkplatz);
- Küche/Gastronomie;
- Gebäudeinduzierter Verkehr (z.B. Pendlerverkehr).

Basierend auf einer Analyse der bestehenden PEFCR-Entwürfe für Bauprodukte aus der PEF-Pilotphase sowie den EN-Normen für Bauprodukte (EN 15978/EN15804) wurden die in Table 3 dargestellten **Lebenszyklusphasen** für die PEF-Bewertung der beiden Bürogebäude definiert.

Table 3: Lebenszyklusphasen für die Bewertung auf Gebäudeebene

Phasen im Lebenszyklus	Folgendes ist enthalten
PEF_A1	Vorverarbeitung und Beschaffung von Rohstoffen sowie Verpackung von Rohmaterialien
PEF_A2	Transport der Rohmaterialien zur Produktionsstätte
PEF_A3	Herstellung der Bauprodukte und der zugehörigen Verpackungen
PEF_A4	Transport zur Baustelle
PEF_A5	Bau/Einbau - für den Bau des Gebäudes erforderliche Prozesse, einschließlich aller Hilfsstoffe, Entsorgungsphase des entsorgten Verpackungsmaterials, etwaige Verluste während des Baus)
PEF_B1	Nutzung
PEF_B2	Instandhaltung
PEF_B3	Reparatur
PEF_B4	Ersatz
PEF_B5	Umbau/Erneuerung
PEF_B6	Betrieblicher Energieeinsatz
PEF_B7	Betrieblicher Wassereinsatz
PEF_C1	Abbruch
PEF_C2	Transport zur Abfallbehandlung und Beseitigung
PEF_C3/C4	Abfallbehandlung und Beseitigung (Sortierung für Abfallbehandlung, Recycling, Verbrennung oder Deponierung aller Materialien bei Ende der Lebensdauer des Gebäudes)

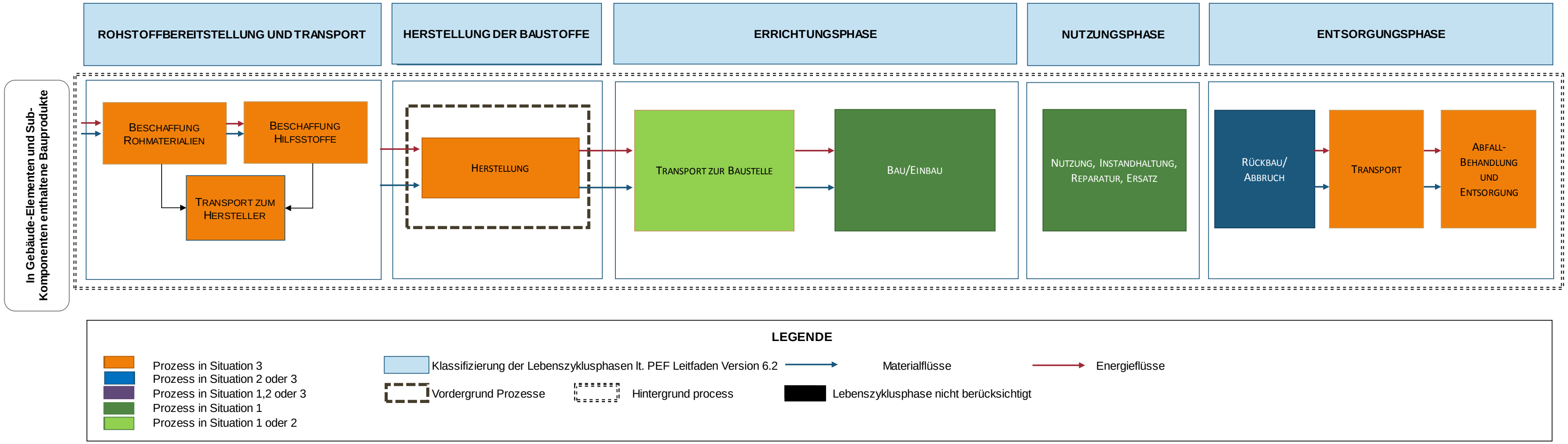


Figure 16: Systemgrenzen für die PEF-Bewertung auf Gebäudeebene

Figure 16 zeigt die **Systemgrenzen** für die Bewertung auf Gebäudeebene, wobei die Lebenszyklusphasen in einer Weise dargestellt werden, die mit den in EN 15804:2012+A1:2013 (Nachhaltigkeit von Bauwerken - Umweltproduktdeklarationen - Grundregeln für die Produktkategorie Bauprodukte) und EN 15978:2011 (Nachhaltigkeit von Bauwerken - Bewertung der umweltbezogenen Qualität von Gebäuden - Berechnungsmethode) definierten Phasen kompatibel ist.

Für jede Lebenszyklusphase wurden spezifische Szenarien zur Bewertung der Umweltauswirkungen auf Gebäudeebene entwickelt. Diese Szenarien konzentrieren sich hauptsächlich auf:

- *Annahmen* im Zusammenhang mit der Bauphase: z.B. Transport von Bauprodukten vom Hersteller zur Baustelle, aber auch der Bauprozess (nutzungsspezifisch soweit möglich);
- *Annahmen* zur Nutzungsphase: Szenarien für die Nutzung der installierten Bauprodukte im Gebäude, Instandhaltung des Gebäudes, Instandsetzungsmaßnahmen, Ersatzmaßnahmen, Sanierungsmaßnahmen, betriebsbezogener Energieverbrauch und betriebsbezogene Wasserverbrauch;
- *Annahmen* in Bezug auf die Entsorgungsphase: Szenarien für Rückbau, Wiederverwendung, Abbruch, Recycling und Entsorgung; einschließlich aller Transporte.

Bei der Definition dieser Szenarien wurden die PEF Guidance Dokumente sowie die Entwürfe der PEFCRs, EN-Normen und nationale Normen verwendet.

Für die Zwecke der PEF-Bewertung wurden Regeln für die Zuordnung auf Gebäude- und Produktebene festgelegt:

- Auf Gebäudeebene könnte die Allokation der Auswirkungen von wiederverwendeten Bauelementen diskutiert werden, dies war jedoch nicht Teil dieser Studie, da der Schwerpunkt auf neuen Bürogebäuden lag. Bei der Erstellung einer PEF-Studie für sanierte Gebäude wird es notwendig sein, Allokationsregeln zu definieren, die sich auf die Verteilung der Auswirkungen zwischen den vorherigen Systemgrenzen und den zukünftigen Systemgrenzen beziehen;
- Auf Produktebene folgt die Allokation dem Ansatz für die Abwicklung multifunktionaler Prozesse in der PEF Guidance 6.1 (Europäische Kommission, 2017).

Die beiden PEF-Studien sind ähnlich aufgebaut wie eine PEF-Screening-Studie. Daher werden keine Cut-offs angewendet. Alle Informationen, die nicht in den Studien enthalten sind, sind demnach auf Datenlücken und nicht auf Cut-offs zurückzuführen.

Eine hierarchische Gliederung des Gebäudes (Elementmethode) wurde verwendet, um Datenlücken weitestgehend zu vermeiden und um Inventardaten auf verschiedenen Sub-Ebenen für die Bewertung des Gebäudes nutzen zu können. Die **Modellstruktur** basiert auf einer hierarchischen Gliederung des Gebäudes in zunehmend feiner Einheiten: Bauelemente, Unterelemente und Materialien (Figure 17).

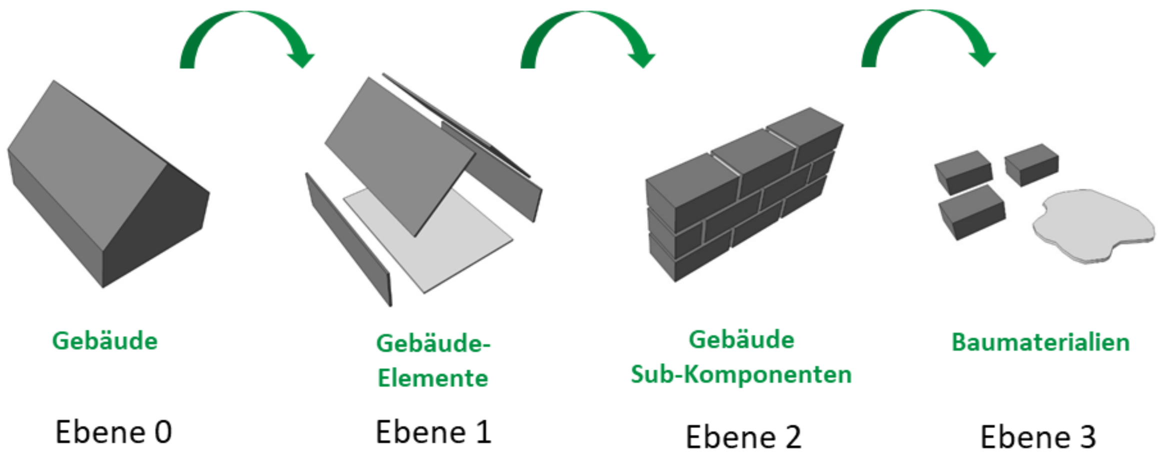
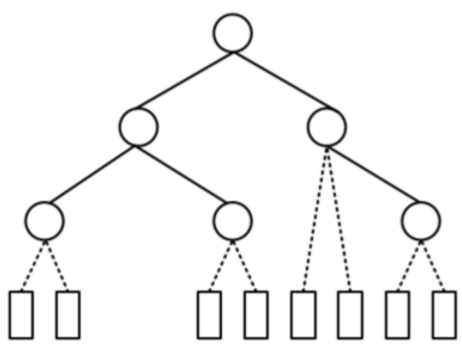


Figure 17: Hierarchische Gliederung des Gebäudes (vgl. Trigaux et al., 2017)

Zur Unterscheidung und detaillierten Analyse der verschiedenen Bauelemente und Gebäudeteile wurde das baumartige Klassifizierungssystem von OmniClass (2015) gemäß ISO 12006-2 (International Organization for Standardization, 2015) verwendet.



- Ebene 0: Gebäude
- Ebene 1: Gebäude-Elemente (z.B. Außenwand)
- Ebene 2: Sub-Komponenten (z.B. Ziegelwand)
- Ebene 3: Baumaterialien (e.g. Ziegel)

Figure 18: Klassifizierung von bauwerksbezogenen Informationen nach ISO 12006-2 (vgl. ISO, 2015)

Der in Figure 19 dargestellte Prozessablauf wurde für dieses Projekt erarbeitet. Zunächst wurden Quellen zur Definition der notwendigen Informationen über Gebäudeelemente, Baustoffe, Szenarien, und die Nutzungsphase im Datenerfassungsprozess identifiziert. In einem zweiten Schritt wurde ein Bauteilkatalog als Tabelle (Excel) erstellt, welche den wichtigsten Input für die Wirkungsabschätzung (LCIA) in der LCA-Software (SimaPro)[36] darstellte.

[36] Die LCA Software SimaPro wurde vom Projektteam aufgrund spezifischer Vorkenntnisse gewählt. Dies impliziert keine grundsätzliche Präferenz, welche Software zur Bewertung verwendet werden sollte.

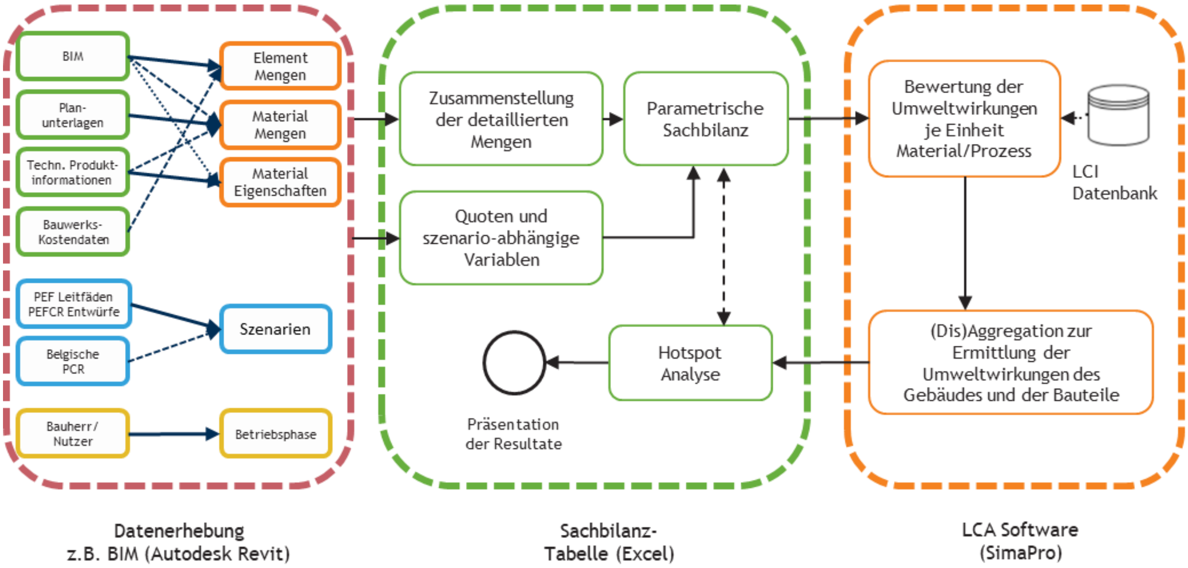


Figure 19: Datenmodell und Bewertungsprozess

Die folgenden Erkenntnisse wurden in der Phase der Sachbilanz-Erstellung gesammelt:

- Datensätze sollten die Anwendung der CFF-Formel (Circular Formula Footprint) ermöglichen;
- Für die Modellierung der Nutzungsphase sind klare Vorgaben erforderlich;
- Nationale Szenarien werden benötigt (z.B. für Produkte für Materialien/Bauelemente, für die kein PEFCR-Entwurf vorliegt);
- Bei der Datenerhebung erwies sich das BIM-Modell als eine wichtige Informationsquelle.

Die **LCIA-Ergebnisse** beider Fallstudien wurden dem PEF Guide folgend berechnet. Es ist zu beachten, dass zwei unterschiedliche Modellierungsansätze für die beiden Fallstudien angewandt wurden um modellierungsspezifische Erkenntnisse ableiten zu können. Das BelOrta Simapro-Modell folgte streng der hierarchischen Struktur in Figure 17, während das BE2226 Simapro-Modell auf Materialebene erstellt wurde, um die Implikationen derart unterschiedlicher Modellierungsansätze zu überprüfen. Der Unterschied in der Modellierung hat vor allem Konsequenzen während der Interpretation der Ergebnisse. Das BelOrta-Modell erlaubt die Auswertung eines Materials, welches in einem bestimmten Element verwendet wird, und dessen Anteil an der gesamten Umweltwirkung des Gebäudes. Das BE2226-Modell unterstützt die unmittelbare Auswertung des Materials und seines Anteils an der Gesamtumweltwirkung auf Gebäudeebene. Beispielsweise gibt das SimaPro-Modell des BelOrta Gebäudes die Wirkung von Beton in Innenwänden und Außenwänden getrennt an, während das Modell BE2226 die Ermittlung der gesamten Umweltwirkung von Beton (in allen Bauelementen aggregiert) erlaubt.

Da sich das PEF4Buildings Projekt nicht auf die absoluten Werte und Ergebnisse konzentrieren sollte, sondern darauf abzielte, die methodischen Aspekte der PEF-Bewertung eines Bürogebäudes zu untersuchen, werden die numerischen Ergebnisse der Studie hier nicht dargestellt. Obwohl die Absicht der Bewertungen der beiden Fallstudien nicht darin bestand, ihre LCIA-Ergebnisse im Detail zu vergleichen, können einige wichtige Erkenntnisse hervorgehoben werden:

- Erstens, unterscheidet sich die Gesamtbewertung der beiden Gebäude deutlich: Obwohl die beiden Gebäude die gleiche Nutzung und eine ähnliche Größe in Bezug auf die Grundfläche haben, repräsentieren diese unterschiedliche Gebäudekonzepte. Das BE2226-

Gebäude zeigt daher eine deutlich geringere Gesamt-Umweltwirkung als das BelOrta-Gebäude. Dies wurde erwartet, da der zweite Fall (BE2226) ein fortgeschrittenes Gebäude (NZEB) ist, während die erste Fallstudie (BelOrta) ein Business-as-usual Fall ist. Es ist jedoch zu beachten, dass die Gebäudeleittechnik (einschließlich Sensoren, Bedienelemente, ...) und Rohrleitungen wegen fehlender Daten für die BE2226 Fallstudie nicht modelliert wurden, deren Beitrag aber als gering eingeschätzt werden;

- Zweitens, unterscheiden sich in den beiden Fallstudien die als die wichtigsten identifizierten Umweltwirkungsindikatoren. Die wichtigsten Umweltwirkungsindikatoren hängen also eindeutig vom Gebäude (Energieeffizienz und verwendeten Materialien), aber auch vom Standort (Strom-Mix) ab. Dies ist besonders dann wichtig, wenn es darum geht, die PEF-Wirkungskategorien für die Anwendung auf Gebäude auf die relevantesten zu beschränken. Darüber hinaus konnte festgestellt werden, dass einige der wichtigsten Umweltwirkungsindikatoren "zusätzliche" Umweltwirkungsindikatoren sind, die in der aktuellen Fassung der EN 15804 und EN 15978 noch nicht enthalten sind;
- Drittens, wurden für beide Gebäude der betriebsbezogene Energieverbrauch (PEF_B6) und die Vorverarbeitung von Rohstoffen (PEF_A1) als eine der wichtigsten Lebenszyklusphasen identifiziert. Für das BelOrta-Gebäude trägt die Nutzungsphase jedoch wesentlich mehr zur Lebenszyklus-Belastung bei als für das BE2226-Gebäude. Da die Nutzungsphase im BE2226-Gebäude geringere Belastungen verursacht als im BelOrta-Gebäude, werden andere Lebenszyklusphasen relevanter;
- Viertens, führte die Identifizierung der relevantesten Prozesse zu einem unterschiedlichen Ergebnis bezüglich der relevantesten Prozesse für die beiden Gebäude. Dies wurde erwartet, da beide Gebäude aus unterschiedlichen Materialien und Elementen bestehen, sich aber auch an einem anderen Ort befinden und somit in der wichtigen Nutzungsphase des Gebäudes ein anderer Strom-Mix verwendet wird.
- Abschließend, hatte die Einbeziehung/Ausschluss der Toxizitätswirkungskategorien einen deutlichen Einfluss auf die Ergebnisse, insbesondere bei der zweiten Fallstudie (BE2226).

3.3. Vorschlag für einen Ansatz zu Benchmarks und Leistungsklassen für Bürogebäude

Um einen möglichen Ansatz zum Benchmarking und zur Definition von Leistungsklassen für neue Bürogebäude vorzuschlagen, wurde eine umfangreiche Literaturrecherche durchgeführt, die sich auf bestehende Berichte zu Gebäudetypologien, Gebäudezertifizierungssystemen, LCA-Richtlinien (wie u.a. EN 15978 und den Entwurf der Product Category Rules (PCRs, dt. Produktkategorienregeln) für Gebäude) und nationale Methoden oder gesetzliche Anforderungen (wie die E+C-Methode in Frankreich, DGNB und BNB in Deutschland, GWW in den Niederlanden, MMG in Belgien) konzentriert. Die untersuchten Methoden werden unter verschiedenen Aspekten verglichen: Die Bedeutung und der Ansatz zur Definition der Benchmark, wie Referenzgebäude definiert wurden, die betrachteten Systemgrenzen, die funktionale Einheit und der Referenzfluss sowie Ansätze zur Definition von Leistungsklassen.

3.3.1. Übersicht der Erkenntnisse

Es wurden mehrere wichtige Unterschiede in der **Bedeutung und den damit verbundenen Ansätzen** für die Definition der umweltbezogenen Benchmarks von Gebäuden festgestellt. Die Literaturrecherche ergab, dass verschiedene Bedeutungen für Benchmarks von Gebäuden verwendet werden, die von Grenzwerten (minimal akzeptable Leistung/Qualität) über einen Referenzwert (aktueller Stand der Technik, z.B. Durchschnitt) und Best-Practice-Wert (Werte, die in Versuchs- oder Demonstrationsprojekten erreicht werden) bis hin zu Zielwerten (Werte, die mitteloder langfristig erreicht werden sollen) reichen. Je nach gewählter Bedeutung werden unterschiedliche **Ansätze und Quellen** zur Ermittlung der Benchmark-Werte angewandt, welche von gesetzlichen Vorgaben, Normen (für Grenzwerte), über statistische Auswertungen und die Bewertung von Referenzgebäuden (für Referenzwerte) bis hin zu politischen Zielwerten oder wirtschaftlichen und technischen Optima (für Zielwerte) reichen. Gebäudezertifizierungssysteme wie BREEAM oder DGNB verwenden in der Regel verschiedene Werte, d.h. Grenzwerte, Referenz- und Zielwerte, um Benchmarks und Leistungsklassen zu definieren. Aktuelle nationale Benchmarks verfolgen meist ausgewogene Wettbewerbsbedingungen (level playing field) mit einer niedrigen Grenze als Ausgangspunkt. Ihr Ziel ist es, einerseits Gebäude mit niedriger Qualität noch zu ermöglichen, andererseits aber auch extrem schlechte Gebäude-Qualitäten zu vermeiden. Benchmarks können im Laufe der Zeit mit dem technologischen Fortschritt und dem Wissen über den Gebäudebestand weiterentwickelt und angepasst werden.

Eine weitere Differenzierung in der Literatur ist die Verwendung von **externen und internen Benchmarks**. Ersteres ist das häufigste und vergleicht ein bestimmtes Gebäude mit einem definierten Referenzgebäude, das sich jedoch in Layout und Materialwahl (manchmal auch in der Energieeffizienz) unterscheidet. Der Ansatz einer internen Benchmark wird seltener verwendet (z.B. von LEED) und vergleicht einen Gebäudeentwurf mit einem Referenzgebäude mit Variation lediglich in Bezug auf die Materialwahl (d.h. die Referenz ist in Bezug auf Layout, Größe und Energieeffizienz identisch mit dem vorliegenden Gebäudeentwurf).

Einige Gebäudezertifizierungssysteme haben darüber hinaus **separate Benchmarks für jeden Umweltwirkungsindikator** definiert (z.B. DGNB), während andere eine **aggregierte Benchmark für die Gesamtbewertung** definiert haben (z.B. die Niederlande). In den Systemen mit Benchmarks für jede Umweltwirkungsindikatoren wird die Endnote durch Gewichtung der unterschiedlichen Bewertungen auf die verschiedenen Umweltwirkungsindikatoren ermittelt. Die Gewichtung der jeweiligen Umweltwirkungsindikatoren ist dann Teil der Methodik.

Aus der Literaturrecherche können wir schließen, dass **Referenzgebäude** zur Bestimmung des Benchmarks entweder reale Gebäude sein können, die das Referenzgebäude repräsentieren, oder virtuelle Gebäude (d.h. z.B. basierend auf einer statistischen Analyse eines repräsentativen Teils des nationalen Gebäudebestands). Diese statistische Analyse unterscheidet oftmals verschiedene Gebäudetypen, -größen, -materialien und -leistungen.

Der am häufigsten vorgefundene Bilanzierungszeitraum (RSP) für Bürogebäude ist 50 Jahre. Ein gebräuchlicher **Referenzfluss** ist "pro Geschoßfläche, pro Jahr". Einige Studien schlagen jedoch vor, die Funktion des Gebäudes zu berücksichtigen, z.B. die Anzahl der Arbeitsplätze im Bürogebäude oder die Anzahl der Personen anhand von Vollzeitäquivalenten. Im Desk Research wurden keine relevanten Annahmen zu Cut-off-Regeln oder Szenarien gefunden.

Figure 20: Leistungsklassen lt. PEF Guidance (Technical Helpdesk PEF, 2016)

In einem Diskussionspapier des PEF Technical Helpdesk[37] wird erläutert, wie die **Leistungsniveaus für Produkte** berechnet werden können (basierend auf den relevantesten Parametern und durch die Bestimmung von marktgerechten Minimal- und Maximalwerten). Die Literaturrecherche zielte darauf ab, zu untersuchen, ob bestehenden Systemen andere als diese Methoden verwendet werden, um Leistungsklassen für Gebäude in zu definieren. Wir können aus der Recherche schließen, dass das **Ziel von Leistungsklassen** unterschiedlich sein kann und den Ansatz zur Definition von Leistungsklassen bestimmt. Für die Definition von Leistungsklassen werden viele Informationen über die relevanten Gebäude benötigt, um diese in verschiedenen Klassen "repräsentieren" zu können und die gewünschten Schwellenwerte ermitteln zu können. Dazu muss wie beim Benchmarking ein Überblick über die Umweltauswirkungen der verschiedenen Gebäude, die von den Leistungsklassen abgedeckt werden sollen, geschaffen werden. Diese können wiederum entweder **reale Gebäude oder virtuelle Gebäude** sein. Da die erforderlichen Datenmengen zur Ermittlung von Leistungsklassen sehr groß sind, werden in der Regel virtuelle Gebäude verwendet. Um die Schwellenwerte zwischen verschiedenen Leistungsklassen festzulegen, stützen sich einige Systeme ausschließlich auf die relative Verbesserung gegenüber dem Benchmark-Wert (z.B. 5%, 10% oder 15% besser als die Benchmark). Andere Systeme (z.B. im Bericht von W/E adviseurs[38]) basieren auf der statistischen Verteilung des analysierten Gebäudebestandes. Figure 21 zeigt eine allgemeine Darstellung des Ansatzes, der in dieser Studie verwendet wurde.

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[37] Technical Helpdesk PEF. (2016). *Issue paper "Determining the EF benchmark and performance classes" - version 3*.

[38] W/E adviseurs. (2014). *Onderzoek "Bepaling kwaliteitsniveaus milieuprestatie van woonfuncties" - Eindrapport*. Retrieved from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2014/11/14/onderzoek-bepaling-kwaliteitsniveaus-milieuprestatie-van-woonfuncties/eindrapport-bepaling-kwaliteitsniveaus-milieuprestatie-we-adviseurs.pdf

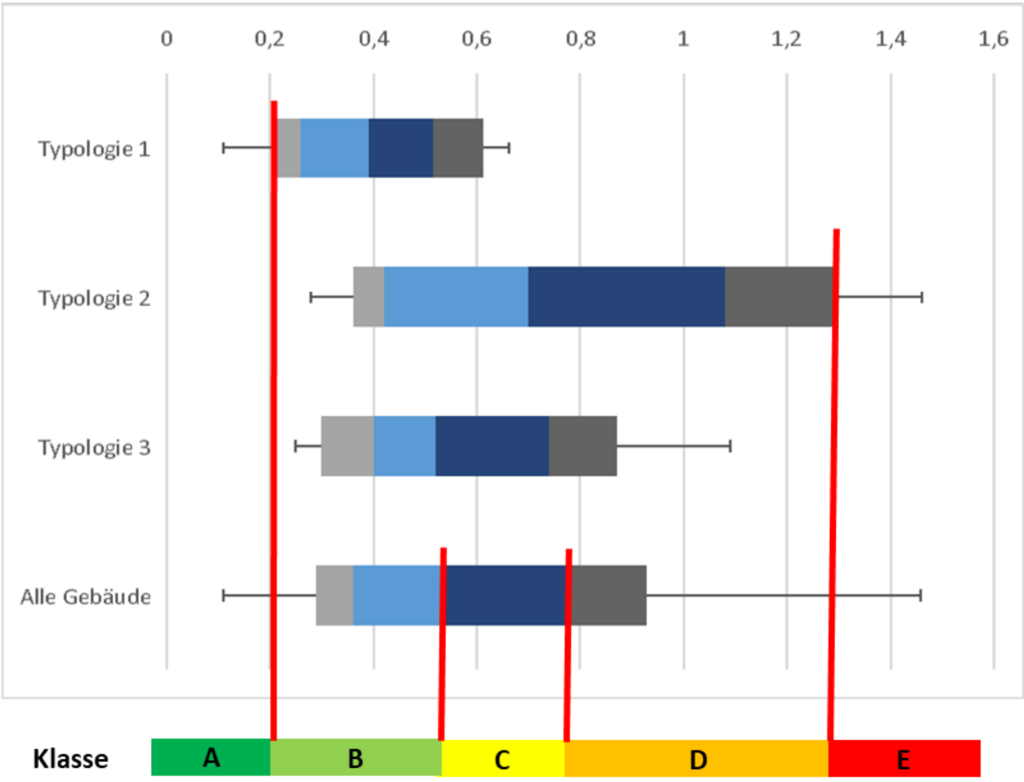

Figure 21: Statistische Informationen als Basis für Leistungsklassen

3.3.2. EMPFEHLUNGEN

Die Empfehlungen basieren auf den Ergebnissen der PEF4Buildings-Studie, dem PEF-Guide und den dazugehörigen Dokumenten, der Literaturrecherche, dem Feedback der Stakeholder und den bisherigen Erfahrungen des Projektteams. Die Empfehlungen werden unter Berücksichtigung bestimmter Annahmen und Ziele formuliert, sie können daher nicht verallgemeinert und auf jede Situation angewendet werden.

Das Projektteam empfiehlt, eine **EU-weit einheitliche Methodik** zur Ermittlung und Bewertung der Umweltauswirkungen von Gebäuden und eine gemeinsame Methodik zur Definition von umweltbezogenen Benchmarks zu definieren. Dies ist notwendig, um einen harmonisierten Ansatz in Europa zu erreichen. Darüber hinaus wird empfohlen, die Benchmark-Werte auf nationaler Ebene zu ermitteln, um externe Faktoren wie Klima, Baupraxis und Planungskultur, welche die Umweltauswirkungen eines Gebäudes beeinflussen können, zu berücksichtigen. Es wird des Weiteren ein **schrittweiser, konservativer Ansatz** empfohlen, d.h. zunächst werden Benchmarks definiert, die anfangs niedrigere, gut erreichbare Grenzwerte darstellen und mit der Zeit zunehmend ambitionierter und strenger werden. Dies erlaubt allen Beteiligten sich zunächst an die Methode zu gewöhnen um sicherzustellen, dass der gesamte Markt im Wandel hin zu Nachhaltigen Gebäuden einbezogen wird.

Um Umwelt-Benchmarks für Bürogebäude zu definieren, sind Erkenntnisse über die durchschnittlichen Umweltauswirkungen von Bürogebäuden in Europa und Variationen im Gebäudebestand erforderlich. Diese Informationen können wahlweise durch **reale oder virtuelle Fallstudien** gewonnen werden. Erste, konservative Benchmarks sollten derart gewählt werden, dass alle Bürogebäude, die die **gesetzlichen Mindestanforderungen** an Energie, Wasser, Brandschutz etc. erfüllen, diese gerade noch erreichen können. Benchmarks, welche auf Verbesserung abzielen, sprich den Zielwert definieren, können auf Grundlage von Best-Practice-Beispielen (Versuchs- oder Demonstrationsprojekte) oder auf der Grundlage von virtuellen Gebäuden mit beispielsweise 30 % weniger Auswirkungen als der Referenzwert erfolgen (d.h., dieser repräsentiert Business-as-usual). Beim zweiten Ansatz könnte die prozentuale Verringerung entweder auf einer statistischen Analyse der Baupraxis in dem betreffenden Mitgliedstaat oder auf der Grundlage der festgelegten politischen Ziele beruhen.

Für die Definition von **Referenzgebäuden** müssen Gebäudetypologien definiert werden, welche die Baupraxis in einem bestimmten Mitgliedstaat repräsentieren. Um die Umweltauswirkungen der verschiedenen Gebäudetypen zu ermitteln, muss der länderspezifische Markteinfluss je Gebäudetyp in einer spezifischen **statistischen Untersuchung** ermittelt werden. Marktunterschiede in Bezug auf Größe, verwendete Materialien und technische Lösungen sind zu berücksichtigen.

Die Literaturrecherche ergab, dass Benchmarks entweder definiert werden können, um die konstruktionsspezifischen und betriebsbezogenen Umweltwirkungen des Gebäudes summiert zu beschreiben, oder aber separate Benchmarks für beide Aspekte entwickelt werden können. Basierend auf der PEF-Studie der beiden Bürogebäude mit einer sehr unterschiedlichen Energieeffizienz in Deliverable D3 (VITO et al., 2018a), empfiehlt das Projektteam eine Benchmark welche sowohl **konstruktionsspezifische als auch betriebsbezogene Umweltwirkungen** beschreibt. Unter Berücksichtigung der praktischen Umsetzbarkeit könnte es einfacher sein, diese (in einer ersten Phase) zu trennen, da in den EU-Mitgliedstaaten bereits betriebsbezogene Benchmarks festgelegt sind. Obwohl konstruktionsspezifische und betriebsbezogene Auswirkungen in einer ersten Umsetzungsphase getrennt werden können, wird empfohlen, die gleichen Umweltindikatoren zu bewerten, eine reibungslose Aggregation in der zweiten Phase der Umsetzung zu ermöglichen.

Während die Literaturrecherche einen Überblick über die verschiedenen Ansätze liefern konnte, ist klar, dass **zusätzliche Daten** auf nationaler Ebene **benötigt** werden, um explizite Empfehlungen zu bestimmten, für die Definition von Referenzgebäuden relevanten, Aspekten aussprechen zu können. In den meisten Ländern fehlt eine umfassende Datenbank für Nicht-Wohngebäude, weshalb die Sammlung von entsprechenden Daten und deren **Aufbereitung in Datenbanken** empfohlen wird.

Die Bereitstellung eines klaren **Referenzflusses** für die Bewertung von Gebäuden wird die Vergleichbarkeit zukünftiger Studien erheblich verbessern. Aus wissenschaftlicher Sicht empfiehlt das Projektteam, eine geeignete funktionale Einheit für das Benchmarking zu definieren, welche die **Funktion von (Büro-)Gebäuden** berücksichtigt (z.B. Vollzeitäquivalente pro Jahr). Die Anforderungen an die Energieeffizienz von Gebäuden, die bereits in allen Mitgliedstaaten festgelegt und auch in aktuellen Zertifizierungssystemen für Gebäude definiert sind, nutzen derzeit jedoch die Einheit m² Geschoßfläche für alle Benchmarks. Das Projektteam empfiehlt daher, unter Berücksichtigung der praktischen Implikationen und um eine konsistente Analyse der Gebäude zu ermöglichen, **m² Geschoßfläche** pro Jahr als den primären Referenzfluss. Bei der Wahl der m² Geschoßfläche empfiehlt es sich, klare und strenge Regeln für deren Definition festzulegen: z.B. Brutto-, Netto- oder beheizte Geschoßfläche.

Des Weiteren wird empfohlen, das **gesamte Gebäude** und seine Elemente zu bewerten: Fundamente, Tragwerk, Gebäudehülle, Innenwände und Zwischendecken, einschließlich aller Ausbauten sowie der technischen Ausstattung. Möbel, IT-Ausstattung, Küchen und externe Elemente wie Parkplätze sollten ausgeschlossen werden. In jedem Fall sollten klare Regeln in einem

PEF Guidance Dokument für Gebäude definiert werden. PEF-spezifische Empfehlungen in Bezug auf Cut-off-Regeln und Szenarien können befolgt werden.

Obwohl eine Benchmark nicht zwischen **Entwurfsstand** (z.B. bei Erteilung einer Baugenehmigung) **und fertiggestelltem Gebäude** (z.B. nach 2 Jahren Nutzung) unterscheiden sollte, empfehlen wir, klare und spezifische Berechnungsregeln zu definieren, wie die Auswirkungen in der Entwurfs- und Nutzungsphase beim Vergleich mit den Benchmarks zu ermitteln sind:

- Entwurfsphase: Die Auswirkungen des erwarteten Energieverbrauchs im Betrieb sollten mit den in den Mitgliedstaaten bereits etablierten Methoden zur Berechnung der Gesamtenergieeffizienz verknüpft werden;
- Nutzungsphase: Die Auswirkungen des Energieverbrauchs sollten auf Primärdaten basieren, d.h. basierend auf Messwerten aus mindestens zwei Jahren (durchschnittlicher Jahresverbrauch).

Um Verlagerungen und Zielkonflikte in Bezug auf die Reduktion von Umweltauswirkungen zu vermeiden, empfiehlt das Projektteam, ein **Benchmark sowohl für jede Wirkungskategorie separat als auch auf aggregierter Ebene** zu erstellen. Sobald die relevantesten Umweltwirkungsindikatoren für Gebäude identifiziert wurden, könnten die Benchmarks auf diese Umweltwirkungsindikatoren beschränkt werden.

Da die **Anforderungen an die Datenqualität** in der Ökobilanz als entscheidend für das Benchmarking angesehen werden, wird empfohlen, den gleichen Ansatz wie bei den PEFCRs zu verfolgen. Dies sichert die notwendige Datenqualität und damit die Repräsentativität definierter Benchmarks.

Ausgehend von den auf nationaler Ebene definierten Benchmarks können **Leistungsklassen** definiert werden. Liegen für eine große Anzahl von bestehenden Gebäuden, die den Bürogebäudebestand repräsentieren, Daten zu Umweltauswirkungen vor, sollten diese verwendet werden. Bei Fehlen solcher Daten, sollten nur wenige repräsentative Gebäude ausgewählt und virtuelle Variationen dieser Gebäude analysiert werden. **Marktunterschiede** in Bezug auf Größe, verwendete Materialien und technische Lösungen sind zu berücksichtigen.

Wenn die gesetzlichen Anforderungen die Untergrenze der ersten Leistungsklassen definieren und eine statistische Analyse die Obergrenze der besten Leistungsklassen definiert, kann dieser Bereich, wie in der PEF-Richtlinie definiert, in fünf Leistungsklassen unterteilt werden.

3.4. Leitfaden für Bewertung auf Gebäudeebene

Das Projektteam untersuchte, **wie die Bewertung der umweltbezogenen Qualität von Bauprodukten mit der Bewertung eines Gebäudes mittels der PEF-Methode zusammengeführt werden kann**.

Folgende Methoden zur Bewertung von Umweltwirkungen auf Gebäudeebene wurden dabei ausgewertet: die Norm EN 15978[39]; CEN/TC 350[40]; in Belgien die „Material based environmental

[39] Bureau for Standardisation (NBN). (2013). NEN-EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

profiles of building elements“ (MMG)[41] in Kombination mit dem belgischen Programm für Environmental Product Declarations (EPD, dt. Umwelt-Produktdeklarationen) und dem kürzlich eingeführten Tool TOTEM[42]; in Frankreich die Methode Positive Energy Low Carbon (E+C-)[43] und verschiedene Softwarelösungen in Verbindung mit den französischen EPDs "Fiches de Données Environnementales et Sanitaires (FDES)"[44]; in Deutschland das DGNB[45]- und BNB[46]-System; und in den Niederlanden die Bewertungsmethode für die Umweltwirkungen von Hoch- und Tiefbauten (GWW)[47] in Kombination mit dem niederländischen EPD-Programm und dem Tool „GPR Gebouw“[48].

Es kann zusammengefasst werden, dass **nationale Systeme** sehr wertvoll sind, da sie in der Regel nationale Richtlinien berücksichtigen und somit das höchste Potenzial haben den lokalen Gegebenheiten gerecht zu werden. Sofern die nationalen PCRs für Bauprodukte konkrete Angaben über die Definition der funktionalen Einheit liefern, führt dies zu einer unkomplizierten Anwendung von EPDs von Bauprodukten für die Ökobilanzierung auf Gebäudeebene.
Es wird empfohlen, in Zukunft **PEFCR(s) auf Gebäudeebene** zu entwickeln, welche die Grundlage für alle (neuen) PEFCRs für Bauprodukte bilden und an bestehende PEFCRs auf Bauproduktebene angepasst werden sollten, beispielsweise in Hinblick auf die konsistente Definition von Lebenszyklusphasen. Derzeit ist die Anzahl der betrachteten Lebenszyklusphasen in den verschiedenen Bauprodukte-PEFCRs unterschiedlich. Das Projektteam empfiehlt, die in Abschnitt 3.2 beschriebenen Lebenszyklusphasen zu berücksichtigen. Wie im vorhergehenden Abschnitt beschrieben, sollte ein klarer Referenzfluss definiert werden, und auf Gebäudeebene klare Regeln in Bezug auf die eingeschlossenen Elemente und Bauteile sowie allfällige Cut-off Kriterien definiert werden. Spezifische PEFCRs sollten für verschiedene Gebäudetypologien entwickelt werden und nationale Szenarien, z.B. zur Nutzungsphase und zum Rückbau des Gebäudes, beinhalten. Eine Differenzierung der Regeln/Richtlinien für PEF-Studien zur Unterstützung während der Planung/ Baugenehmigung und nach Fertigstellung des Gebäudes ist erforderlich. Klare Richtlinien zur Modellierung der Nutzungsphase und des Betrachtungszeitraum sowie der damit verbundenen Referenznutzungsdauern sind notwendig. Auf Gebäudeebene müssen PEFCR(s) für Gebäude Klarheit über die Verfahren zur Allokation von Umweltwirkungen von wiederverwendeten Bauelementen (vor allem bei Renovierungsprojekten) schaffen, indem die Grundsätze für die Allokation der Auswirkungen zwischen früheren Systemgrenzen und zukünftigen Systemgrenzen

[40] http://portailgroupe.afnor.fr/public_espacenormalisation/centc350/index.html
[41] Openbare Vlaamse Afvalstoffenmaatschappij (OVAM). (2013). Environmental profile of building elements [update 2017]. Retrieved from http://www.ovam.be/sites/default/files/atoms/files/Environmental%20profile%20of%20building%20elements%20-%20update%202017.pdf
[42] https://www.totem-building.be/
[43] République française. (2017). Référentiel « Energie – Carbone » pour les bâtiments neufs – Méthode d’évaluation de la performance énergétique et environnementale des bâtiments neufs. Retrieved from http://www.batiment-energiecarbone.fr/wp-content/uploads/2017/06/referentiel-energie-carbone-methode-evaluation-2017-07-01.pdf
[44] http://www.inies.fr/accueil/
[45] http://www.dgnb.de/
[46] https://www.bnb-nachhaltigesbauen.de/
[47] Stichting Bouwkwaliteit. (2014). Assessment Method Environmental Performance Construction and Civil Engineering Works (GWW), (November), 89. Retrieved from https://www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf
[48] https://www.gprsoftware.nl/

festgelegt werden (z.B. in Bezug auf die Weiter- oder Wiederverwendung von Elementen aus bestehenden Gebäuden). Auf Produktebene sollte die Allokation dem Ansatz für die Handhabung multifunktionaler Prozesse in der neuesten Version des PEF Guidance Dokuments folgen.

Um ein ganzes Gebäude zu modellieren werden zudem generische Daten in erweitertem Umfang benötigt. Es wird daher empfohlen, eine gemeinsame EF-Datenbank für die häufigsten Prozesse bereitzustellen, z.B. unter Verwendung von PEF-konformen Datensätzen, i.e. mit Integration der CFF-Formel, die von der EU erworben wurden.

Ein weiterer Aspekt, der die Umsetzung der Ökobilanzierung auf Gebäudeebene verbessern kann, ist die **Verknüpfung mit digitalen Planungswerkzeugen (CAD- und BIM-Tools), Bewertungswerkzeugen und PEF-konformen Datenbanken**. Dies kann die Datenerfassung erheblich vereinfachen und den Aufwand für die Ökobilanzierung in der Praxis erheblich reduzieren. Um einen parametrischen Ansatz in der Modellierung komplexer Gebäude zu unterstützen, muss eine flexiblere Parameterstruktur in Bezug auf unterschiedliche Aufbauten und Mengen von Elementen und Materialien gefunden werden. Wir empfehlen eine hierarchische Gliederung des Gebäudes wie in Figure 17 dargestellt.

Die Entwicklung und Bereitstellung einer generischen **Vorlage für die Datenerhebung** und – Sachbilanzerstellung wird empfohlen, um PEF-Studien von Gebäuden in der Praxis zu unterstützen. Diese Vorlage kann den zu entwickelnden PEFCRs beigefügt werden.

Heute können nur wenige **Bewertungsinstrumente** alle PEF-relevanten Umweltwirkungsindikatoren bewerten. In Zukunft könnten allerdings alle PEF-Kategorien in diese Tools integriert werden, um Verlagerung von Umweltwirkungen zwischen verschiedenen Umweltwirkungsindikatoren zu vermeiden. Die meisten aktuellen Bewertungsinstrumente konzentrieren sich auf die Produktionsphase und Bauphase, da es an Informationen zu nutzungsspezifischen Prozessen (Wartung, Instandsetzung, Sanierung etc.) fehlt. Da jedoch alle Lebenszyklusphasen berücksichtigt werden sollten, wird empfohlen, eine PEF/LCA-Software zu verwenden, die es erlaubt, die LCIA-Ergebnisse direkt auf der Ebene des Gebäudes, auf Ebene der Lebenszyklusphasen, des spezifischen Beitrags von Elementen in jeder Lebenszyklusphase und auf der Ebene der Materialien/Prozesse zu extrahieren. Es wäre hilfreich, wenn PEF/LCA-Software in Zukunft die Hotspot-Analyse (Identifikation der relevantesten Umweltwirkungsindikatoren, Lebenszyklusphasen und Prozesse) direkt in der Software ermöglichen würde.

Bei PEF-Studien von Gebäuden wird immer eine kritische Überprüfung der Ergebnisse empfohlen, um sicherzustellen, dass die Bewertung ausgewogen, vollständig und mit erforderlicher Genauigkeit sowie in Übereinstimmung mit der neuesten Version des PEF Guidance Dokuments erfolgt.

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ANNEXES

ANNEX 1 – DELIVERABLE D3: REPORT ON PEF STUDY OF NEWLY BUILT OFFICE BUILDING

See separate document “Deliverable D3”.

ANNEX 2 – DELIVERABLE D4: PROPOSAL FOR APPROACH FOR BENCHMARK AND CLASSES OF PERFORMANCE FOR OFFICE BUILDINGS

See separate document "Deliverable D4".

Annex 3 – Deliverable D6: Guidance document for the assessment at the building level

See separate document “Deliverable D6”.

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PEF4Buildings

Study on the Application of the PEF Method and related guidance documents to a newly office building (ENV.B.1/ETU/2016/0052LV)

Deliverable D3: Report on PEF study of newly built office building

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INTRODUCTION

This report is focussing on the results of two PEF case studies on newly built office buildings summarising the outcomes from the two PEF studies and will be integrated as an Annex to the final study report for this project for the European Commission (DG ENV).

The report is focussing on the task 1 of the contract No 07.0201/2016/746615/ETU/ENV.B.1 "Study on the application of the PEF method and related guidance documents of a new office building".

The objective of the first task was to test the applicability of the PEF method (and the latest versions available of the related guidance documents developed in the framework of the Environmental Footprint pilot test phase) to a new office building. The focus of this first task was to propose approaches to tackle the methodological challenges identified during the PEF assessment of the newly built office buildings. In this framework two case studies have been carried out to be able to double check the proposed methodological approach by applying it to two case studies in a different context in order to ensure the overall learnings are not case-specific or context-specific.

Two case studies that have been assessed are:

- BelOrta building of AR-TE in Belgium;
- BE2226 building of Baumschlager & Eberle, Lustenau in Austria.

BelOrta case study

For the newly built office building PEF assessment, we selected the office building **BelOrta** (3000 m²) in Sint Katelijne Waver, Belgium, designed by AR-TE. It is built in 2013-2015 and is seen as a representative building regarding building typology, energy performance and technology. The architectural firm AR-TE was actively involved in the PEF assessment, especially with regard to the data gathering phase (bill of materials and life cycle inventory). More information on this building is available in Annex 3 of this report.

This case study is furthermore chosen for the following reasons:

- The BelOrta building is built in a moderate climate which is seen as representative for a large part of Europe;
- The building is a compact building with an inner courtyard to maximise daylight in the offices. This typology is a broadly used typology for office buildings in Europe;
- The Building fulfils the energy performance requirements of to date;
- The Building technology is according to current common practice, with facades partially glazed and partially opaque (facing bricks as outer finishing layer). This was preferred over a fully glazed office building in order to cover a wider range of construction products in the assessment;
- A BIM-model of the building is available which is an important advantage for an efficient gathering of the bill-of-materials needed for the life cycle inventory of the PEF study;
- We have good contacts with the architectural firm AR-TE which minimised the risks for data problems during the inventory phase.

BE2226 case study

In addition to the PEF assessment of the BelOrta office building a second PEF study was conducted on an additional building. The office BE2226 of Baumschlager & Eberle in Lustenau, Austria, was added in order to further test the PEF methodology in another context. This second case was chosen as this was feasible (advanced data inventory already available) and because it allows to test the PEF in different contexts. More information on this building is available in Annex 4 – Detailed Data Collection BE2226 Building – of this report. This second case study has been chosen for the following reasons:

- This building is seen as less representative for current common practice, but is an advanced nearly zero energy building (no active heating/cooling installed in the building). The PEF study of this more advanced case study in addition to the BelOrta building (current common practice) will allow to have better insights in most relevant life cycle stages/environmental impact categories and hot spots for a nearly zero energy building of this type compared to a building based on current energy performance standards. Moreover, the assessment of this second case will support the second task regarding benchmarking and performance classes;
- The building is located in a different climate and different country which allows to cover different building materials, technologies, building practice (e.g. exterior finishing of the walls in stucco instead of facing bricks; different window types, etc.) and user behaviour.

This project report (Deliverable D3) comprises of 5 chapters and 6 annexes:

- Chapter 1 – Activity 1.1 – Definition of the scope, system boundaries life cycle stages and scenarios;
- Chapter 2 – Activity 1.2 – Development of the LCA model for the office building assessment;
- Chapter 3 – Activity 1.3 - Life Cycle Inventory;
- Chapter 4 – Activity 1.4 – Life cycle Impact Assessment;
- Chapter 5 – Conclusions and recommendations;
- Annex 0-A – Minutes of the 1st stakeholder meeting in Brussels, including feedback of stakeholders;
- Annex 0-B – Minutes of an additional stakeholder meeting in Vienna;
- Annex 1 – Excel file with LCI data, modelling details and overall BelOrta building structure;
- Annex 2 - Excel file with LCI data, modelling details and overall BE2226 building structure;
- Annex 3 – Detailed data collection BelOrta building;
- Annex 4 - Detailed data collection BE2226 building;
- Annex 5 - Comparative analysis of system boundaries for the PEFCRs for construction products.

CHAPTER 1 EXECUTIVE SUMMARY

The main objectives are to test the applicability of the PEF method to a new office building and to propose approaches for the methodological challenges identified. The results of this study in terms of accurate contributions per environmental impact category are not the main outcome expected in this project, but rather a mean to a more generic purpose.

Goal and scope

In this context the definition of the scope of the PEF study for an office building is represented by what is included in the assessment with respect to the functional unit (what, how much, how well, how long), system boundaries (including the life cycle stages) and scenarios. The reference flow is the amount of product needed to fulfil the defined function and shall be measured in m^2, m^3, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.

For the purpose of this study the building as a whole is considered, without the infrastructure for accessing the building. The PEF assessment will be carried out according to the different life cycle stages of the building, where all life cycle stages, from cradle to grave will be considered. Based on a cross-analysis of the life cycle stages defined in the draft PEFCRs for the construction products already developed, but also in the EN norms related to construction products (EN 15978/EN15804), the life cycle stages presented in Table 0.1 have been defined for the assessment of an office building.

Table 0.1: Life cycle stages for the assessment at building level

LCS name	The following shall be included
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment
PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL

PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

Figure 0.1 presents the system boundary diagram for the assessment at the building level, where the life cycle stages are presented in a manner compatible with the one existing in EN 15804:2012+A1:2013 (Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products) and EN 15978:2011 (Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method).

A relevant discussion at this point is related to the data needs requirements as defined in PEF context as no clear rules are available in the PEF Guide on the sources of data for PEF studies of buildings. It is considered though that a more extended consultation with relevant stakeholders should take place related to how primary versus secondary data should be used when doing assessment at building level. Thus, while in line with the general PEF Guide specific data should be used for processes which are under the direct operational control of the producer, considering that no products are directly produced at building level, the use of specific data is not mandatory. Generic data were be mostly used for the LCI. The generic datasets were chosen as representative as possible to the real situation (e.g. electricity mixes according to the country mix where the operation takes place, etc.) and adapted if needed. Any data gaps were filled using the best available generic or extrapolated data.

Development of LCA model for the office building assessment

The aim of this LCA model is to assess office buildings with the PEF method for both the level of the building materials and building elements. The aim is moreover to use PEF studies – available in future – at different scale levels (e.g. building materials, building sub-elements, building elements) in PEF studies of buildings. In order to allow for this linkages, a hierarchical decomposition of the building (element method) is used. The model structure is based on a hierarchical subdivision of the building in smaller entities based on a functional approach (Figure 0.2). The element method subdivides a building (level 0) in building elements (level 1) such as 'loadbearing outer walls', 'pitched roof', 'foundation', etc. Each of these are then subdivided in building sub-elements (level 2). These sub-elements are on their turn composed of different building materials (level 3). Each of the levels in the subdivision of the building are connected via ratios. These ratios represent the amount of the lower level (material/ (sub-) element used in the higher level.

The analysis of the impact of a building can be done at several levels, such as at the level of the entire building, per building elements, sub-elements or materials. These levels of analysis are however not in direct relation with the level of dissagregation of the datasets used to develop the model.

The complexity of the entire assessment at building level exercise requires the use of several tools during the various steps of development. Therefore a process flow was elaborated for this project (see Figure 0.3).

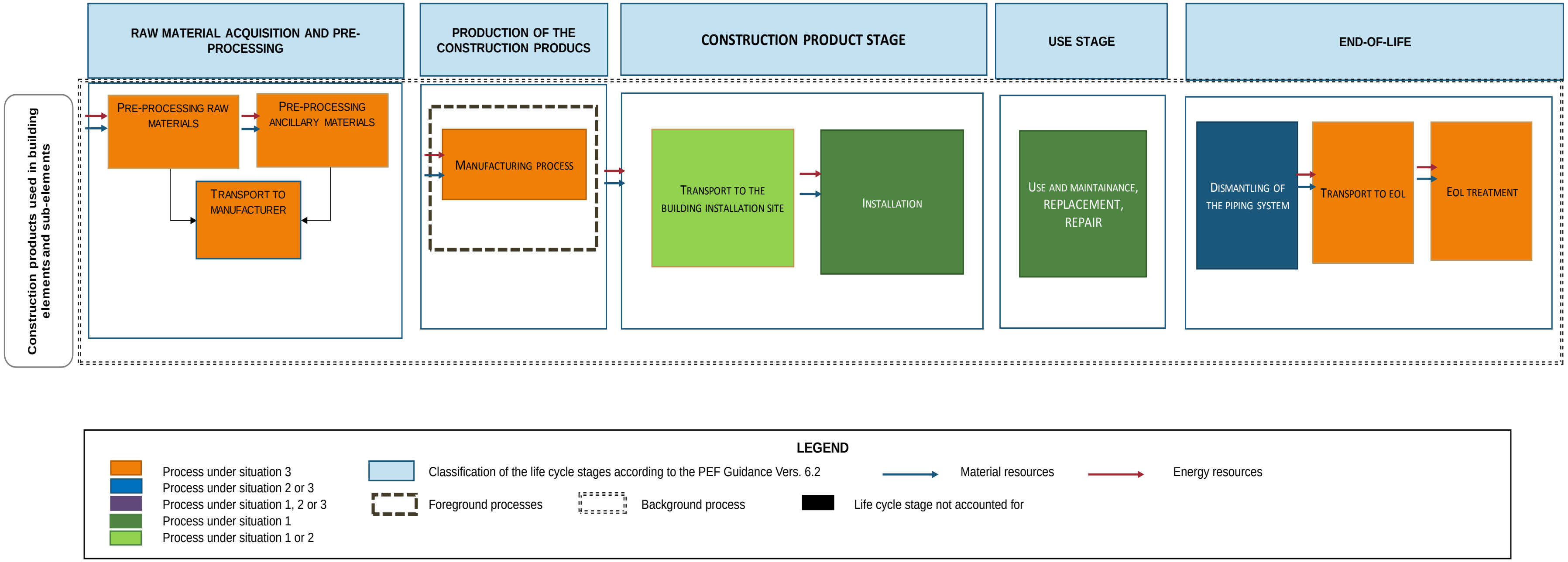


Figure 0.1: System boundary diagram for assessment at building level

The building element catalogue needs different types of information. More specifically, information about the elements, sub-elements and materials regarding specifications and quantities of the different entities is needed. Besides quantities, material specific characteristics (e.g. density of the material) are needed to define the complete dataset. Entity quantities are extracted from a Building Information Model, building plans, technical information sheets and the building cost sheet. Secondly, information is needed about the scenarios that apply during the different life cycle stages. If available, scenarios for transport and end-of-life stages are determined by the national guidelines which give more specific information complementing the respective PEFCRs or PEF guidance. Scenarios considering maintenance (including cleaning, small and big maintenance) and replacement are determined by national guidelines. A third type of information is related to the use phase and consists of the energy and water use in the assessed building. In this study data on the energy and water consumption is obtained from the building owners. In case of an assessment of a new building, this data could be obtained via building simulations.

In a user friendly manner, the models of both BelOrta and BE2226 buildings are developed following the hierarchical approach in spreadsheet files. Models and sheets follow a tree-like structure, which extends gradually to higher levels of detail. The intention was to allow an easy adaptation of the model to other building scenarios by using a consistent structure as well as making use of parameters in SimaPro[1]. The datasets used for modelling are mainly from Ecoinvent 3.3 and ELCD databases, as the datasets purchased by the Commission with the purpose to be used for PEF studies were not available even at the date of drafting this report (second half of July 2017).

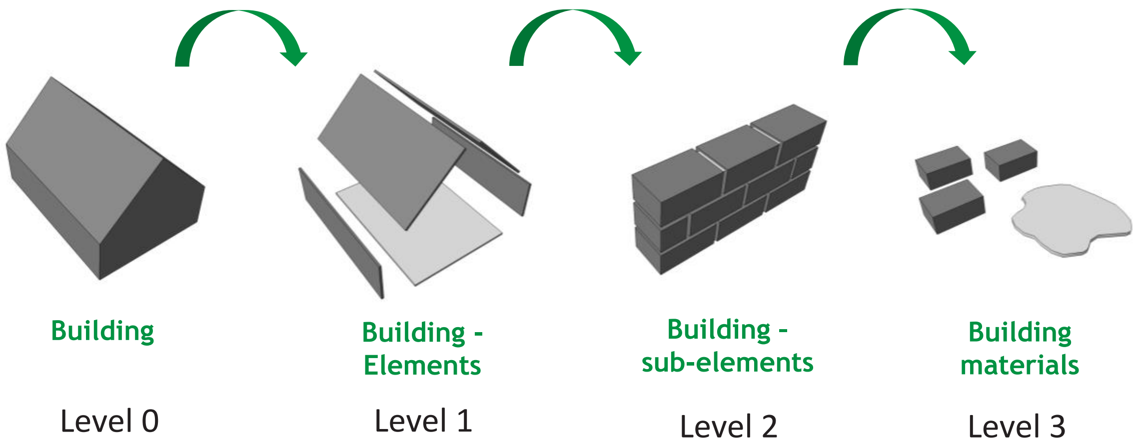


Figure 0.2: Hierarchical de-composition of the building (Trigaux et al., 2017)

[1] The SimaPro LCA software was selected because the project team is used to work with it. It does not imply any preference in software to be used, neither by the EC or the project team.

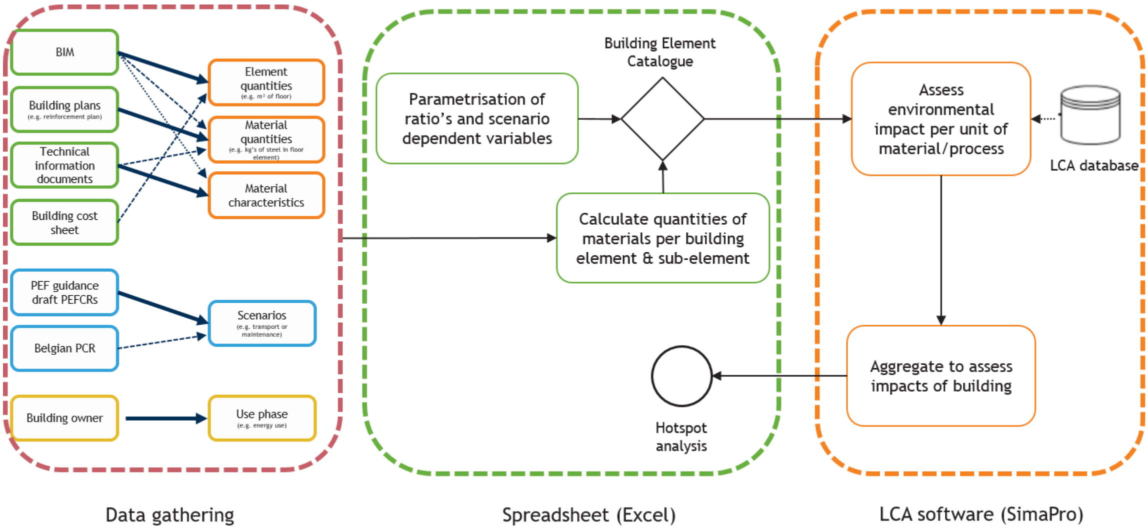


Figure 0.3: Data model development process flow

Life cycle inventory

The **BelOrta building** is an office building situated in a suburban region in Flanders (Belgium) designed by the architectural office ar-te and finished in 2014. The building is an extension to an existing building of the BelOrta company. The BelOrta building represents a business as usual office. The building has a net floor surface of 3000 m². The two-story building has an inner patio around which the office and meeting rooms are organized. Although a lot of information was available for the BelOrta building in a detailed way, we were still lacking some minor elements. Firstly, data were lacking for some building elements (e.g. internal shading system, sectional door). These elements have been left out of the modelling as these are very limited compared to the full bill of materials of the building and any estimation would have increased the uncertainty of the model. These are reported as data gaps.

The **BE2226 building** is an office building situated in a suburban context in Lustenau (Austria). The six story building finished construction in 2013 and has a net floor area of around 2700 m². It was designed by architects Baumschlager & Eberle who are also the main user of the building, with their offices taking half the floors in the building. The building was specifically designed to operate with an advanced building concept that does not require active heating or cooling systems. Instead, indoor air quality and occupancy are constantly measured to automatically open and close ventilation panels next to the fixed glazing windows. This concept is supported by very thick brick walls and their high thermal mass as well as good thermal performance of around 8 W/m² required for heating the building in winter times. This amount is covered by waste heat from users and technical appliances (including lighting). The BE2226 building consists of a minimum of constructive elements due to thoughtful simplifications in composition, construction and detailing by the architects. Its BIM model could hence provide reasonably complete quantities of the buildings elements. However, some elements were not well documented and were not modelled in detail in BIM (e.g. raised floor system, lighting fixtures, building automation systems, etc.). These elements were hence either subject to data gaps or simplifications in the presented assessment.

Life cycle impact assessment

As this project does not intend to focus on the absolute values and results obtained, but aims at understanding the methodological aspects of calculating a PEF of an office building, only a limited number of the results are reported.

The LCIA results of both case studies were calculated according to the PEF Guide. These are slightly different than the ones mentioned in the Guidance document v6.1/v6.2. As the latter were however not yet available in the SimaPro software, we could not assess the case studies according to this latest version. More specifically, the impact categories as mentioned in Table 0.2 were assessed. The impact assessment has been done at the level of the characterised values and at the level of the normalised and weighted results. For the latter the normalisation factors EC-JRC Global (2010 or 2013), per person have been used (see Table 0.2). The weighting set is based on the weighting set included in the Guidance document v6.2. The weighting factors from the Guidance document however have been rescaled as these include the impact categories 'resource use, mineral' and 'resource use, energy carriers' as two separate ones, while our set of impact categories solely includes one indicator 'mineral, fossil and renewable resource depletion'. For the rescaling the two resource indicators have been considered as one indicator, receiving the weight of '7,55', equal to the weighting of the indicator 'resource use, mineral' in the Guidance document v 6.2. The rescaled weighting factors are summarised in Table 0.2. The hotspots have been identified in line with the Guidance document v6.1. The hotspots were analysed in terms of most relevant impact categories, life cycle stages and processes.

Table 0.2: Impact categories and related indicators (PEF Guide), Normalisation factors (EC-JRC Global (2010 or 2013), per person) and weighting set

Impact category	Normalisation	Weighting set: GD v6.2 rescaled	Indicator
Climate change	7,07E+03	0,22971	kg CO2 eq
Ozone depletion	1,22E-02	0,06883	kg CFC-11 eq
Non-cancer human health effects	1,55E-04	0,02007	CTUh
Cancer human health effects	1,24E-05	0,02323	CTUh
Particulate matter/Respiratory inorganics	5,07E+00	0,09773	kg PM2.5 eq
Ionizing radiation, HH	2,41E+02	0,05465	kBq U235 eq
Photochemical ozone formation, HH	4,53E+01	0,05214	kg NMVOC eq
Acidification terrestrial and freshwater	5,61E+01	0,06763	molc H+ eq
Eutrophication terrestrial	1,64E+02	0,04047	molc N eq
Eutrophication freshwater	6,54E+00	0,03054	kg P eq
Eutrophication marine	3,04E+01	0,03229	kg N eq
Ecotoxicity freshwater	5,20E+06	0,02094	CTUe
Land use	3,74E+03	0,08661	kg C deficit
Water resource depletion	6,89E+01	0,09282	m^3 water eq
Mineral, fossil and ren resource depletion	1,93E-01	0,08235	Kg Sb eq

PEF results for BelOrta building

Figure 0.4 graphically represents the characterized results at the building level, indicating the contribution of each life cycle stage. From the graph it is clear that the use phase and the pre-processing phase are the most important life cycle stages. Environmental benefits are clearly visible as well during the end-of-life stage of the building.

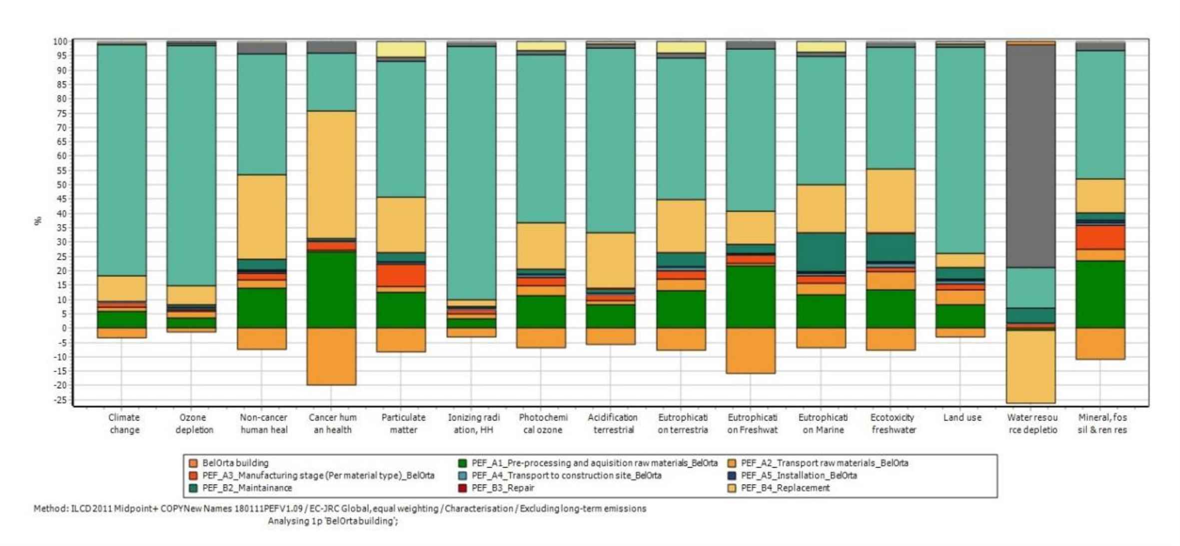


Figure 0.4: BelOrta – Characterised results of the building

Figure 0.5 shows the normalised results for the BelOrta building, considering the whole building and its full life cycle.

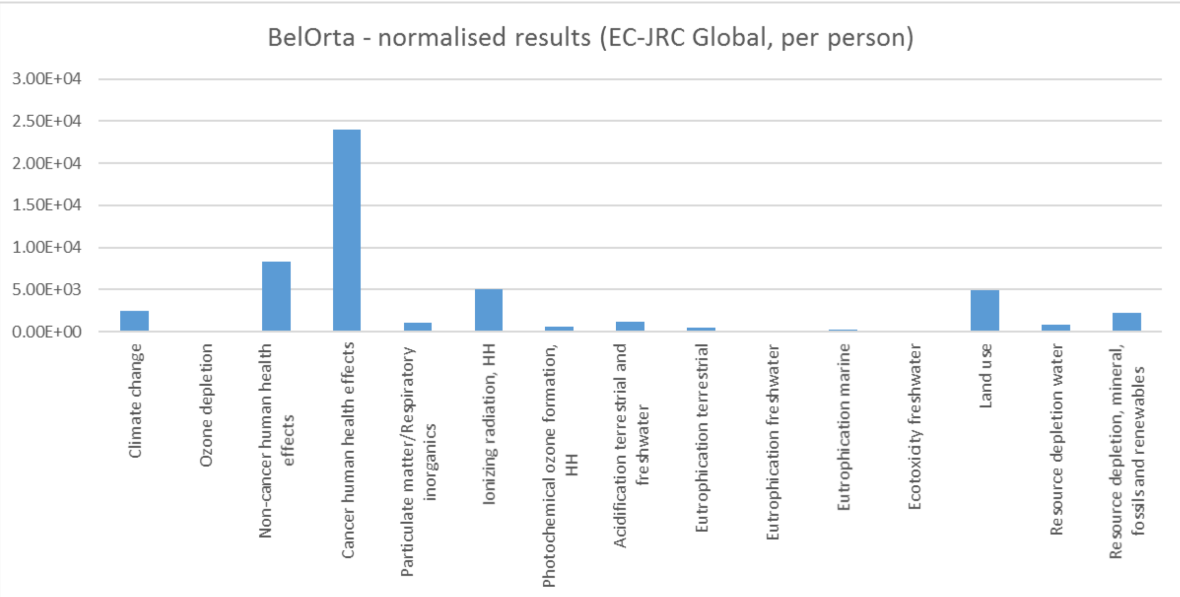


Figure 0.5: BelOrta – normalised results

Figure 0.6 shows the weighted results for the BelOrta building, considering the whole building and its full life cycle. The results show that excluding toxicity leads to lower overall environmental impacts.

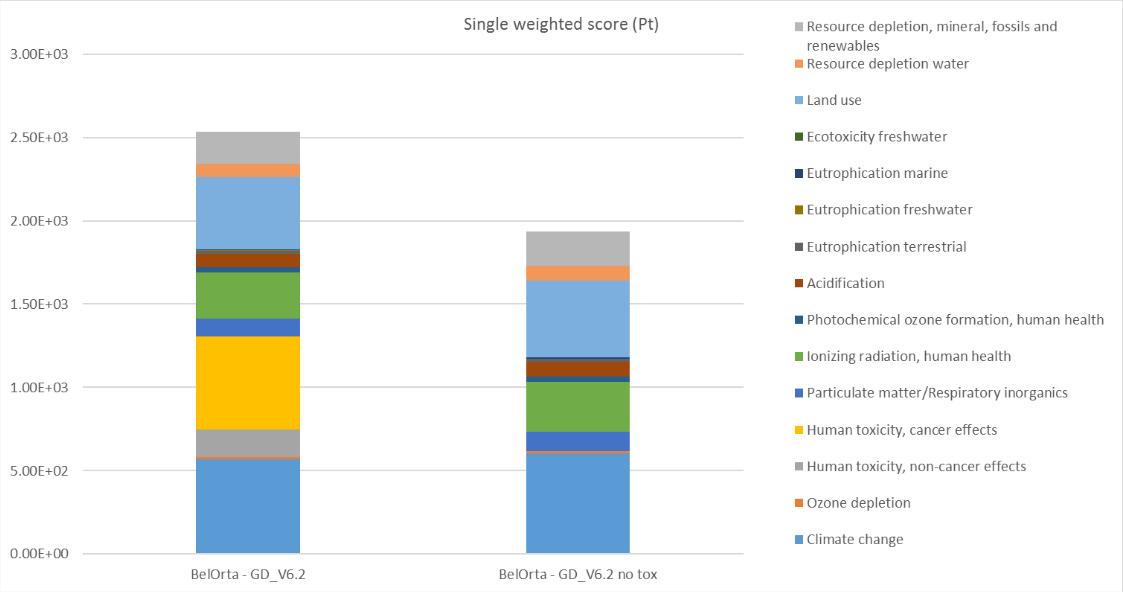


Figure 0.6: BelOrta – weighted results

The hotspots are defined at the level of the most relevant impact categories, most relevant life cycles stages and most relevant processes and are listed in the report.

PEF results for BE2226 building

Figure 0.9 illustrates the contribution of each life cycle stage by the characterized results at the building level. The most important life cycle stages for the majority of the impact categories of BE2226 are the use phase (even for NZEB building) and the pre-processing phase. Environmental benefits are clearly visible as well during the end-of-life stage of the building.

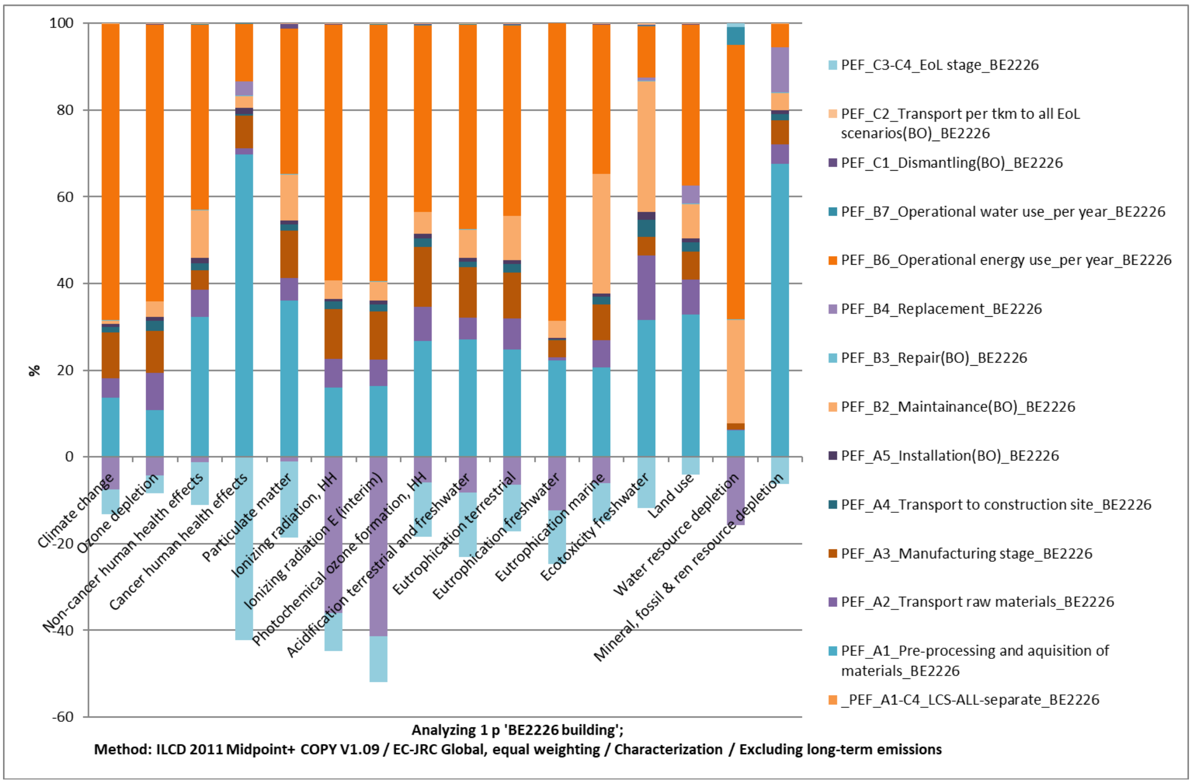


Figure 0.9: BE2226 - characterised results of the building

The normalised results for the BE2226 building are shown in Figure 0.10, considering the whole building and its full life cycle. Human health effects (both for non-cancer and cancer effects) is dominating the normalised results.

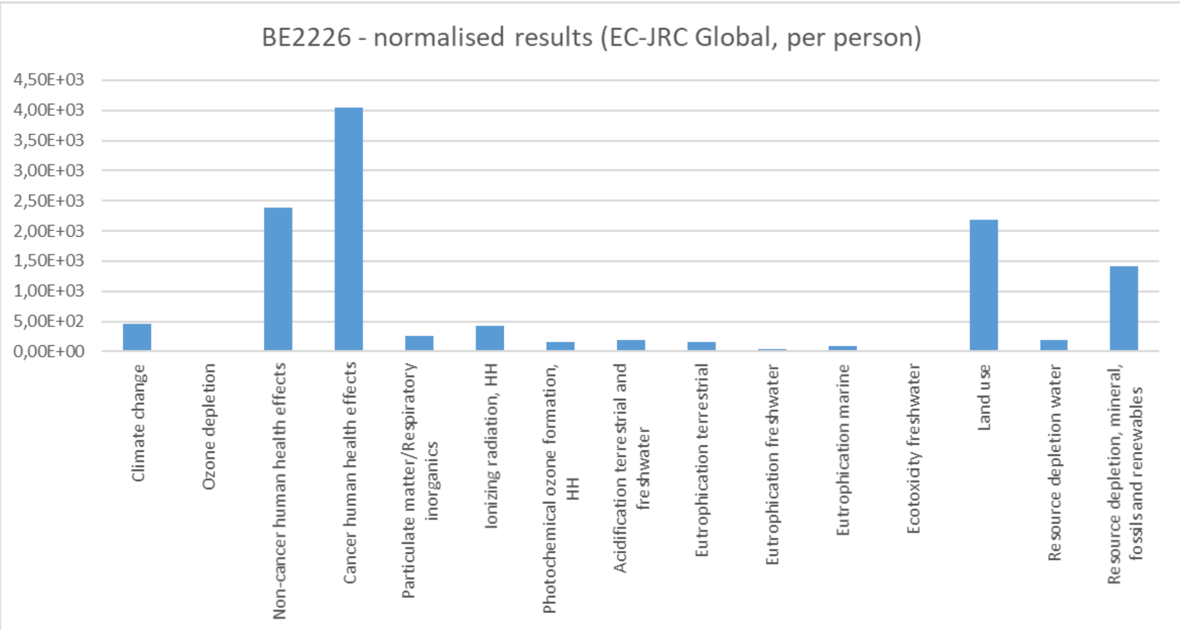


Figure 0.10: BE2226 - normalised results

The weighted results for the BE2226 building are shown in Figure 0.11, considering the whole building and its full life cycle. The results show, similar to the results from the BelOrta case study, that excluding toxicity leads to lower overall environmental impacts.

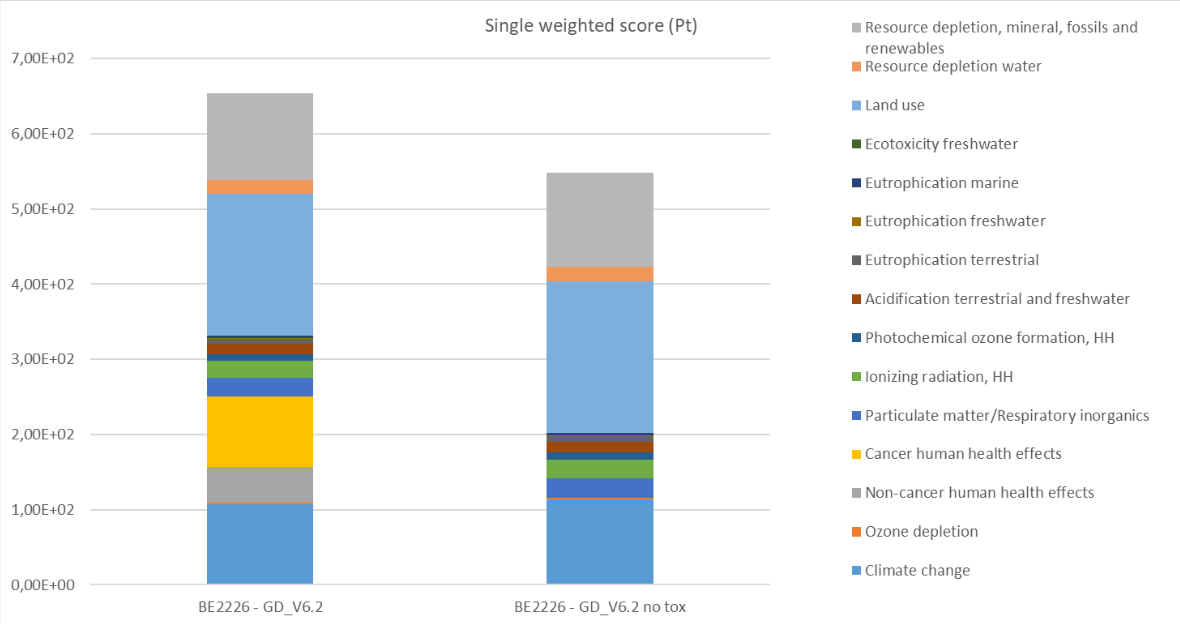


Figure 0.11: BE2226 - weighted results

The hotspots are defined at the level of the most relevant impact categories, most relevant life cycles stages and most relevant processes and are listed in the report.

Comparison of the two cases

Although the intention of the two assessments of the two cases is not to compare their LCIA results in detail, some important outcomes can be highlighted. Firstly, looking at the overall weighted score of the two buildings, we notice a significant difference in overall impact. The results for BE2226 building clearly show a lower impact than the BelOrta building, whether toxicity is considered or not. This was expected as the second case (BE2226) is an advanced building (NZEB) while the first case (BelOrta) is a business-as-usual case. Secondly, the most relevant impact categories identified differ between the two cases and hence clearly depend on the building (energy performance and materials used), but also on the location (electricity mix). We can furthermore conclude that several of the most relevant impact categories are 'additional' impact categories which are not included in the current version of the EN 15804 and EN 15978. Thirdly, for both buildings the PEF_A6 (operational energy use) and PEF_A1 (pre-processing of raw materials) phase have been identified being amongst the most relevant life cycle stages. For highly energy efficient buildings other life cycle stages become relatively more relevant. Finally, the identification of the most relevant processes leads to a different set of most relevant processes for both buildings. This was to be expected as both buildings consist of different materials and elements, but are also located in a different location and hence a different electricity mix is used during the important use phase of the building

Conclusions and recommendations

At the start of the project, **several basic documents** (PEF Guide, PEF guidance document v 6.1 and draft PEFCRs for construction products) were screened in order to ensure that our PEF study at building level is in line with all the PEF requirements. It was time consuming to screen all documents and make sure that all requirements were met. We therefore want to recommend/confirm the importance of a PEFCR at building level in future. When analysing the various **draft PEFCRs of construction products**, we noticed that these are not fully aligned in terms of definition of life cycle stages and scenarios. Also for this reason a PEFCR at building level that forms the base for all (new) PEFCRs for construction products is recommended. This PEFCR at building level should ensure:

- That life cycle stages are consistently defined across PEFCRs of all construction product categories;
- Alignment between PEFCR at building level and PEFCRs at the construction product level.

Besides the draft PEFCRs for construction products, we could benefit from the available **Belgian horizontal PCR for Buildings and MMG method** (national LCA methods for building elements) to define the life cycle scenarios for many of the materials/building elements for which no draft PEFCR was yet available. It is recommended to include such national scenarios in the PEFCR for buildings in future.

The PEF studies done in this research were studies of **buildings that were designed and constructed already**. A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear **guidelines to model the use phase** are moreover crucial as this life cycle stage is assumed to be the most relevant one for the majority of the buildings. One important parameter in this context is the reference study period and related references service lives.

The challenges and issues that people meet while using LCA at the building level are also valid for PEF. PEF specific issues are mainly the availability of PEF compliant generic datasets and the quality of the existing generic datasets (not always PEF compliant).

Since the PEF endorses the use of the CFF formula it is recommended that all generic datasets allow the application of the CFF formula. This should be a recommendation for further development. The purchased PEF compliant datasets the Commission bought is already a first step in that direction.

For the modelling of the building, we have chosen for a **hierarchical decomposition of the building** in line with the element method for cost control. Once the structure of the model was defined, the **data collection process** could start. This proved to be an intensive process where a high level of detail is needed to enable an accurate assessment. This level of detail is currently not available as such in design documents. A quite extensive list of documents needed to be searched for and examined to find all the data needed for the PEF study. Following **learnings** can be formulated based on the data gathering process performed in this study:

- BIM was an important source with added value that made this study feasible within the foreseen timeframe;
- The risk for errors increases with the number of documents that need to be combined to find all the necessary data. The number of documents hence should be as limited as possible, ideally everything should be combined in one single document, e.g. a BIM model;
- Important aspects for a BIM model to be used for LCA:
    - Completeness and accuracy (modelled and un-modelled elements);
    - Level Of Geometry (LOG) for modelled elements;
    - Level Of Information (LOI) regarding specification of material information.

It is hence recommended to specific BIM requirements to allow a better data provision for PEF (LCA) purposes and identify ways of integrating LCA data into BIM.

With regard to **data needs requirements for PEF studies of buildings** no clear rules exist yet. In our study we assumed that the Product stage consists of processes in Situation 3, while Construction products stage and Use stage are mainly in Situation 1 and 2, as defined in DNM of the Guidance document. Considering that no products are directly produced at building level, the use of specific data is not mandatory. For the goal of this project it was considered in agreement with the Commission that there is no added value to put time and effort in collecting specific data as this would require a lot of time and endanger the other parts of the project. We nevertheless acknowledge that the use of specific data would enhance the data quality and should be used in future when specific PEF compliant datasets will be available for construction products.

It is recommended to include in a PEFCR for buildings a definition of processes that are / are not under operational control of the building commissioner. A more extended consultation with relevant stakeholders should take place related define how primary versus secondary data should be used when making PEF assessments at building level.

As buildings are complex entities, also the PEF model was highly complex consisting of large amounts of data. Due to this complexity, the risks of errors are high and as mentioned before, a systematic approach is necessary. As LCA is an iterative approach and our model was a combination of Excel and SimaPro, parametrisation of the model was introduced in order to avoid manual remodelling during each iteration. This approach greatly supported the integration of the parameters of the CFF formula and was also useful for the development of the first case study, BelOrta. The concept of using element and material specific ratios, to describe density and proportion of a certain construction material contained within a sub-element or element, was very useful for both case studies. However, the use of parameters for total quantities of materials or elements in the building, i.e. to establish a link between BIM and the SimaPro model via Excel, applicable for different building case studies, was found not feasible in the time given as the two buildings assessed were still very different in terms of element composition, materials used, etc. and would thus require a more refined generic structure to establish such a link properly. Thus no parameters for material quantities were used in the BE2226 assessment, while the parameters introduced for the CFF formula were of great help also for this case study.

The complexity of the model implies a time consuming process to establish the model. A generic template for the data collection and modelling is therefore recommended if PEF studies of buildings should become mainstream.

Regarding the life cycle inventory, it was found that a more extended list of generic datasets is needed to model an entire building and that the current Ecoinvent datasets did not allow to apply the CFF formula without adapting them. It is therefore recommended to:

- provide a database with construction materials in line with PEF;
- Integrate the CFF formula in the datasets.

The models of the two cases allowed to assess the building in a fairly easy way. For the *BelOrta building* the results as presented in this chapter and the hotspot analysis as required by the PEF method could be directly extracted from the SimaPro model, except for the process contribution of the processes in the life cycle stages PEF_A2 and PEF_A4. For the hotspot analysis, it would be helpful if these life cycle stages are modelled in a disaggregated form. The BelOrta SimaPro model allows to directly extract the LCIA results at the level of the building, at the level of the life cycle stage, at the level of the element in each life cycle stage, and at the level of the material/process. For the *BE2226 building* the modelling in SimaPro was done on material level for all main building elements (foundation, walls, floors, etc.), as the required total quantities for this could be directly extracted from the BIM model with the required accuracy. Secondary elements, like windows and doors, were modelled as aggregated datasets combining the materials contained within one piece of element. This modular approach allowed for a detailed modelling of these elements and offers an efficient way of modelling that could as well be used for a changing number of elements e.g. windows during a design process. Results derived from SimaPro could thus directly be used for the analysis of most relevant life cycle stages and impact categories. For most relevant processes the same issues as mentioned for BelOrta already were faced, as transport had to be disaggregated in excel afterwards – this limitation however can be overcome when modelling these life cycle stages accordingly, with material-specific transport values. The above mentioned modelling aspects are in part related to the applied workflow and software solutions and may well be different in other cases.

The inclusion/exclusion of the toxicity impact category clearly influences the results to a significant extent, especially for the second case study. As weighting adds an additional level of uncertainty to the LCIA, it is recommended to investigate the influence of the weighting to the results. This can be done either by testing the robustness of the results when several weighting sets are used, or either by extending the identification of the most relevant life cycle stages and processes to a longer list of impact categories (not limiting it to the most relevant impact categories or increasing the minimum level of three impact categories as now required by the PEF Guidance document v6.2). The results of the two cases moreover revealed that several of the most relevant impact categories identified are ‘additional’ impact categories which are not included in the current version of the standards EN 15804 and EN 15978.

The identification of the most relevant impact categories, life cycle stages and processes was done in excel after exporting the LCIA results from the SimaPro software. Macro’s were developed in excel (visual basic) to identify the most relevant impact categories, life cycle stages and processes in order to avoid time consuming manual work. It would be helpful if in future the LCA software would allow to do this directly in the software.

CHAPTER 2 ACTIVITY 1.1: DEFINITION OF SCOPE, SYSTEM BOUNDARIES, LIFE CYCLE STAGES, SCENARIOS

The main objectives are to test the applicability of the PEF method to a new office building and to propose approaches for the methodological challenges identified. The results of this study in terms of accurate contributions per environmental impact category are not the main outcome expected in this project, but rather a mean to a more generic purpose.

In this context, during the first activity 1.1, the following aspects were defined in line with the PEF method, detailed in the sections below:

- Scope and functional unit;
- Reference flow;
- Life span of the building;
- System boundary;
- Life cycle stages;
- Scenarios.

Several documents have been used as methodological basis, as follows:

- PEF Guide (Parliament & Committee, 2013);
- PEF Guidance document (v. 6.1 mainly and for limited aspects v. 6.2) (European Commission, 2017);
- EN 15978 & EN 15804;
- Five draft PEFCRs for construction products:
  - Draft PEFCR for "Metal Sheets for Various Applications" Revision 0.9d (Bollen et al., 2016);
  - Draft final PEFCR Decorative Paints Version 6.2 (Technical Secretariat Decorative Paints, 2016)
  - Draft final PEFCR for Thermal Insulation version 4.4 (Technical Secretariat of the PEF thermal insulation pilot, 2016)
  - Draft final PEFCR for hot and cold water supply piping systems in the building Version 4.1 (Technical Secretariat PEF pilot on piping systems, 2016)
  - Draft final PEFCR for Photovoltaic modules used in photovoltaic power systems for electricity generation (Technical Secretariat of the PEF photovoltaic electricity generation pilot, 2016)
- National guidelines / PCRs if available:
  - BE_PCR Draft 4.1 - National Annex to EN 15804 +A1 - Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (Bureau for Standardisation (NBN), 2017);
  - AT_PCR General guidelines, Product Category Rules for building related products and services, Version 2.2 – PCR Part A: General Rules for LCA assessment and requirements on the project report (Bau-EPD, 2017).

As a general rule the PEF requirements have been followed in most aspects (scope, functional unit, application of the CFF formula), with limited number of exceptions that will be detailed in the report.

2.1. Definition of scope

In this context the definition of the scope of the PEF study for an office building is represented by what is included in the assessment with respect to the functional unit (what, how much, how well, how long), system boundaries (including the life cycle stages) and scenarios.

2.1.1. Functional unit

The functional unit is one office building with reference service period of 50 years, assessed from the bill of materials according to element method, referring to entire building.

The key aspects used to define the functional unit are presented below.

- **What?**
    - Office building excluding the surroundings.
- **How much?**
    - One office building.
- **How well?**
    - Energy performance and thermal comfort;
    - Relevant technical and functional requirements.
- **How long?**
    - 50 years of reference study period.

2.1.2. Reference flow

The reference flow is the amount of product needed to fulfil the defined function and shall be measured in m^2, m^3, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.

For the purpose of this study the building as a whole is considered, without the infrastructure for accessing the building. In order to make the PEF assessment a **reference “office building system”** shall be considered. The following building elements shall be included in the reference flow:

- Foundation and sub-structure;
- The structural frame, including beams, columns and slabs;
- Staircases;
- External walls, cladding and insulation;
- Windows;
- Floors and ceilings;
- Internal walls;
- Doors;
- Roofs;
- Heating and cooling systems;
- Sanitary systems;

- Electrical systems.

For informative purposes Annex 5 - Building elements specified in GPP guideline, DGNB assessment, EN 15978 and proposal for elements included in the PEF4Buildings study provides a comparison between what is included in the scope in other norms/documents that assess the environmental impact of buildings.

Not included in the reference flow are:

- Consumables (e.g. IT equipment, paper, furniture);
- Surroundings (e.g. parking lot);
- Kitchen/ catering (because of benchmarking purposes);
- Commuter transport.

The reference flow shall be reported at the level of building element, sub-element and materials.

2.2. SYSTEM BOUNDARIES

The PEF Guidance (European Commission, 2017) indicates that the system boundary shall include a system diagram clearly indicating the processes and life cycle stages that are included in the product system. The diagram shall include an indication of the processes for which company-specific data are required.

First an overview is given of the life cycle stages that have been defined for the PEF assessment of an office building (paragraph 1.2.1). Then a system diagram is presented that clearly indicates the processes and life cycle stages that are included in the building system boundaries for the PEF assessment (paragraph 1.2.2).

The system boundaries for this PEF study on newly built office buildings are defined from the perspective the designer/architect. This means that everything that the designer/architect can influence shall be included in the system boundaries.

2.2.1. LIFE CYCLE STAGES

The PEF assessment will be carried out according to the different life cycle stages of the building, where all life cycle stages, from cradle to grave will be considered.

Following this indication, life cycle stages have been defined for the assessment of an office building. This definition was based on a cross-analysis of the life cycle stages defined in the draft PEFCRs for the construction products already developed, but also in the EN norms related to construction products (EN 15978/EN15804). The details of this analysis can be found in Annex 5.

The findings of this analysis show multiple differences between the approach towards defining the life cycle stages for various construction products, as follows:

- Number of LCS different: 15 (paints), 12 (TI), 9 (piping), 5 (PV), 4 (metal sheets);
- 3 PEFCRs have more than 1 LCS for the acquisition of the raw materials. In order to have a PEF for building with data from these PEFCRs aggregation of these LCSs is needed;
- For the PEFCR on paints the transportation stages are covered but the modelling deviates (transport type and distance vs fuel consumption and emission). For PEF4Buildings it is not feasible to follow the primary data approach;

- Infrastructure for manufacturing stage not included in all PEFCR (cut-off for piping systems);
- Most existing PEFCRs do not include this Use phase or consider it only as additional information;
- Some of the stages during the use phase can be assessed only at building level, in an integrated way. It is recommended to develop specific scenarios in the PEFCR for buildings;
- An overall scenario for dismantling/demolishing should be developed for the building level. At the moment for products only 2 PEFCRs include some basic scenarios;
- As the PEF method requires the application of the Circular Footprint Formula (CFF), module D from EN 15804 is partly covered in life cycle stage PEF_A1 and PEF_C3/C4. The CFF can be arranged in a modular way, to fit for example the structure of the EN 15804 standard (see figure 2 in the PEF guidance document version 6.2 where the CFF is presented and re-arranged in different modules).

Based on this analysis the life cycle stages presented in Table 1 have been defined for the assessment of an office building. It is recommended to use these **life cycle stages for any other type of building. Besides using them for assessment at building level it is also recommended to use them as a reference for aligning the life cycle stages from various PEFCRs for construction products and when developing new PEFCRs for construction products.**

Table 1: Life cycle stages for the assessment at building level

LCS name	The following shall be included
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment
PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL
PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

2.2.2. System boundary diagram and relation with the PEF Data Needs Matrix

As defined in section 2.2.1, the PEF assessment will be carried out according to the different life cycle stages of the building. Figure 1 presents the system boundary diagram for the assessment at the building level, where the life cycle stages are presented in a manner compatible with the one existing in EN 15804:2012+A1:2013 (Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products) and EN 15978:2011 (Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method):

- *Product stage*: manufacturing of all construction products, including transport and all processes upstream of the manufacturing stage, e.g. raw material supply, packaging or energy provision;
- *Construction process stage*: transport of all construction products from the manufacturers to the building construction site and the installation of all construction products in the building (construction process);
- *Use stage*: use or application of the installed construction products in the building, maintenance of the building, repair activities, replacement activities, refurbishment activities, operational energy use and operational water use;
- *End-of-life stage*: de-construction, reuse, demolition, recycling and disposal; including all transport.

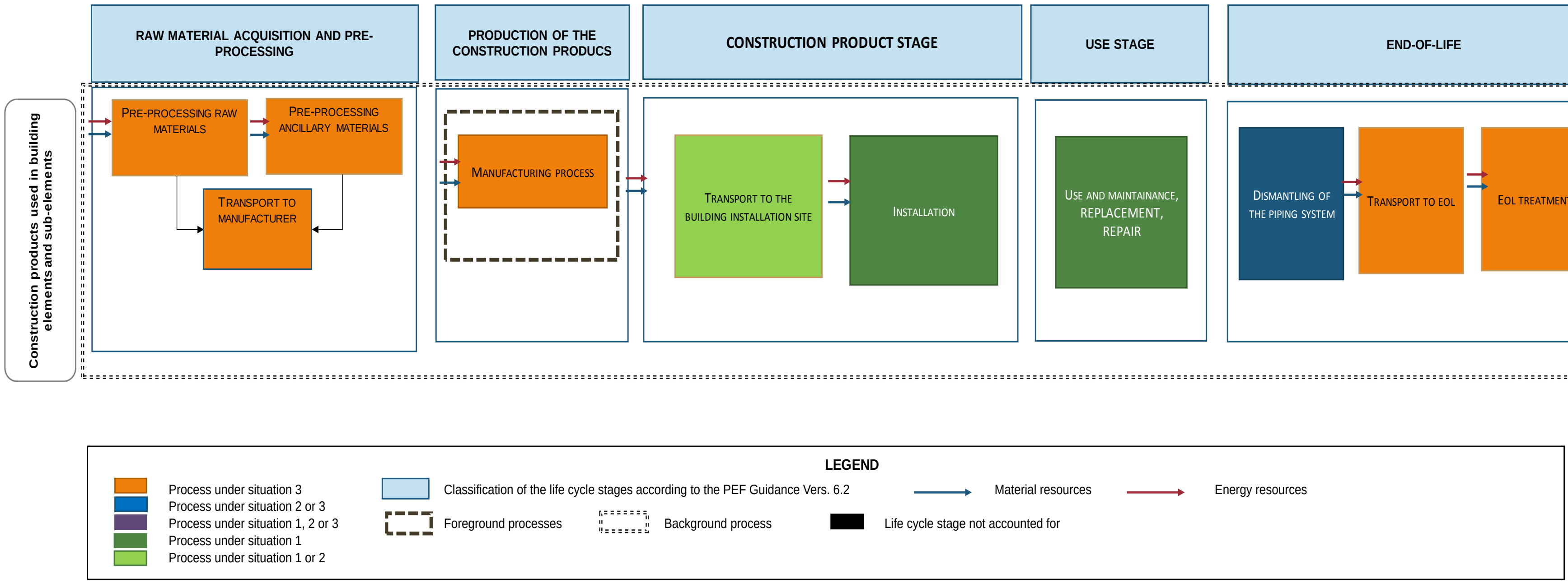


Figure 1: System boundary diagram for assessment at building level

A relevant discussion at this point is related to the data needs requirements as defined in PEF context as no clear rules are available in the PEF Guide on the sources of data for PEF studies of buildings. The PEF Guidance (European Commission, 2017) indicates that the DNM shall be used [by the PEFCR applicant] "*to evaluate which data is needed and shall be used within the modelling of its PEF, depending on the level of influence the applicant (company) has on the specific process.*" The following three cases of level of influence are defined in the DNM and are explained below:

1. **Situation 1**: the process is run by the company applying the PEFCR;
2. **Situation 2**: the process is not run by the company applying the PEFCR but the company has access to (company-)specific information;
3. **Situation 3**: the process is not run by the company applying the PEFCR and this company does not have access to (company-)specific information.

A company [implementing the PEFCR] shall first determine the level of influence (Situation 1, 2 or 3 described below) the company has for each process in its supply chain. This decision determines which processes will be used for the assessment, depending on the level of importance as well (most relevant processes or other processes).

While at product level this approach is clear and explicit, at the building level the level of influence shifts, as the "building owner[2]" will have a potential influence at a different level than the construction products manufacturers. From this perspective the life cycle stages/processes in situation 1 or 2 will compared to a construction products manufacturer.

For the purpose of this study it was considered that the *Product stage* consists of processes in Situation 3, while Construction products stage and Use stage are mainly in Situation 1 and 2. It is considered though that a more extended consultation with relevant stakeholders should take place related to how primary versus secondary data should be used when doing assessment at building level.

Thus, while in line with the general PEF Guide specific data should be used for processes which are under the direct operational control of the producer, considering that no products are directly produced at building level, the use of specific data is not mandatory. For the goal of this project it was considered in agreement with the Commission that there is no added value to put time and effort in collecting specific data as this would require a lot of time and endanger the other parts of the project. We nevertheless acknowledge that the use of specific data would enhance the data quality and should be used in future when specific PEF compliant datasets will be available for construction products.

Generic data were be mostly used for the LCI. The generic datasets were be chosen as representative as possible to the real situation (e.g. electricity mixes according to the country mix where the operation takes place, etc.) and adapted if needed.

[2] Constructor, building owner, commissioner of the building, or similar can apply in this situation showing the same level of influence relative to their core activity of constructing the building.

2.3. SCENARIOS

For each life cycle stage specific scenarios are necessary for the assessment of the environmental impact at building level.

These scenarios are mainly focusing on:

- *Assumptions related to construction process stage*: e.g. transportation of construction products from manufacturers to building construction site, but also the construction process (use specific as much as possible);
- *Assumptions related to the use stage*: scenarios for the use of the installed construction products in the building, maintenance of the building, repair activities, replacement activities, refurbishment activities, operational energy use and operational water use;
- *Assumptions related to End of Life stage*: scenarios for the de-construction, reuse, demolition, recycling and disposal; including all transport.

In defining such scenarios, the PEF Guidance as well as the draft PEFCRs, EN norms and national norms have been used, as mentioned before. Specific information was extracted and cross-analysed, and adequate scenario was defined either based on the scenarios from these documents, or based on expert experience.

Detailed information on assumed scenarios for each life cycle stage are provided in section 3.3.

2.4. ALLOCATION RULES

For the purpose of this study rules for allocation at building level and at product level have been identified as necessary.

At building level, the discussion can be opened related to the allocation of the impacts of re-used building elements. While not applied in the presented study, **setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary** (such as the reuse of pile foundation of previous building).

At product level the allocation follows the approach for the handling of multi-functional processes in the PEF Guidance 6.1 (European Commission, 2017). In this direction the co-product allocation already existing in the datasets used was not altered, ensuring thus a consistent approach.

2.5. CUT-OFF RULES

As specified in the PEF Guidance (European Commission, 2017), the criteria for the exclusion of inputs and outputs (cut-off rules) are intended to support an efficient calculation procedure. They shall not be applied in order to hide data.

Currently the rules in the PEFCRs for construction products are not aligned with the one from the PEF Guidance 6.1 and 6.2.

This study is set up similarly as a screening study. Therefore no cut-off are applied. All information that is not included in the study is due to data gaps (see next paragraph) and not to cut-offs.

The complete overview of the inventory is presented in Chapter 3 of this report.

2.6. DATA GAPS

When applying the PEF method to the complex building system some challenges were encountered due to data gaps. The data gaps occurring in these studies are of two types:

- Data gaps due to lack of information;
- Data gaps due to lack of datasets (modelling alternatives).

These data gaps are detailed as part of the life cycle inventory for each life cycle stage (see chapter 3).

Generally, the data gaps related to the lack of information are:

- Incomplete information related to the building elements, layers and materials due to incomplete documentation (BIM, plans and other sources);
- Unavailability of scenarios – e.g. for construction stage scenarios;
- Lack of information on the final (as-built) status of the buildings.

With respect to these data gaps and due to the lack of modelling alternatives, the following approach is taken: whenever no sufficiently representative specific or generic data are available for a certain process, it should be filled with a data collection and/or a selection of available datasets that is a best available proxy. Any data gaps should be filled using the best available generic or extrapolated data.

When implementing this approach for the building cases, we found that often no such proxy dataset was available in the generic databases for modelling the recycling processes.

Proxies that are prescribed are not considered as data gap.

CHAPTER 3 ACTIVITY 1.2: DEVELOPMENT OF LCA MODEL FOR THE OFFICE BUILDING ASSESSMENT

During the second activity 1.2, the basic LCA model to be used for the PEF study for both case studies was developed.

The aim of this LCA model is to assess office buildings with the PEF method for both the level of the building materials and building elements. The aim is moreover to use PEF studies – available in future – at different scale levels (e.g. building materials, building sub-elements, building elements) in PEF studies of buildings. In order to allow for this linkages, a hierarchical decomposition of the building (element method) is used.

3.1. HIERARCHICAL DE-COMPOSITION OF THE BUILDING (ELEMENT METHODS)

The model of the office building is structured in such a way that it allows for PEF studies at material, sub-element, building element and entire building level. This approach hence allows to combine the PEF assessments of lower scale levels to be integrated and combined until the level of the building. (Trigaux, Wijnants, De Troyer, & Allacker, 2017)

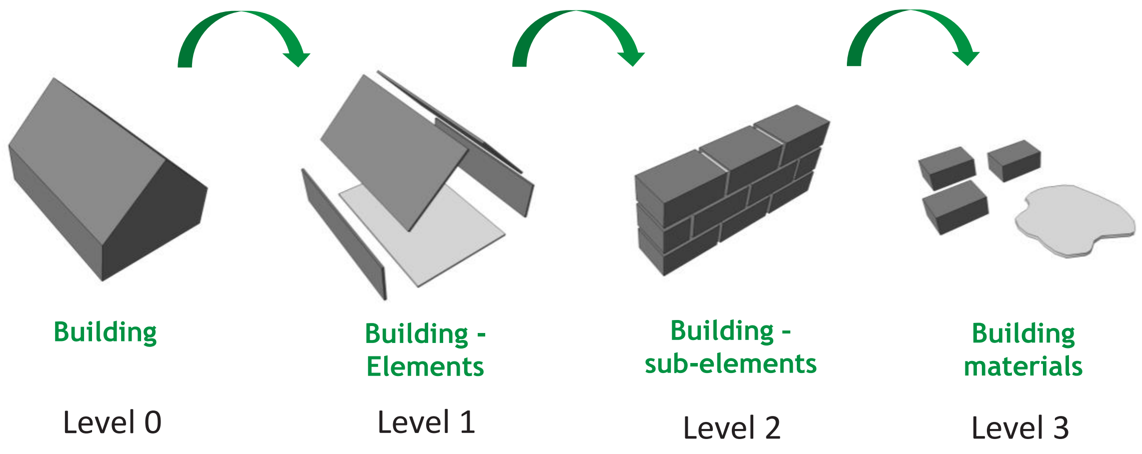


Figure 2: Hierarchical de-composition of the building (Trigaux et al., 2017)

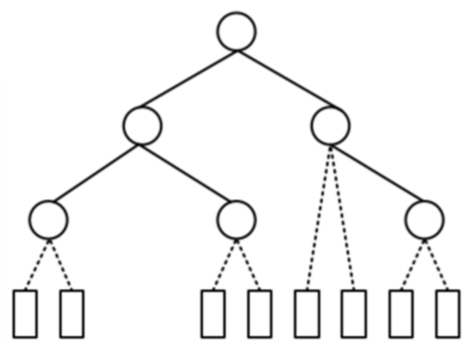
The model structure is based on a hierarchical subdivision of the building in smaller entities based on a functional approach (Figure 2). The hierarchical structuring of the building is based on the **element method for cost control** (De Troyer, 2008)**,** which subdivides a building in 'independent' functional elements. Although this approach is cost-based, it perfectly fits with the LCA approach. The element method for cost control was extended to LCA studies of buildings in *(Allacker, 2010)* and forms the base of the Belgian national method for LCA of buildings (MMG) *(Allacker et al., 2013).* The element method subdivides a building (level 0) in building elements (level 1) such as 'loadbearing outer walls', 'pitched roof', 'foundation', etc. Each of these are then subdivided in building sub-elements (level 2). These sub-elements are on their turn composed of different building materials (level 3). Each of the levels in the subdivision of the building are connected via

ratios. These ratios represent the amount of the lower level (material/ (sub-) element used in the higher level. An example of the use of this ratios is shown in Figure 3 for the construction of a floor element.

Level 1: Building element				Level 2: Building sub-element			Level 3: Building material		
Building Element	Quantity element	Quantity sub-element	Unit	Building sub-element	Unit	Ratio sub-element / building element	Material	Material unit	Ratio material/sub element
Concrete floor on earth	1148		m^2						
		1148	m^2	Vinyl Tiles	m^2	1			
							Vinyl Tiles	*m^2*	*1.0*
							Butyl Acrylate	*kg*	*0.3*
		1148	m^2	Concrete Screed	m^2	1			
							Concrete In Situ	*m^3*	*0.1*
		1148	m^2	PUR	m^2	1			
							Polyurethane Flexible Foam	*kg*	*3.0*
		1148	m^2	Concrete Floor	m^2	1			
							Reinforcing Steel	*kg*	*22.2*
							Concrete In Situ	*m^3*	*0.3*

Figure 3: Hierarchical decomposition of floor element making use of ratios

For distinction and detailed analysis of the different building elements and sections of the building the tree-like building element classification system of OmniClass (2015) is used in compliance with ISO 12006-2 (International organization for Standardization, 2015)**.**



- Level 0: Building
- Level 1: Building elements (e.g. external walls)
- Level 2: Building sub-elements (e.g. brick wall)
- Level 3: Building materials (e.g. bricks)

Figure 4: Adopted framework for classification according to ISO 12006-2 (ISO, 2015)

3.1.1. Level of analysis for the PEF assessment of the two office buildings

During the work on the PEF4Buildings project it became apparent that there was incomplete agreement or not full alignment regarding the anderstanding of some concepts when it came to analysing the results.

First of all, distinction must be made between the concepts of "level of disaggregation of a dataset" and "level of analysis".

Level of dissagregation of a dataset

Regarding the level of disaggregation, the PEF Guidance 6.2 refers to it in the following sections:
- Chapter 4, Terms and definitions;
- Section 7.4;
- In Annex H2 of the PEF Guidance 6.2.

Thus, in the context of PEF studies we encounter datasets that can be:
- Aggregated – contains only elementary flows;
- Partially disaggregated at level 1 - contains elementary flows and activity data, and that only in combination with the complementing aggregated datasets that represent the activities yields a complete aggregated LCI data set;
- Disaggregated at level 2 – the complementing aggregated datasets are also disaggregated at level 1 at their turn.

Level of analysis

When looking at a building level during this project we have the following hierarchical levels of the building, and situations when applying datasets to the model of the building (ISO, 2005).
- Level 0 – Building;
- Level 1 – Building element;
- Level 2 – Building sub-element;
- Level 3 – Building material.

The analysis of the impact of a building can be done at several levels, such as at the level of the entire building, per building elements, sub-elements or materials. These levels of analysis are however not in direct relation with the level of dissagregation of the datasets used to develop the model.

Furthermore, following the PEF method, the focuss of the analysis is on the hotspots that need to be identified (see chapter 5). While for the identification of the most relevant impact categories and life cycle stages the analysis is straight forward, it is not as easy to determine the right level of analysis for the most relevant processes though. In this direction the PEF Guidance indicates that "*Each most relevant impact category shall be further investigated to identify the most relevant processes used to model each life cycle stage. The processes shall be modelled as disaggregated at level-1*."[3]

As explained above, a building is a complex system therefore in the context of this project the decision on "which is level-1 in this context?" was taken by the project team after consultation with the European Commission.

[3] PEF Guidance 6.1

Definintion of level -1 in the framework of the level of analysis

In defining level-1 it was relevant to determine the perspective of the developer of a building (such as an architect), as this would be the level where the results of this analysis can be used. Thus, from a building developer's view point, he/she will look at the products that will be delivered at the construction site, be it raw materials (sand), prefab elements (prefab walls, reinforcing steel), parts of a building element (window frames, glazing) or even complete building elements (condensing boiler). The selection of materials to be used for constructing the building is also done at this level, and it is therefore desirable to set level -1 at this level.

Table 2 below provides an example of level-1 was defined for some specific cases, where the cells in green represent level-1.

Table 2: Example on Level -1 definition for some specific cases

Hierarchical level number	Name of the building level	Example 1	Example 2	Example 3
Level 0	Building			
Level 1	Building elements	Internal glazed wall	Concrete storey floor 45 cm	CoolingMachine
Level 2	Building sub-elements	AluminiumFrame	ConcretePrefabFloor	
Level 3	Building materials	1 material used	3 materials used	
	Comments	1 dataset used (as only 1 available)	For each material at least 2 datasets used to model to allow application of the CFF formula.	1 dataset used (no CFF applied as not possible)

Defining level-1 as the level of products delivered at the construction site does not make the analysis of the two analysed office buildings easier though, as currently the existing datasets are available at a different disaggregation level. Currently the model was developed with whatever was available, where besides creating the various building elements and sub-elements using the materials they were made from. Besides this the CFF formula implementation also required yet one more level, increasing thus the level of granularity.
The examples above show how level-1 can be at different hierarchical levels of a building, and can also have various levels of dissagregation when it comes to datasets.This situation will idealy change in the future, where datasets will be available at the right level of disaggregation, with the CFF formula already inbuilt, to allow their easy use in the model.

At the moment the analysis at level-1 (as the products are delivered at construction site) was done by aggregating in Excel the results at the datasets level up to the right level, as per the definition.

3.2. DATA MODEL DEVELOPMENT PROCESS FLOW

The complexity of the entire assessment at building level exercise requires the use of several tools during the various steps of development.

Experience from previous studies showed the importance of a good elaborated model were information can easily be exchanged between different tools and were different information types can be combined. This flow even gains more importance when dealing with more complex systems such as buildings. Therefore a process flow was elaborated for this project (see Figure 5).

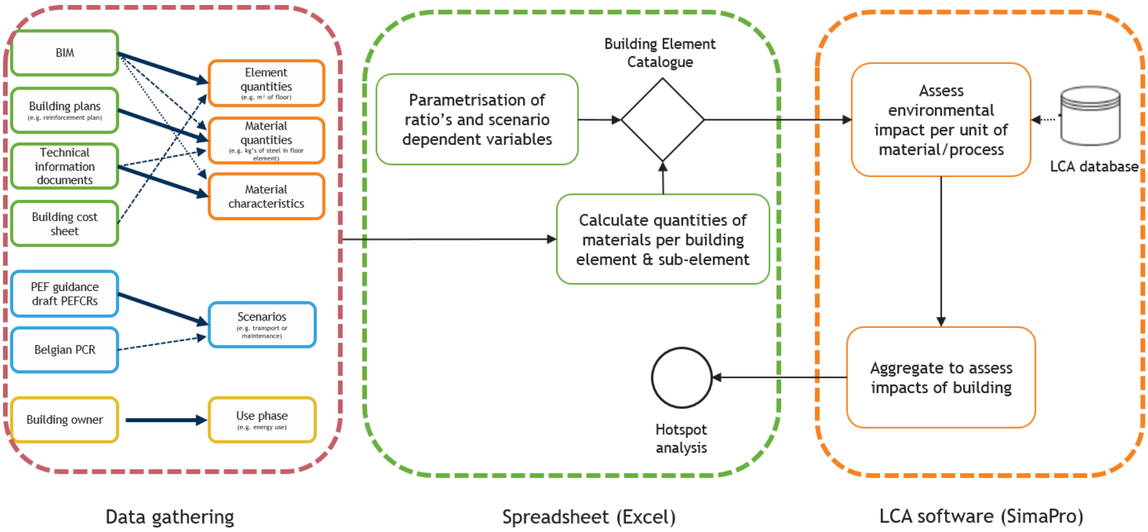


Figure 5: Data model development process flow

First of all, sources to define the necessary information on building elements, building materials, scenarios, use phase are identified in the data gathering process.

In a second step, a building element catalogue of the building's components is developed in a spreadsheet (Excel). In this catalogue quantities of materials per unit of building element are specified as well as scenarios that apply on the different materials and building elements during the different life cycle phases. Hence, all the different data sources are brought together in this catalogue and are the main input for the life cycle inventory assessment (LCIA) in the LCA software (SimaPro)[4].

The modelling is further done in the LCA software, which is linked to the LCA database (Ecoinvent, others), which provides the specific datasets with information on the environmental impact of each material/input. In the end LCIA results are exported to spreadsheet files for hotspot analysis.

In the following sections the methodology of the different steps in this flow are discussed.

[4] The SimaPro LCA software was selected because the project team is used to work with it. It does not imply any preference in software to be used, neither by the EC or the project team.

3.3. Data Collection & Development of Life Cycle Inventory (LCI)

A crucial part for the LCIA is the building element catalogue. This catalogue is used to structure the LCIA model in the LCA software and to determine the material, sub-element and sub-element quantities. Besides these aspects, the scenarios for the different life cycle stages are defined at this point.

3.3.1. Data Collection

The building element catalogue needs different types of information (see Figure 6). More specifically, information about the elements, sub-elements and materials regarding specifications and quantities of the different entities is needed. Besides quantities, material specific characteristics (e.g. density of the material) are needed to define the complete dataset. Entity quantities are extracted from a Building Information Model, building plans, technical information sheets and the building cost sheet.

Secondly, information is needed about the scenarios that apply during the different life cycle stages. If available, scenarios for transport and end-of-life stages are determined by the national guidelines which give more specific information complementing the respective PEFCRs or PEF guidance.

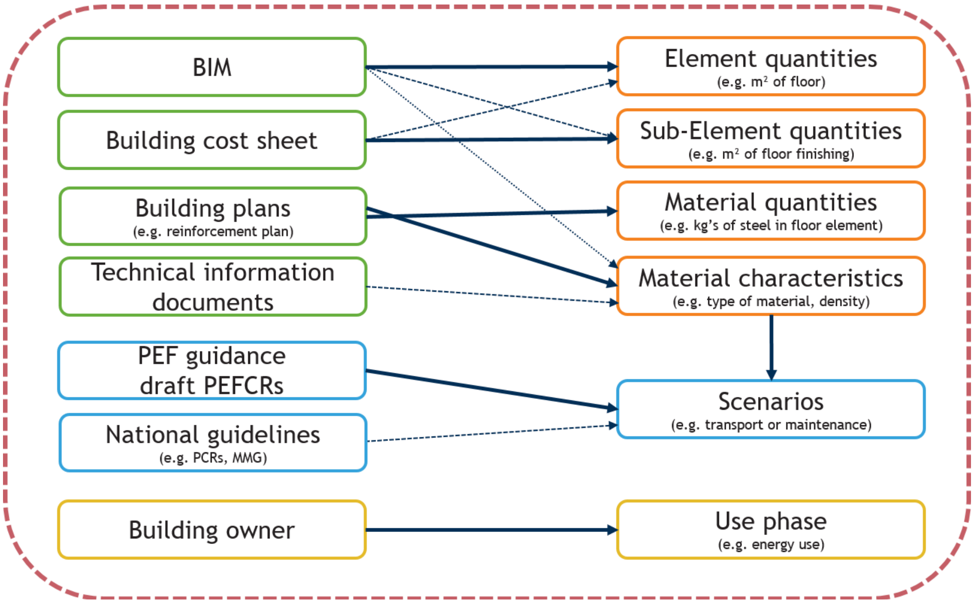


Figure 6: Data Gathering

Scenarios considering maintenance (including cleaning, small and big maintenance) and replacement are determined by national guidelines.

A third type of information is related to the use phase and consists of the energy and water use in the assessed building. In this study data on the energy and water consumption is obtained from the building owners. In case of an assessment of a new building, this data could be obtained via building simulations.

Section *4.1 Data collection for BelOrta building* and *4.2 Data collection for BE2226 building* will discuss the specific data sources for the different case studies as well as present data gaps.

3.3.2. DEVELOPMENT OF LIFE CYCLE INVENTORY

The life cycle inventory is elaborated in a spreadsheet document to obtain a structured inventory that can be used for other projects too. The spreadsheet tool can be divided into three main parts.

A first part is the input for the life cycle inventory and consists of a material database in which materials are defined with their units and PEF specific parameters (e.g. A, B, R1, R2, R3 and Q).

Secondly, some processing tabs are defined. In general, there are two types of processing tabs. First, there are element related tabs. These define the different elements with their sub-elements and the building materials therein. Moreover, in this tab maintenance processes and replacements on the level of the building sub-elements are defined. Secondly, there are scenario (e.g. transport scenario) related tabs for the different life cycle stages. These tabs often use the total material amounts extracted from the element related tabs.

Thirdly, there are output related tabs providing the information needed as an input for the LCIA in the LCA software. This output data are mainly the values of ratios, quantities and material parameters.

Further information about the life cycle inventory is given in the Annexes 1-4.

BIM models as data source

The added value of coupling Building Information Modelling (BIM) with Life Cycle Assessment (LCA) is that it reduces the time needed for the data gathering process by generating automatically many of the quantity data needed. In the sustainability evaluation of a building, BIM supports the data gathering and promises potentials for an iterative design optimization approach. However, important aspects to consider of a BIM models quality are:

- the completeness of the building model (modelled and un-modelled building elements);
- the Level of Geometry (LOG) for modelled geometries and elements, as well as;
- the Level of Information (LOI) regarding e.g. specification of material information.

All of these aspects can differ widely regarding on the modelling practice and workflow.

The partial incompleteness and inaccuracy in the model has to be considered when using it as a basis for quantities used in the LCA. The scope definition of the assessment therefore also specifies the modelled and un-modelled building elements, which are either subject to cut-off or added to the LCI manually.

Thus developing the workflow of this study, an analysis of the BIM models was conducted to specify their contents and the Level Of Development (following Swiss BIM specifications (SIA, 2016)). The overall Level Of Geometry (LOG) for both models can be described as LOG 200, with more detail and LOG 300 in primary building elements (walls, floors, roof). For this reason, quantities of primary elements are evaluated through the specific volume and area of their sub-elements (Level 2, e.g. composition layers), whereas the quantities for secondary elements (doors, windows, etc.) are assessed based on the overall size and type of the element (Level 1) and the specific material amounts calculated in the spreadsheet inventory files.

3.4. SimaPro Model

3.4.1. Introduction

The SimaPro LCA software was selected for this PEF4Buildings project and the assessment of the two office buildings because all partners within the project team were used to work with it. However it does not imply any preference in software to be used, neither by the EC nor by any of the project partners of the project team.

3.4.2. Hierarchical, tree-like structure

In a user friendly manner, the models of both BelOrta and BE2226 buildings are developed following the hierarchical approach in spreadsheet files. Models and sheets follow a tree-like structure, which extends gradually to higher levels of detail. The intention was to allow an easy adaptation of the model to other building scenarios by using a consistent structure as well as making use of parameters in SimaPro[5].

Figure 7,
Figure 8 and
Figure 9 show examples of the BelOrta model in SimaPro.

[5] The SimaPro LCA software was selected because the project team is used to work with it. It does not imply any preference in software to be used, neither by the EC or the project team.

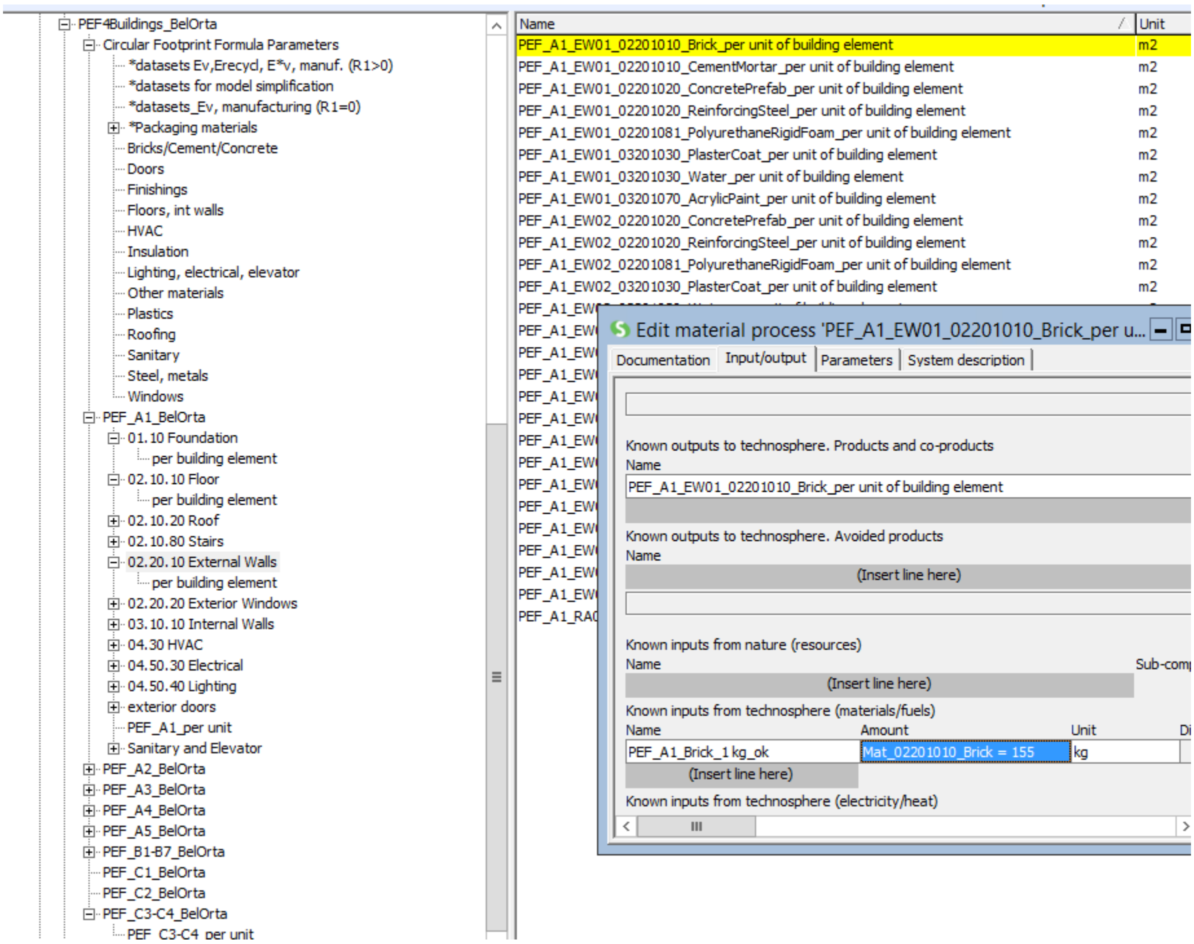


Figure 7: Tree-like structure of the BelOrta model in SimaPro

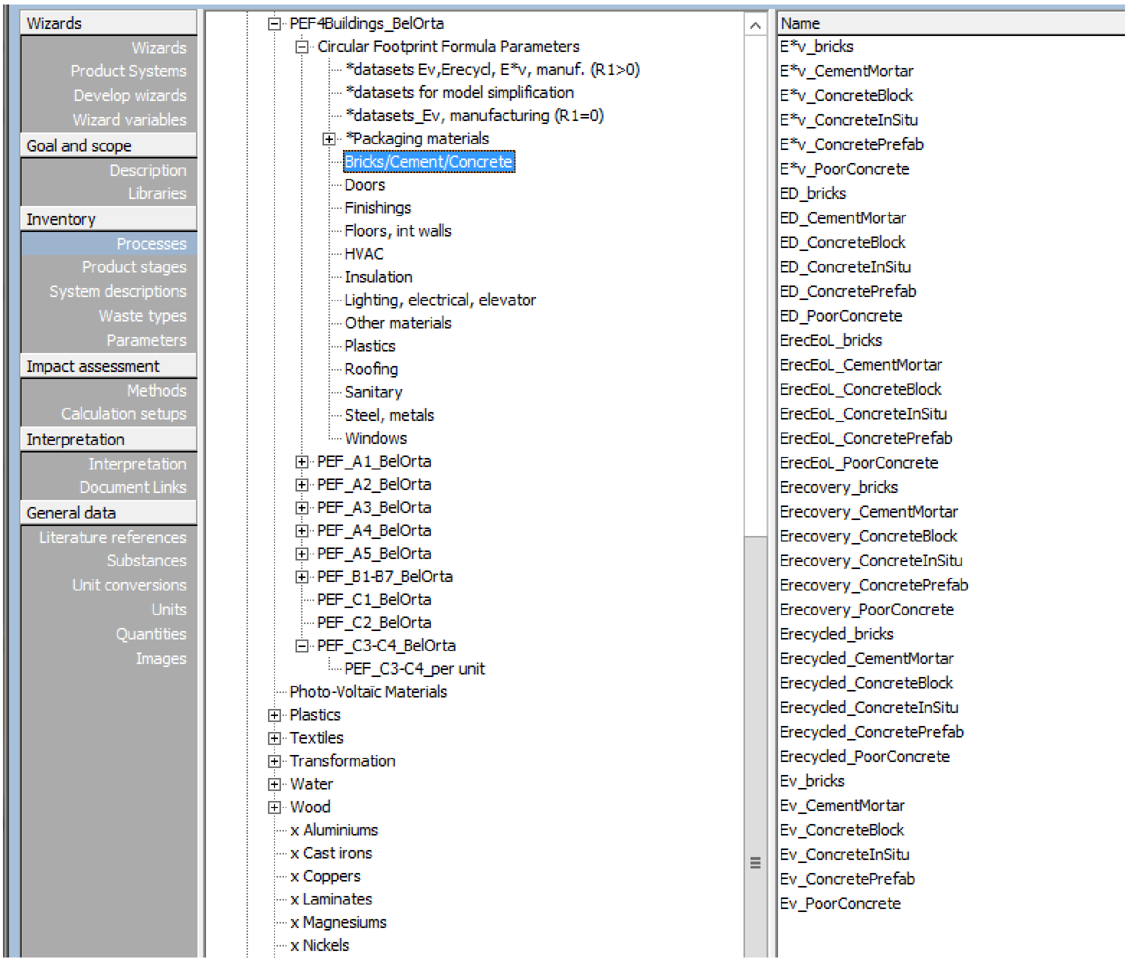


Figure 8: Mini-database with materials that allows the application of the CFF formula in a consistent manner

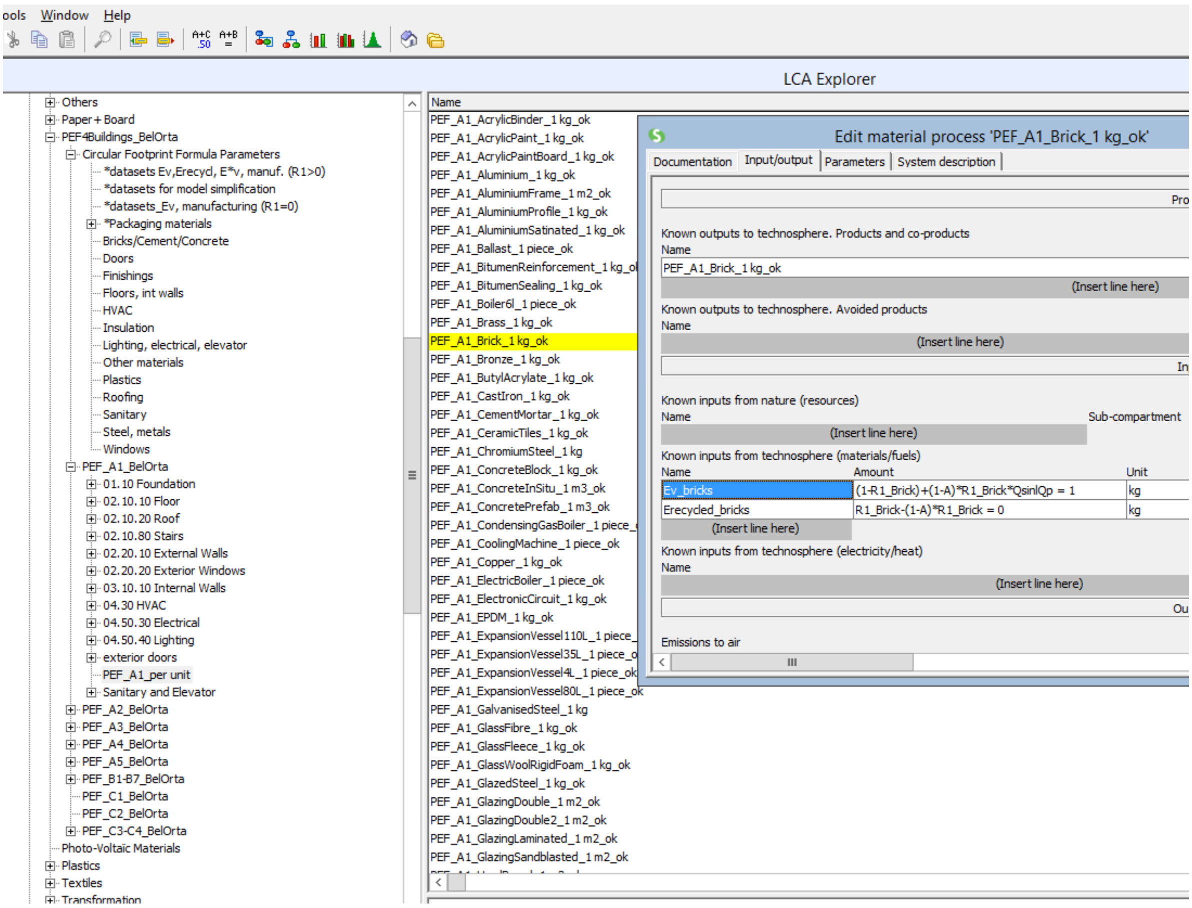


Figure 9: Application of CFF formula using parameters

The model has specific folders for each life cycle stage, but also a separate folder where a mini-database of materials used in the modelling is created. This project specific database allows a consistent approach in the application of the CFF formula throughout the model. This folder allows the user friendly modelling of the Circular Footprint parameters (Ev, E*v, Erecycled, ErecEoL, ED, ER). In this way the necessary level of detail/granularity can be handled consistently across the system.

Besides the structure per life cycle stages, we have also tried two different approaches for allowing the visibility of the element and material level. In this direction for the LCS PEF_A1 the model was developed per material used in each element and sub-element, while for the BE2226 building the level of detail for this life cycle stage was only at material per building level. This allowed us to test the flexibility of the model to different buildings, but also how the model can easier produce results at the necessary level of detail. The BelOrta model can provide directly in SimaPro information on the impact per element and per material. However, due to the high complexity of the model it would still require some processing in Excel for the extraction of meaningful information from the results.

The BE2226 model provides only information at the level of material, but it is quite easy and straight forward to couple this information with the Excel file from Annex 2 and extract the information at element and sub-element layer, if needed.

For the life cycle stages PEF_A3 and PEF_C3-C4 the model is developed per material only. The time and resources limitation for this project as well as the level of complexity of the model led to the conclusion that this approach is the most feasible one for meaningful results.

The transportation related life cycle stages were modelled in a more simplified manner, with the calculation of total amounts and distances done in Excel for the entire building (application of CFF parameters was taken into consideration accordingly).

3.4.3. DATABASES AND TYPE OF DATASETS USED FOR MODELLING

The datasets used for modelling are mainly from Ecoinvent 3.3 and ELCD databases, as the datasets purchased by the Commission with the purpose to be used for PEF studies were not available even at the date of drafting this report (second half of July 2017).

The Ecoinvent datasets for a specific material include, in general, in one dataset the raw materials extraction information, at times their transportation and also the production process. However, in order to apply the CFF formula specific datasets that define Ev and Erecycled must be defined, reason for which these original datasets are split for the purpose of this project to contain only the virgin part, or the recycled part or the production process. This approach does not assure a particularly good data quality, but it is considered sufficient as a proof of concept in the framework of this study.

3.4.4. PARAMETRISATION AND CODING CONVENTIONS

Besides the tree-like structure the model is also developed using parameters. There are over 1300 parameters in BelOrta model. Generally, the number of parameters is related to the complexity of the building, respectively the number of building elements, sub-elements and materials within the spreadsheet data collection.

Parameters were used to define the ratios at material, sub-element, element and building level (amounts) but also for the CFF parameters (A, B, R1, R2, R3), and for specific scenarios, such as distance to EoL. Figure 10 below shows examples of parameters with the allocated values.

Additional	
Parameter	Value
A2_tKm_T1Ev	6560.219192
A2_tKm_T2Ev	2007107.894
Dem1	0.0111
Dem2	0.0135
Dem3	0.0189
Dem4	0.1935
R2_EoL_LR	0.938403475
R3_EoL_LR	0.060364595
R2_EoL	0.936819071
R3_EoL	0.061917311
AM_BelOrta	7474661.715
Inc_AM	51858.52063
Land_AM	420397.5536
Rec_AM	7002405.64
Dist_Inc	100
Dist_Land	50
Dist_Rec	150
P_Inc	0.85
P_Land	0.85

Exterior windows	
Parameter Material	Value
MAT_02202010_GlazingDouble	1.0
MAT_02202020_GlazingDouble2	1.0
MAT_02202020_WindowFrAl_1	9.5
MAT_02202020_WindowPolyamide_1	0.9
MAT_02202020_WindowFrAl_2	6.6
MAT_02202020_WindowPolyamide_2	0.9
MAT_02202010_WindowFrAl_3	16.9
MAT_02202010_WindowPolyamide_3	3.2
MAT_02202010_WindowFrAl_4	14.0
MAT_02202010_WindowPolyamide_4	3.2
MAT_02205020_Aluminium	2.7
MAT_02205020_Plywood	0.0

Floor	
Parameter Element	Value
FL01_03203020_VinylTiles	1147.7
FL01_02101090_ConcreetScreed	1147.7
FL01_02101091_PUR	1147.7
FL01_02101010_ConcreteFloor	1147.7
FL02_03203020_CeramicTiles	1358.5
FL02_02101090_ConcreetScreed	1358.5
FL02_02101010_ConcretePrefabFloor	1358.5
FL03_03203020_CeramicTiles	220.3
FL03_02101090_ConcreetScreed	220.3
FL03_02101091_PUR	220.3
FL03_02101010_ConcreteFloor	220.3
FL04_03203020_FloorMat	14.8
FL04_02101090_ConcreetScreed	14.8
FL04_02101091_PUR	14.8

Figure 10: Example of parameters used in the model

The naming of the parameters, but also of the intermediary flows created for each sub-element and element follow a consistent coding convention based on the OmniClass codes. The way they have been systematically developed and used can be seen in Annex 1 and 2.

The code of building element and material are maintained in SimaPro same as in the LCI stage, in line with the hierarchical de-composition of the building. Below some examples show the correlation:

- Element_material: EW01_02201010_Brick -> Amount of element_material in the unit of element: Mat_EW01_02201010_Brick.Amount of sub-element: FL01_03203020_VinylTiles (1148 m²) ->Amount of material: MAT_03203020_VinylTiles (1 m²) -> MAT_03203020_ButylAcrylate (0,3 kg).

The use of these parameters allowed the adaptation of the model during the iterative process of this PEF assessment on building level by supporting easy changes and to push certain values to the corresponding parameters in SimaPro.

While the SimaPro parameters to include the CFF values in the assessment were very useful to the second case study, the model of BE2226 did not use parameters for the amounts of materials. Quantities have been entered to SimaPro manually to adapt the existing SimaPro model of BelOrta.

The assessment of BE2226 was based on the original information for the Life Cycle Stages PEF-A1, PEF-A2 and PEF-A3, PEF-B4 and PEF-B6 as well as for PEF-C3 and PEF-C4.The impacts of other LCS were evaluated based on the assessment of the Belgian case study BelOrta and applied to the BE2226 case study using generalized values derived from the BelOrta model.

3.5. LEARNINGS AND RECOMMENDATIONS RELATED TO DEVELOPMENT OF LCA MODEL

The learnings related to the development of the LCA model are listed below:

- Structured model needed for this type of projects;
- Intensive data gathering process for this type of buildings, a high level of detail is needed. On building level this data is not always evidently added to building specific documents. Thus a chance for errors arises (often contradictory information if there is not a proper folder with the exact building dossier. Secondly, simplifications and representative assumptions are required if detailed data is not available;
- Parametrized LCA model needed. -> link between excel and LCA could be further elaborated for future projects. (Extracting the model from spreadsheet tool or other user friendly interface);
- Possible errors because of different types of documents: double counting, data gaps;
- Complexity of the product system “building” requires sophisticated modelling with a generic inventory structure suitable to assess different buildings while providing specific and comparable results for numerous assessments;
- Coding/naming conventions to automate process in BIM and building LCA;
- Consideration required regarding limitations of specific LCA software regarding dynamic link with Excel/BIM suitable to be easily adopted for a wide variety of buildings.

The recommendations related to the development of the LCA model are listed below:

- Provision of PEF data for all relevant sub systems in the building to improve applicability in a building design context;
- BIM could provide a centralized model where all the needed data is gathered and thus support LCA purposes by including LCA data in BIM;
- Important aspects to consider regarding the suitability and workflow of using BIM models:
    - Completeness and accuracy of the model – Level of Development;
    - Level of Geometry (LOG) of building elements, as well as;
    - Level of Information (LOI) for element and material specifications;
- Standardisation of building element structure as well as building element classifications on European level, suitable for application in BIM models and LCA;
- Development of BIM-ready datasets, e.g. environmental data aggregated on different levels depending on the planning stage the assessment should be carried out in. E.g. data of building elements in early design stages, detailed data on level of sub-elements and material composition for design development, tender stage and beyond;
- Based on the findings of this study, a more flexible parameter structure for the amounts of elements and materials has to be found to further support a parametric approach applicable to other buildings while acknowledging the constraints in BIM and LCA software’s functionality.

CHAPTER 4 ACTIVITY 1.3: LIFE CYCLE INVENTORY

This chapter introduces the two case studies and describes the data collection and life cycle inventory for both case studies. A two-step procedure was hence followed for activity 1.3. In a first step, the bill of materials (activity data) in relation to the defined reference flow has been compiled for the two case studies, in line with the previously described hierarchical element method (see Activity 1.2). This is described in section 4.1 and 4.2. This is followed by the life cycle inventory for the various life cycle stages. This is discussed in detail in section 3.3. The learnings related to the life cycle inventory are finally summarised in section 0.

4.1. DATA COLLECTION FOR BELORTA BUILDING

4.1.1. DESCRIPTION BELORTA BUILDING

The BelOrta building is an office building situated in a suburban region in Flanders (Belgium) designed by the architectural office ar-te and finished in 2014. The building is an extension to an existing building of the BelOrta company. The BelOrta building represents a business as usual office. The building has a net floor surface of 3000 m². The two-story building has an inner patio around which the office and meeting rooms are organized. The building is modelled according to the scope and system boundaries of this project defined in section 2.1 and 2.2. A detailed description of the different elements can be fined in Annex 3.

Figure 11: BelOrta Building (Architectenvenootschap ar-te bcvba, 2015a)

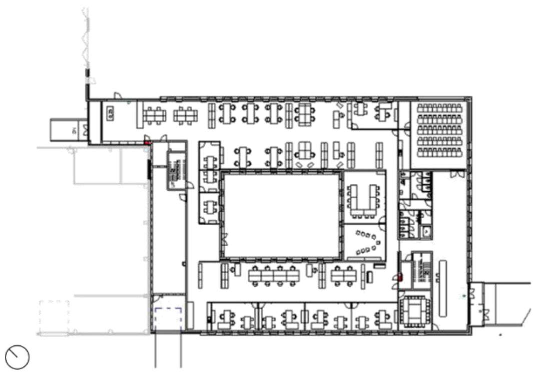


Figure 12: Groundfloor BelOrta Building (Architectenvenootschap ar-te bcvba, 2015b)

4.1.2. DATA SOURCES

Building elements

As discussed in section 3.3.1 various necessary data sources were available for the data collection. A first source for the BelOrta building was the **BIM model** made available by the architectural office ar-te. From this BIM model mainly element quantities (e.g. m² of a certain floor type) were extracted. This BIM model furthermore provided information about the quantities of sub-elements (e.g. m² of floor finishing layer in certain floor type). Nonetheless, the BIM model included limited information regarding the material quantity used in a certain sub-element and regarding the characteristics of a material used. For example, a sub-element was defined to be an insulation layer but the insulation material (e.g. stone wool, XPS …) was not defined, neither was the lambda value of the materials available. Moreover, some adaptations to the model were necessary to extract the sub-element quantities as some layers were defined in a generic way for the whole building. An example of these adaptations is the subdivision of the defined concrete layer for the building in a concrete layer for floors and one for external walls. In this way, it was possible to extract the amount (m²) of concrete layer used in external walls (with a certain thickness) and the amount (m²) used in floors (with a different thickness). In addition, there were also some elements and sub-elements not modelled in the BIM model. Examples of these gaps are the inner finishing layer of walls, HVAC systems, electrical services etc.

To fill these data gaps building plans, technical information sheets and the building cost sheet were consulted. An important source of information were the **technical information sheets** which included information about the material characteristics as well as about their quantities in a sub-element. With these two sources, still some data gaps and uncertainties remained regarding the element quantities for which the **building cost sheet** could give more information. Finally, the **building plans** were checked for any remaining data lacking about the sub-element and material quantities (e.g. the amount of steel used in the foundations).

It should be noted that even with this extensive list of information some elements were still modelled in a simplified way. For example the HVAC systems were modelled as an amount of the main material(s) of the various components in the system because there was not enough information available about the exact material composition of each component. A similar simplification was done for other elements where detailed information about their composition was lacking (see Annex 3 for a detailed overview).

A detailed representation of the information extraction from the various sources is given in Annex 3.

Building scenarios

To define the different <u>transport</u> scenarios information about the **material/element characteristics** (type of material, place of production) is needed. This information is combined with the different **guidelines** (BE PCR, PEFCRs, PEF guidelines) to choose the correct scenario for each materials/ building element and for each life cycle stages. More information about the chosen scenarios can be found in section *3.3.2 LCI for LCS PEF_A2. Transport of the raw materials to production site* and section *3.3.4 LCI for LCS PEF_A4 Transport to building site*.

For cleaning, maintenance and replacement scenarios only very limited information was available from the building owner. Therefore, the scenarios as well as the cleaning and maintenance processes were defined based on national **guidelines** (mainly **MMG**) and experience from the project team. More information about the scenarios chosen for the different building elements can be found in Annex 3.

Similar as for the transport scenarios, scenarios for end-of-life were defined based on the material and the different **guidelines**. More information can be found in section *3.3.13 LCI for LCS PEF_C2. Transport to EoL*.

Use phase

As the building is already in use, information about energy and water use was provided by the **building owner (who is also the building user)**. As the building is an extension to an existing building and there is only one energy bill, the energy and water use was only available for the whole building (existing and new extension). As only a PEF study is made of the extension, data were however needed for this part solely. The yearly operational energy and water use for the extension has therefore been calculated as the difference between the average consumption of the two years since the completion of the extension and the average consumption of the three years before the extension was in use.

4.1.3. MISSING BUILDING ELEMENTS

Although a lot of information was available for the BelOrta building in a detailed way, we were still lacking some minor elements. Firstly, data were lacking for some building elements (e.g. internal shading system, sectional door). These elements have been left out of the modelling as these are very limited compared to the full bill of materials of the building and any estimation would have increased the uncertainty of the model. These are reported as data gaps.

Furthermore, some elements were outside of the system boundaries and thus not modelled (e.g. site works, furniture, kitchen).

The complete list of elements can be found in Annex 3.

4.2. DATA COLLECTION FOR BE2226 BUILDING

The intention of assessing a second case study in the framework of this study was to provide more insight regarding the applicability of the developed assessment workflow on different buildings as well as to feed the discussion regarding benchmarks on building level. To fulfil this purpose, the framework conditions and scenarios are kept the same and only the building type and quantities are adapted to the second case study both in the spreadsheet and in SimaPro. More detailed information on the BE2226 case study can be found in Annex 2 and 4.

4.2.1. DESCRIPTION OF BE2226 BUILDING

The BE2226 building is an office building situated in a suburban context in Lustenau (Austria). The six story building finished construction in 2013 and has a net floor area of around 2700 m². It was designed by architects Baumschlager & Eberle who are also the main user of the building, with their offices taking half the floors in the building. The building was specifically designed to operate with an advanced building concept that does not require active heating or cooling systems. Instead, indoor air quality and occupancy are constantly measured to automatically open and close ventilation panels next to the fixed glazing windows. This concept is supported by very thick brick walls and their high thermal mass as well as good thermal performance of around 8 W/m² required for heating the building in winter times. This amount is covered by waste heat from users and technical appliances (including lighting).

In the framework of this study, the building represents an advanced building concept based on monolithic structures, high thermal mass and passive air-conditioning strategies. For this second case study, the bill of materials and BIM model were available and followed a hierarchical subdivision similar to the one applied in this study. Only small adaptations were thus necessary to be in line with the method proposed.

Figure 13: BE2226 building (Source: www.baumschlager-eberle.com/projekte/ projektdetails/project/buerogebaeude.html)

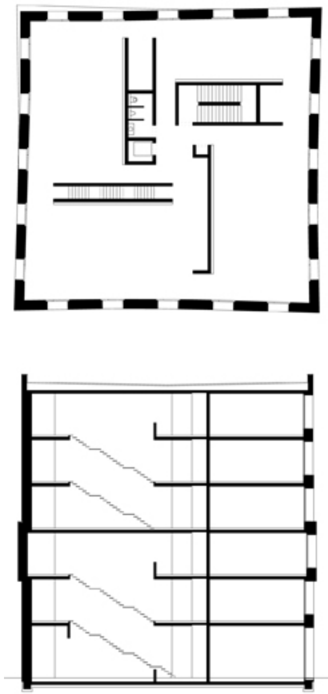


Figure 14: Floorplan and section of BE2226 (Source: architects Baumschlager-Eberle)

4.2.2. DATA SOURCES

Building elements

Information on the building elements in BE2226 as well as their quantities were derived **primarily from the BIM model**, which was created based on the **architects building documentation (**building plans, sections, technical information sheets, etc.) prior to this study. For detailed quantity take-off detail drawings from the architect were used to refine the BIM model's geometry. Material specifications were refined based on detailed composition information on building elements and sub-elements. A detailed **element composition catalogue** issued by the project's building physicists was used for that matter. **Product-specific information** was used wherever available, e.g. to specify the properties of the bricks used in both the external and internal walls of the BE2226 building.

Building scenarios

To support comparability of the two case studies for benchmarking and limit the differences in framework conditions for comparability the BE2226 scenarios are based on the assessment of BelOrta.

Thus, following the Austrian PCR and the BelOrta case study, transport scenarios are based on the material characteristics (type of material, place of production) as derived from the **PEF guidelines** and the Belgian **PEFCRs**.

The cleaning, maintenance and replacement scenarios used for the assessment of BE2226 remained consistent with the ones specified based on the Belgian **MMG** approach for the first case study.

The end-of-life scenarios were based on the available relevant PEFCRs and the PEF Guidance document.

The assessment of BE2226 is based on original information and quantities for Life Cycle Stages PEF-A1, PEF-A2, PEF-A3 and PEF-A4, PEF-B4, PEF-B6 and PEF-B7 as well as for PEF-C3 and PEF-C4.The impacts of other LCS, namely PEF-A5, PEF-B2, PEF-B3 as well as PEF-C1 and PEF-C2, were evaluated based on the assessment of the first case study and included in the BE2226 assessment using fractions derived from the BelOrta SimaPro model.

The ratio defined to evaluate these stages is based on the net floor area (NFA) of the two buildings. The ratio of 3000m² NFA (BelOrta) to 2400m² (BE2226) thus resulted in a ratio of 80% being applied to the LCS mentioned.

This was chosen as a feasible and valid approach as it affects a limited number of LCS which usually show no big relevance on the overall results of the building, an experience that is confirmed by the results of the BelOrta case study. Nonetheless, this opens the discussion on benchmarking to compare results and the relevance of defining appropriate functional units for this matter – a discussion which will be further elaborated on later in the project.

Use phase

The assessment of the use phase was based on the building's **operational energy and water consumption** provided by the **building owner**. Based on **measurements from the first three years** of operation (2014-2016) an average annual energy consumption was calculated. As the building has no active heating or cooling system all of this is electric energy consumption. Electricity is used to power e.g. lights, computers, the automated ventilation panels as well as all other technical appliances. Data on the operational water consumption was also provided by the building owner with a value of 80 m³ per year.

4.2.3. MISSING BUILDING ELEMENTS

The BE2226 building consists of a minimum of constructive elements due to thoughtful simplifications in composition, construction and detailing by the architects. Its BIM model could hence provide reasonably complete quantities of the buildings elements. However, some elements were not well documented and were not modelled in detail in BIM (e.g. raised floor system, lighting fixtures, building automation systems, etc.). These elements were hence either subject to data gaps or simplifications in the presented assessment.

Furthermore, some elements were outside of the system boundaries and thus not modelled (e.g. site works, furniture, kitchen …).

The complete list of elements can be found in Annex 4 – Detailed Data Collection BE2226 Building.

4.3. LIFE CYCLE INVENTORY PER LIFE CYCLE STAGES FOR BOTH CASES

During the life cycle inventory the data collected for each building for all hierarchical levels was linked to the life cycle stages. Inventory data was gathered for each construction product and process identified within the system boundaries. The following sections explain the specific approach for each life cycle stage. More in-depth details on scenarios and datasets can be found in the annexes whenever the case.

4.3.1. LCI FOR LCS PEF_A1. PRE-PROCESSING AND ACQUISITION OF CONSTRUCTION PRODUCTS AND OTHER MATERIALS

This life cycle stage includes the acquisition and pre-processing of all raw materials for construction products and all other materials used in the functional unit throughout the reference service period.

The “PEF_A1” worksheets of Annex 1 and Annex 2 list all building elements and layers included in the model. Additional worksheets provide the specific details regarding the type of materials (construction products and other materials) and amounts included in each layer, as shown in Figure 15 below. This life cycle stage should include also the packaging of the raw materials, but in the context of this project we did not have access to this information. Such information is included to a certain extent in the datasets used for modelling, but in an un-systematic manner. **Packaging of raw materials is therefore a data gap.**

Level 1: Building element				Level 2: Building sub-element			Level 3: Building material		
Building Element	Quantity element	Quantity sub-element	Unit	Building sub-element	Unit	Ratio sub-element / building element	Material	Material unit	Ratio material/sub element
Concrete floor on earth	**1148**		m^2						
		1148	m^2	Vinyl Tiles	m^2	1			
							Vinyl Tiles	*m^2*	*1.0*
							Butyl Acrylate	*kg*	*0.3*
		1148	m^2	Concrete Screed	m^2	1			
							Concrete In Situ	*m^3*	*0.1*
		1148	m^2	PUR	m^2	1			
							Polyurethane Flexible Foam	*kg*	*3.0*
		1148	m^2	Concrete Floor	m^2	1			
							Reinforcing Steel	*kg*	*22.2*
							Concrete In Situ	*m^3*	*0.3*

Figure 15: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_A1 life cycle stage - building elements, with layers and materials with corresponding ratios

Specific information on CFF parameters (A, B, R1, R2, R3, etc.) and conversion factors is provided in an additional worksheet, as well as details on the datasets used for modelling.

There were overall 96 different materials used throughout various life cycle stages[6].

With respect to the datasets used for modelling several aspects are relevant, as follows:

- The information on raw materials (i.e. sand, clay) for the necessary construction products and other products used in the building is not directly available in the information sheet of the product, but it is included in the generic datasets available in Ecoinvent for the respective construction products, such as bricks, concrete, and so on. **While at product level a PEF profile would be based on specific amounts of raw materials as activity data, in the case of the PEF profile of a building the specific amounts (activity data) could only be collected as of the level of construction products. Discussion has to take place on the requirements for primary data at building level with corresponding implications in terms of availability of datasets and the way they should be developed (see further below)**;

- The approach described in section 3.4 regarding the **definition of Ev and Erecycled** applied, **which means that the Ecoinvent datasets were split to create new datasets in which only the inputs and outputs related to the virgin/recycled content are included**. Also the inputs/outputs related to the manufacturing process of the materials (such as brick) constitutes another dataset which is used in PEF_A3. After the necessary split of the Ecoinvent unit processes (disaggregated datasets) the newly resulted datasets were aggregated to avoid unnecessary complexity of the model and to allow a meaningful extraction of results in a useful manner for the future users (an architect, as potential user,

[6] The materials used for the use phase (cleaning products and such) are included in this list of materials in PEF_A1. Also many of these materials are used in other life cycle stages such as Replacement.

would not need information on the impact of the clay used in the bricks of the building, but eventually on the impacts of the bricks themselves);
This split is an artificial process, which may not be fully accurate when looking at each input one by one, as for each material specific inside knowledge on the technology behind would be necessary besides the logic of developing a dataset. However, at the moment it is the best approach identified to allow the application of the CFF formula in the context of this project;

- **All the datasets used represent generic, secondary datasets. However ideally for a PEF profile of a specific building, primary datasets should be used**, such as "raw materials for Wienerberger bricks produced in Belgium" or "raw materials for wooden window frames produced in Austria", as each producer might well have different technologies, therefore inputs and outputs that will result in different impacts;
- In this direction, while the discussion on primary vs. secondary datasets for PEF at building level still has to take place with the stakeholders, taking into account our previous experience with PEF and LCA in general we suggest the development of a database with multiple construction products developed in a flexible way to allow a meaningful use of the information. As an example a producer could provide a disaggregated dataset for its construction product that would distinguish between the raw materials part (specific inputs and packaging, with differentiated virgin input and recycled content that would allow the application of the CFF formula), with similar information on the transportation of the raw materials and clear information with respect to the specific production process (with the necessary packaging as well).
- Besides this, for some of the raw materials in the construction products (such as sand, clay…), transportation of the raw materials is often included in the generic datasets of Ecoinvent. **For the construction products where transport of raw materials is included in the dataset of the construction product our PEF4Building model currently double counts the transport of the raw materials as this is separately modelled in our model (see subsequent section).** As the purpose of this project was not to obtain highly accurate results but mainly to highlight the applicability of the PEF method at building level and highlight difficulties encountered, we considered that it was not an added value at this moment to try to tackle this double counting. Especially, because it would be a very time consuming process to avoid this double counting, we decided not to remodel all the datasets. Nevertheless, it is important to highlight this modelling issue.

The availability of appropriate datasets for all necessary materials that allow the consistent application of the CFF formula would improve significantly the end result for this life cycle stage. It would also ensure that no double counting of transportation of the raw materials used for the production of the construction products occurs.

4.3.2. LCI FOR LCS PEF_A2. TRANSPORT OF THE RAW (ENGINEERING) MATERIALS TO THE PRODUCTION SITE

The development of scenarios for the transportation of raw materials covered the type of truck to be used, the distance for transportation, payload and empty return. These scenarios were based on the following sources (as it can be visualized in Figure 16):

- Existing PEFCRs - for a very limited number of materials;
- PEF Guidance 6.1 - mainly the payload and empty return;
- Default scenario, assumed by project experts based on previous experience - for all other materials for which no specific scenario was available in the PEFCRs. This scenario is a simplified approach using the transport type truck 16-31 t (Euro 5), with a distance of 550

km[7]. While this distance is considered reasonable for Belgian and Austrian context, it can still be insufficiently accurate for some materials, which can lead to overestimations for some materials (such as concrete, for which raw materials are generally transported from lower distances) or underestimations (for metals possibly). Also **these scenarios do not include other means of transportation, such as ships, which would well be the case for some raw materials as concentrates for metals**.

				Truck						tkm				
Material	Quantity (Unit)	Unit	Ratio (kg/unit material)	Lorry >32t (EURO5)	Lorry 16-32t (EURO5)	Lorry 7.5-16t (EURO5)	Lorry 3.5-7.5t (EURO5)	Distance (km)	Payload* Empty return	Lorry >32t (EURO5)	Lorry 16-32t (EURO5)	Lorry 7.5-16t (EURO5)	Lorry 3.5-7.5t (EURO5)	Total
Reinforcing Steel	153805	kg	1	0%	100%	0%	0%	550	0.5	0	42296	0	0	42296
Concrete In Situ	1878	m³	2400	0%	100%	0%	0%	550	0.5	0	1239695	0	0	1239695
Butyl Acrylate	414	kg	1	0%	100%	0%	0%	550	0.5	0	114	0	0	114
Vinyl Tiles	1148	m²	2.8	0%	100%	0%	0%	550	0.5	0	884	0	0	884
Polyurethane Flexible Foam	4363	kg	1	100%	0%	0%	0%	500	0.255	556	0	0	0	556

Default scenario
PEFCR Insulation
PEF guidance v6.1

Figure 16: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_A2 life cycle stage- transport means, distance, payload, empty return

The types of trucks used throughout this project for the various transportation life cycle stages are:

- Lorry, >32 t (Euro 5), modelled using the Ecoinvent 3.3 dataset "Transport, freight, lorry >32 metric ton, EURO5 {RER}| transport, freight, lorry >32 metric ton, EURO5 | Alloc Rec, S"
- Lorry, 16-32 t (Euro 5), modelled using the Ecoinvent 3.3 dataset "Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Alloc Rec, S"
- Lorry, 7,5 - 16 t (Euro 5)), modelled using the Ecoinvent 3.3 dataset "Transport, freight, lorry 7.5-16 metric ton, EURO5 {RER}| transport, freight, lorry 7.5-16 metric ton, EURO5 | Alloc Rec, S"
- Lorry, 3,5 – 7,5 t (Euro 5)), modelled using the Ecoinvent 3.3 dataset "Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Alloc Rec, S"

[7] The scenario for all other products from supplier to factory from PEF Guidance 6.1 (section 7.12.2) was considered, but analysing Belgian context and specific scenarios for similar products in the PEFCRs the project team considered the distance of 550 km a more appropriate assumption. Once primary data will be available this assumption can be corrected. For the purpose of this project it allows us to determine the implementability of the PEF method. Specific scenarios should be developed for PEFCR at building level.

As mentioned in the section above, and additional double counting takes place at times related to the way the datasets for various construction products have been developed in Ecoinvent (see 3.4.2).

It would be therefore recommended to have specific scenarios developed (distances and means of transportation) at least per categories of materials, for an improved accuracy of the result.

4.3.3. LCI FOR LCS PEF_A3. MANUFACTURING OF THE CONSTRUCTION PRODUCTS

The manufacturing process for each construction product was modelled using either the existing datasets for the specific products from Ecoinvent (by splitting the datasets to distinguish the specific inputs for manufacturing part only) or generic production processes such as extrusion processes and average metal working. Details on the used datasets are provided in Annex 1 and Annex 2, and the way they were split can be seen in the model directly.

The inputs and outputs considered for the manufacturing were mainly related to most commonly used ancillary materials, energy inputs, sometimes water flows, emissions, waste flows and packaging materials whenever available. **While this is in line with the logic of developing such a dataset, considering that these datasets were split artificially from the material input (virgin and recycled content) it is likely that they are not perfectly in line with the actual technological process for the respective materials.** This is currently a limitation related to the available datasets and the necessity to apply the CFF formula. This approach was agreed upon with the commissioner and for the purpose of this project is considered to cover these practical needs. **In terms of quality it is expected that in the future appropriate datasets will be developed to allow the modelling of PEF profiles of various materials.**

For the model, all available datasets were used in an aggregated form to allow an appropriate level of analysis of the results. This approach is valid for both the Belgian and Austrian building.

The topic on primary vs. secondary datasets already presented above remains valid here, as part of defining the processes in situation 1, 2 or 3 for each material.

4.3.4. LCI FOR LCS PEF_A4. TRANSPORT TO BUILDING SITE

The development of scenarios for the transportation of raw materials were based on the following sources (as it can be visualized in Figure 17:

- Existing PEFCRs - for a very limited number of materials, when a PEFCR was available and the product was produced in a foreign country;
- PEF Guidance 6.1 - also very few of the assumptions;
- BE-PCR v4.1 – section 7.3.2.1 and TABLE 5 – *Default transport scenarios (module A4)* specific to Belgian context for both case studies (as opposed to the default scenario in the PEF Guidance which is at European level instead).

The specific means of transportation used, distance, payload and empty return can be found for each and every construction material in Annex 1 for the Belgian building and respectively Annex 2 for the Austrian building.

Generally, the scenarios from these sources are sufficient for the modelling of a PEF profile for this life cycle stage. In the future country specific scenarios will be needed and one general scenario in a PEFCR for buildings would be applicable over Europe.

Material	Quantity [Unit]	Unit	Ratio [kg/unit of material]	Truck				Distance [km]		tkm			
				Lorry >32t (EURO5)	Lorry 16-32t (EURO5)	Lorry 7.5-16t (EURO5)	Lorry 3.5-7.5t (EURO5)	Factory -> Constructi on site	Payload* Empty return	Lorry >32t (EURO5)	Lorry 16-32t (EURO5)	Lorry 7.5-16t (EURO5)	Lorry 3.5-7.5t (EURO5)
Reinforcing Steel	153805	kg	1	0%	100%	0%	0%	100	0.64	0	9844	0	0
Concrete In Situ	1878	m³	2400	0%	100%	0%	0%	100	0.5	0	225399	0	0
Butyl Acrylate	414	kg	1	0%	0%	100%	0%	100	0.64	0	0	27	0
Vinyl Tiles	1148	m²	2.8	0%	90%	10%	0%	100	0.64	0	185	21	0
Polyurethane Flexible Foam	4363	kg	1	0%	100%	0%	0%	100	0.255	0	111	0	0

BE PCR v4.1
PEFCR Insulation
PEF guidance v6.1

Figure 17: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_A4 life cycle stage

4.3.5. LCI FOR LCS PEF_A5. CONSTRUCTION - PROCESSES NECESSARY FOR THE CONSTRUCTION OF THE BUILDING, INCLUDING ALL ANCILLARY MATERIALS, EOL OF THE PACKAGING MATERIAL DISPOSED, ANY LOSSES DURING CONSTRUCTION)

Regarding the construction process the information available was very scarce, which is the reason for the data gap related to the necessary inputs and outputs, especially, such as energy use, ancillary materials, equipment, specific emissions during the construction process.

The waste flows related to the material losses were though modelled. The loss rate for each material was determined based on information from the PEFCRs and the Belgian MMG, as it can be seen in the Figure 18.

Thus the corresponding amounts of each construction material used in the building was modelled, with the allocation of the impacts for the entire life cycle up to disposal (PEF_A1, A2, A3, A4, C2, C3/4) included for these disposed materials, in line with the modularity principle.

Material	Loss rate
Reinforcing Steel	5%
Concrete In Situ	5%
Butyl Acrylate	5%
Vinyl Tiles	5%
Polyurethane Flexible Foam	2%

PEFCR Insulation

Belgian MMG

Figure 18: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_A5 life cycle stage – loss rate for each construction material

4.3.6. LCI FOR LCS PEF_B1. USE STAGE

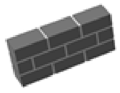
No specific inputs were considered for this life cycle stage as no specific information on release of substances from façade, roof, floor covering and other surfaces (interior and exterior) were available.

4.3.7. LCI FOR LCS PEF_B2. MAINTENANCE

The scenarios for the maintenance life cycle stage was developed for the Belgian building based on the MMG scenarios. Similar approach was taken also for the Austrian building, as no other specific data was available.

Thus cleaning and small maintenance were considered for various building sub-elements, on yearly basis and for the entire life span of the building, as it can be seen in Figure 19. The modelling of this life cycle stage includes the modelling of the original materials used (See PEF_A1) and the transportation during the product and construction process stage (see PEF_A2 and PEF_A4). The disposal (see PEF_C3-C4) is only taken into account for the small maintenance scenarios but not for the cleaning scenarios. The modelling does not include the manufacturing (see PEF_A3), installation (see PEF_A5), dismantling (see PEF_C1) or transportation to EoL (see PEF_C2) due to time constraints. The impact of this omitted steps however, is considered marginal at the scale of the entire building. Specific details regarding the amounts used can be found in Annex 1 and Annex 2.

Scenarios during Use Stage: B2-B3-B4 Maintenance – Repair – Replacement



Building - sub-elements

Level 1: Building element				Level 2: Building sub-element			Yearly Cleaning	SM	BM	Replacement			
Building Element	Quantity Element	Quantity Sub-element	Building element - unit	Building Sub-element	Unit	Ratio sub/building element		*Process*	*Process*	*Replacement ?*	*Frequency*	*Black-out period*	*Number of Replacement*
Concrete floor on earth	1148		m²										
		1148	m²	Vinyl Tiles	m²	1	Cleaning Water & Soap	No SM	No BM	Yes	15	8	2
		1148	m²	Concrete Screed	m²	1	No Cleaning	No SM	No BM	No			0
		1148	m²	PUR	m²	1	No Cleaning	No SM	No BM	No			0
		1148	m²	Concrete Floor	m²	1	No Cleaning	No SM	No BM	No			0

SM – small maintenance
BM – big maintenance

Belgian MMG

Figure 19: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_B2 life cycle stage

The following operations, presented in Table 3 have been considered for the cleaning and small maintenance operations.

Table 3: Operations included in the cleaning and small maintenance

Cleaning processes	**Unit at building element level**	**Description and materials used for the respective process**	**Unit**
Cleaning Vacuuming Water & Soap	m²	Cleaning of internal finishing with water and soap	
		Water	kg
		All Purpose Cleaner	kg
		Vacuuming	kWh
Cleaning Water & Soap	m²	Cleaning of internal finishing with water and soap	
		Water	kg
		All Purpose Cleaner	kg
Cleaning Roof	m²	Cleaning of roof finishing with high-pressure water jet	
		High Pressure Cleaning	hour
Cleaning Stairs	step	Cleaning concrete staircases with water and soap	

		Water	kg
		All Purpose Cleaner	kg
Cleaning Windows & Doors	m²	Cleaning windows and doors with water and soap	
		Water	kg
		All Purpose Cleaner	kg
Cleaning Vacuum	m²		
		Vacuuming	kWh
Cleaning Concrete	m²		
		Water	kg
		All Purpose Cleaner	kg
Small maintenance			
Internal Finishing Plaster	m²	maintenance of plaster finishing layer	
		Plaster Coat	kg
		Water	kg
External Finishing Water	m²	maintenance of plaster finishing layer	
		High Pressure Cleaning	hour
Floor Carpet	m²	maintenance of carpet floor cover	
		Cleaning Shampoo	m²
		Butyl Acrylate	kg

Specific scenarios for the materials used for the maintenance (soap, vacuum cleaning, etc.) were developed either using existing Ecoinvent datasets or as proxy such as electricity used for the respective maintenance operation. Below Table 4 shows the scenarios used for modelling the processes used in this life cycle stage. **As it can be seen these scenarios can be further improved with more specific data. It is therefore recommended to develop such data for PEF related purposes.**

Table 4: Modelling of materials used for PEF_B2 Maintenance life cycle stage

Material	Dataset used	Unit	Details
Water (for high pressure cleaning)	Tap water {Europe without Switzerland}| market for | Alloc Rec, S	hr	based on source https://www.kaercher.com/int/professional/high-pressure-cleaners/cold-water-high-pressure-cleaners/middle-class/hd-9-19-mx-plus-15249220.html
All Purpose Cleaner	Soap {RER}| production | Alloc Rec, S	kg	1 kg for 2000 m^2; Proxy as no other dataset is available in Ecoinvent
Vacuuming	Electricity, low voltage {BE}| market for | Alloc Rec, S (0,01 kwh/m2)	kWh	0,01 kWh/m2
High Pressure Cleaning			
Cleaning Shampoo	Soap {RER}| production | Alloc Rec, S	kg	1 kg for 2000 m^2; Proxy as no other dataset is available in Ecoinvent
Ammonia Cleaning Agent	Ammonia, liquid {RoW}| market for | Alloc Rec, S	kg	

4.3.8. LCI FOR LCS PEF_B3. REPAIR

Similarly with the life cycle stage PEF_B2, the life cycle stage PEF_B3 is developed at building sub-element level and it includes the following operations, as listed in Table 5.

Table 5: Operations included in the big maintenance (repair)

Big maintenance/ Repair	Unit at building element level	Description and materials used for the respective process	Unit
Internal Finishing Paint	m²	maintenance of paint of finishing layer	
		Water	kg
		Ammonia Cleaning Agent	kg
		Acrylic Paint	kg
Internal Finishing Paint Board	m²	maintenance of paint of finishing layer	
		Water	kg
		Ammonia Cleaning Agent	kg
		Acrylic Paint Board	kg
Brickwall	m²	maintenance of brickwall, cleaning and refilling joints	
		High Pressure Cleaning	hr
		Cement Mortar	kg
Carpet	m²	maintenance of carpet flooring	
		Polyamide Tufted	kg
		Acrylic Binder	kg
Ceramic Tiles		Big maintenance - floor finishing - glued ceramic tiles	
		Cement Mortar	kg
EPDM Roof	m²	big maintenance of EPDM roof covering for flat roof	
		EPDM	kg
		Butyl Acrylate	kg
Plaster	m²	big maintenance of internal plaster finishing layer walls	
		Plaster Coat	kg
		Water	kg
		Water	kg
Full System wall Board	m²	big maintenance of full system wall board part 5% replacement	
		Chromium Steel	kg
		Plaster Boards	kg
Glazed System wall Frame	m²	big maintenance of glazed system wall Frame 5% replacement	
		Aluminium Frame	m²
Glazed System wall Glass	m²	big maintenance of glazed system wall Glazing part 5% replacement	
		Glazing Laminated	m²

As it can be seen these operations consider both cleaning materials but also partial replacement as repairs. These have been modelled as the original materials (see PEF_A1), and taking into account all impacts for their transportation during the product and construction process stage (see PEF_A2 and PEF_A4) and disposal (PEF_C3-C4). The model however does not include the transportation steps (C2), the dismantling (C1) and the installation (A5) of these repairs due to time constraints. The impact of this omitted steps however, is considered marginal at the scale of the entire building. Specific details regarding the amounts used can be found in Annex 1 and Annex 2.

Similarly, as for PEF_B2 life cycle stage, these scenarios can be further improved with more specific data. It is therefore recommended to develop such data for PEF related purposes.

4.3.9. LCI FOR LCS PEF_B4. REPLACEMENT

Some building elements such as vinyl tiles, ceramic tiles, floor mats, EPDM roofing, windows, have been replace once of more times during the life span of the building of 50 years. In the life cycle stage PEF_B4 the impacts for the raw materials, transportation, manufacturing production to installation, installation and the transportation of the disposed materials together with their disposal should be considered.

In Annex 1 and 2 the specific details on which building elements have been replaced can be found in the worksheets related to PEF_A1. The model however does not include the dismantling (C1) and the installation (A5) of these replaced elements due to time constraints. The impact of this omitted steps however, is considered marginal at the scale of the entire building. An under estimation of the impacts for this life cycle stage has to be noted though.

4.3.10. LCI FOR LCS PEF_B5. REFURBISHMENT

No specific inputs were considered for this life cycle stage as no new building components are included/planned for the buildings modelled in this project.

4.3.11. LCI FOR LCS PEF_B6 AND PEF_B7. OPERATIONAL ENERGY USE AND OPERATIONAL WATER USE

For the PEF_B6 Operational energy use and PEF_B7 Operational water use, for both case studies, primary data on operational energy and water consumption was gathered from the building owner/user. The gathered information includes the electricity – at the grid but also the on-site photovoltaic production, gas, gasoil (as part of the older heating system of the old part of the building) and water. The datasets modelled are shown in Table 6 below and the corresponding amounts for the two buildings are provided in Annex 1 and Annex 2.

A yearly average was calculated based on the available measurements for the specific case. The water used for the cleaning operations (PEF_B2 and PEF_B3) was not considered, to avoid double counting.

Table 6: Modelling of inputs used for PEF_B6 and PEF_B7 – Operational energy and water use

Energy Source	Unit	Description	Datasets used
Electricity	MJ	Electricity, low voltage, production BE, at grid	Electricity, low voltage {BE}| market for | Alloc Rec, U
Electricity	MJ	Electricity, medium voltage, production AT, at grid	Electricity, medium voltage {AT}| electricity voltage transformation from high to medium voltage | Alloc Rec, S
Gas	MJ	Natural gas; related to the kettle	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Alloc Rec, U
Gasoil	MJ[8]	Diesel, gasoil	Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, light fuel oil, at boiler 10kW condensing, non-modulating | Alloc Rec, U
Water	kg	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, S
Electricity PV (Belgian building only)	MJ	Electricity generated by PV panel	Electricity, low voltage {BE}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Alloc Rec, U

[8] Gasoil data is provided in liter. For modelling a conversion factor was used including the density of the gasoil and the caloric value of gasoil.

4.3.12. LCI FOR LCS PEF_C1. DISMANTLING

The dismantling of the buildings will take place after the reference service life of the building of 50 years will be up. The development of a scenario for the dismantling of the building looked at the available information for this life cycle stage in literature sources, focusing to determine a realistic scenario for the current Belgian and Austrian context and practices.

The main alternatives considered for the development of a scenario were the information included in the Ecoinvent report on demolition[9] and the information from European Hiser[10] project (Holistic recycling and recovery of valuable raw materials from complex construction and demolition waste).

Within **Task 4.1** of the Hiser project the **current practice in demolition of a non-residential building in Flanders**[11] was monitored in order to provide reference data for LCA and LCC assessments on demolition waste management. **In Flanders, (semi-)selective demolition is current practice**. This is mainly driven by economic reasons (high landfill fees, lower gate fees at recycling plants for materials that are selectively removed). This current selective demolition practice aims at the selective removal of hazardous materials (e.g. asbestos) and materials with a high value (e.g. metals). Special attention goes to the production of a qualitative stony fraction that is easy to process into recycled aggregates. Within this project this scenario is referred to as the '*Business-as-Usual (BaU) selective demolition (SD)*' case (BaU-SD scenario). In total 11.577 ton of demolition waste was sorted on-site and transported to waste disposal or treatment facilities.

This case of demolition is considered representative in Belgium, reason for which a similar approach will be applied for development of the dismantling scenario for the BelOrta building.
The following steps of dismantling are considered:

- Pre-demolition inventory;
- Manual removal phase;
- Structural demolition phase;
- Sorting on-site phase.

In the following paragraphs the different steps of the dismantling are described and the principles followed in the development of the scenarios explained.

1. Pre-demolition inventory

For buildings, bigger than 1000 m³ with a (partially) non-residential function, a pre-demolition inventory is mandatory[12]. Also, every building requires an asbestos inventory prior to demolition by a company[13], which can be integrated in the pre-demolition inventory. The pre-demolition inventory should contain an overview of all hazardous and non-hazardous materials that are

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[9] Ecoinvent report 13.III part V

[10] http://www.hiserproject.eu/index.php

[11] an old milk factory within the municipality of Gierle in Flanders was monitored over a period of 8 months in 2015-2016

[12] according to article 4.3.3. in the Flemish regulation on sustainable management of material chains and waste: VLAREMA (https://navigator.emis.vito.be/mijn-navigator?woId=44297)

[13] according to Royal Decree of 16th of March 2006, related to the protection of employees against risks on contamination by asbestos (http://www.werk.belgie.be/defaultTab.aspx?id=618)

available in the building, together with their EURAL-code, estimated quantity, location and appearance.

This stage does not involve environmental impacts, but it is relevant to include it for future more complex analysis of the building which might involve cost impacts (LCC).

2. Manual removal phase

In the first stage, the building is manually stripped from hazardous materials (e.g. asbestos, fluorescent lamps) and materials that were easy to remove (e.g. furniture, suspended ceilings). Asbestos (e.g. roof tiles, ventilation caps, fuses) will be removed by a specialized contractor. The non-hazardous materials will be selectively removed and divided in three fractions: *metals, wood and a residual fraction* (e.g. plastics, thermal insulation). Also, the windows will be manually dismantled in the glass part and the frame part. This specific action is done manually with the help of small dimension machinery (drilling machines and similar).

Except for the use of the small machinery (electrically charged) there aren't any environmental impacts related to this phase either. It was not possible to assess how much energy is necessary for the small machinery, but it is considered to be very small amounts[14]. In the framework of the PEF4Buildings project this input is neglected.

3. Structural demolition phase

After the manual removal phase, the structural building is demolished using bulldozers and hydraulic excavators (equipped with sorting grapples and concrete crushers). Practice shows that in this phase the removal of thermal insulation materials is difficult, and requires extra-efforts due to the fact that it is generally glued.

For this phase, the following inputs and outputs are considered:

1. Transport of the machines to the demolition site:
    - 2 Hitachi 350 hydraulic machines (35,09 tons), 1 New Holland 485 (51,1 tons), 1 Kabuto bulldozer (20 tons) and 1 aerial work platform (10,05 tons) were considered. It is difficult to assess the relation between the number of machines used and the size of the building to be demolished, which is why for BelOrta building we will just maintain the same number of machines as in the Hiser project;
2. Capital goods (related to the use of the machines);
3. Energy – fuel used by the machines;
4. Ancillary materials;
5. Emissions.

Comparison with the inputs and outputs in the BaU-SD case are also provided for comparison.

Note: in the Belgian BaU-SD scenario the amounts were collected for the entire building, where the same machines were used to demolish bricks, concrete and all other building elements. The

[14] For comparison we can provide the info for the dismantling of the piping system

collection of the data on the necessary energy (fuel) for the demolition process was not determined taking into consideration the specific material demolished, but it was at the overall level of the building.

a) Scenario for the transport of machines to demolition site:
   - In Hiser project exact distances between the depo and the demolition site were used;
   - In BelOrta case we assume that the depo is in Antwerp, therefore the assumed distance to the demolition site is of 30 km;
   - In the be 2666 case the assumed distance was 30 km.

Table 7: Demolition phase: machines used

Machines used	Weight of the machines (ton)	Transport of the machines (km)
Hitachi 350 (1)	35,09	30
New Holland 485	51,1	30
Kabuto	20	30
Aerial work platform	10,05	30
Total transportation of machines (return trip to/from depo)	151,33	**60**

b) Scenario for capital goods

No specific scenario was identified for capital goods within this project, in line with the PEF methodology, therefore we consider this as a data gap. **It is recommended to develop datasets that can cover these capital goods for future PEF profiles of buildings.**

c) Scenario for the energy (fuel) used by the machines for the demolition process

The data for BaU-SD collected data at the level of the entire building was transposed in average energy per kg demolished, regardless of the type of material. However in reality the amount of energy used is dependent on the type of material demolished.

In order to develop a scenario for BelOrta building the information in Ecoinvent report 13.III part V was used (Table 3.20). The table below shows how the values from Table 3.20 were used through a multiplication factor to calculate the energy necessary for demolishing the BelOrta building. By taking the material with the lowest amount of energy necessary as the baseline (bricks, plaster boards, etc.) the scenario for BelOrta building are higher (worst case scenario) than the average obtained for BaU-SD scenario.

Table 8: Scenario for the energy used by the machines for the demolition process

	Ecoinvent report			BaU-SD	BelOrta
Material demolished	**Demolition energy (MJ/kg)**	**Multiplication factor per material type (material with smallest value considered as baseline)**	**PM emissions during demolition**	**Demolition energy (MJ/kg)**	**Demolition energy (MJ/kg)**
concrete, not reinforced	0,0437	1,2170	yes	0,0111	0,0135
reinforced concrete	0,0612	1,7040	yes	0,0111	0,0189
cement (in concrete) and mortar	0,0437	1,2170	yes	0,0111	0,0135
concrete gravel	0,0437	1,2170	yes	0,0111	0,0135
brick	0,0359	1	yes	0,0111	0,0111
plaster board, gypsum plaster	0,0359	1	yes	0,0111	0,0111
plaster cardboard sandwich	0,0359	1	yes	0,0111	0,0111
reinforced plaster board	0,0359	1	yes	0,0111	0,0111
reinforcement steel	0,6259	17,4151	no	0,0111	0,1935
cement fiber slab	0,0359	1	yes	0,0111	0,0111

d) Scenario for ancillary materials

The ancillary materials used for the BaU-SD is mainly hydraulic oil and engine oil. The amounts were collected for the entire demolition process, and we prorated them per kg demolished waste. Below table shows the amounts used for modelling the ancillary materials for the demolition process in the PEF4Buildings project.

Table 9: Scenario for ancillary materials for the dismantling process

Ancillary materials	Amount per kg demolished waste (litre)
Hydraulic oil	2,07E-06
Engine oil	1,04E-06

e) Emissions

No emissions were measured during the HISER project, therefore for the PEF4Buildings project the amounts used were based on Ecoinvent report no. 13 Life Cycle Inventories of Waste Treatment Services, part V "Building material disposal", table 3.4 and 3.20). Table below presents the amount of emissions used for modelling for this project.

Table 10: Emissions during dismantling process

Emissions	**Amount per kg demolished waste (kg)**
Particulates, < 2.5 um	7,00E-06
Particulates, > 2.5 um, and < 10um	2,66E-05
Particulates, > 10 um	3,50E-05

4. Sorting on-site phase

The selective demolition of the heterogeneous construction led to the sorting on-site of different waste fractions, primarily of stony origin. During the structural demolition phase, materials were also sorted on site in different fractions: *stony material*, *steel* (concrete reinforcement), *aluminium* (window frames), *wood and a residual fraction* (e.g. roofing, thermal insulation). The stony material was subdivided in the following fractions: *a pure concrete fraction* (e.g. foundation, concrete slabs), *a mixed stony fraction* (e.g. walls) *and a reusable brick fraction*. This latter fraction consisted of high-grade façade bricks with lime mortar (cf. easily removable).

Once different waste fractions are sorted on-site, they are gradually removed and transported to different end-of-life, crushing (e.g. concrete and mixed stony fraction) and recycling facilities (e.g. steel and aluminium fraction) or stored/sold as reclaimed products (e.g. bricks and wooden beams). Landfilling of building demolition waste is seldom in Flanders, due to high landfill taxes and a disposal ban of stony and other fractions that could lead to useful applications, reuse and recycling.

The sorting process takes place in parallel with the structural demolition phase, and the same machines are used for the sorting process. It is considered that the overall inputs and outputs are the same for both these steps, with 40% of the inputs and outputs allocated to the structural demolition phase, and 60% to the sorting process. Therefore the information presented above for the structural demolition applies similarly here, prorated accordingly (*1,5).

4.3.13. LCI for LCS PEF_C2. Transport to EoL

The development of scenarios for the transportation of raw materials covered the type of truck to be used, the distance for transportation, payload and empty return. These scenarios were based on the following sources:

- BE-PCR v4.1, considering the Belgian specific context:
  - Information on transportation mean(Lorry, 16-32 t (Euro 5)), distances(incineration 50 km, landfill – 100 km), payload (85%) and empty return (100%);
  - The scenario for transport to recycling was developed to take into consideration Belgian context based on expert judgement (Lorry, 16-32 t (Euro 5), 150 km, 85% payload and 100% empty return);

Information for some products existed in the 5 draft PEFCRs, however in this context to use country specific scenario’s instead of European ones was considered the appropriate approach to take.

Detailed information regarding the EoL scenarios and amounts of materials transported for each construction product are available in Annex 1 and Annex 2.

CFF formula applied to the transportation to EoL in line with the PEF rules.

4.3.14. LCI FOR LCS PEF_C3-C4. DISPOSAL AT EOL (RECYCLING, INCINERATION AND LANDFILL OF ALL MATERIALS AT THE EOL OF THE LIFE OF THE BUILDING)

The end of life scenario of each material used in the building was determined for both Belgian and Austrian case specifically.

Thus for BelOrta Building the EoL scenarios were developed based on the BE-PCR 4.1 (Table 6 – Default end-of-life scenarios), basically following the indications from both PEF Guidance and draft PEFCRs to use country specific data whenever available. Annex 1 provides complete information with the specific EoL scenario for each construction product in a similar way as shown in Figure 20.

Material	Quantity	Unit	Ratio [kg/unit of material]	EOL Process		
				Recycling (R2)	Incineration (R3)	Landfill (1-R2-R3)
Reinforcing Steel	153805	kg	1	95%	0%	5%
Concrete In Situ	1878	m³	2400	95%	0%	5%
Butyl Acrylate	414	kg	1	0%	95%	0%
Vinyl Tiles	1148	m²	2.8	5%	95%	0%
Polyurethane Flexible Foam	4363	kg	1	0%	95%	5%

BE PCR v4.1

Figure 20: Information included in the Excel worksheet of Annex 1 (similar to the one in Annex 2) on PEF_C3-C4 life cycle stage: quantity, EoL scenario (recycling, incineration, landfill)

In order to enhance transparency of the remodelling if needed, Annex 1 and Annex 2 also provide information on the dataset used to model the EoL with. In order to allow the implementation of the CFF formula E*v, ErecEoL, ED and ERR have been defined for each material.

It must be specified that this definition process (in "Material Database" worksheet from Annex 1 and Annex 2) can be much improved with more specific datasets for each material. For the moment, lacking such specific information, the approach taken is the following for the various CFF parameters:

- ***E*v***
  - When R2 = 0 E*v was not relevant therefore it was not modelled (10 cases);
  - In 36 cases E*v was equated with Ev. In some instances this approach is correct, but not in all. It will be necessary that in the future adequate discussion to take place for each case individually.
  - In 22 cases while E*v was also assimilated with Ev, most of them being more complex materials, such as sanitary, HVAC, window related materials or electronics, this approach was considered to avoid having a data gap, but for accurate results these approach must be updated with appropriate datasets whenever available;
  - For materials such as lighting elements and electronic circuit no acceptable proxy could be identified, and the knowledge on the appropriate scenario for this elements must be more specific, which would require much more time than available for this project. This part is therefore neglected, and can be considered a

data gap. We can only say that the involved amounts are small compared to all materials used for the entire building. However it might be the case that their composition might have higher contribution to some specific impact categories, which in this case will be missed out.

- $E_{recyclingEoL}$
  - This parameter was modelled similar with the approach existing in some draft PEFCRs (PEFCR for thermal insulation) as a sorting process (see Table 11 below) and a transportation step to recycling (150 km, by Lorry, 16-32 t (EURO 5), same as for C2).
  - Adding a recycling process would have been necessary, but this step was affected by the lack of availability of appropriate datasets or acceptable proxies as follows:
    - For metals, the dataset "Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Alloc Rec, S" was considered, but the dataset is empty in SimaPro, therefore it made no sense to add it to the model;
    - Similarly for HDPE and LDPE, PET, PP, PS, PVC materials the datasets such as "PE (waste treatment) {GLO}| recycling of PE | Alloc Rec, U" were considered but they were again empty and hence not modelled;
    - No other proxies were available for the any of the other categories of materials.
    - **It is therefore recommended to develop datasets for recycling processes that would allow a completion of the model.**
    -

Table 11: Modelling approach for ErecEoL

Name	Amount per kg	Unit	Dataset used for modelling	Source
INPUT				
Handling in sorting plant	1/density of specific material	m^3	Excavation, hydraulic digger {RER}| processing | Alloc Rec, S	Ecoinvent 3
Electricity for mechanical sorting processes	2,20E-03	kWh	Electricity mix, AC, consumption mix, at consumer, < 1kV BE S	Ecoinvent 3
Infrastructure sorting plant	1,00E-10	piece	Sorting facility, for construction waste {CH}| sorting facility construction, for construction waste | Alloc Rec, S	Ecoinvent 3
OUTPUT				
Emission in sorting plant	0,00792	MJ	Heat, waste	Ecoinvent elementary flow

- ***EER covering the part of the CFF formula*** $E_{ER} - LHV*X_{ER,heat}*E_{SE, heat} - LHV*X_{ER,elec}*E_{SE, elec}$
  - For a number of 49 materials it was not specifically modelled as it was not relevant (R3 = 0);
  - For the rest of the materials this parameter was assimilated with the incineration process without[15] energy recovery as a way of integrating all the particles of the formula, using a similar simplified approach as used in the PEF for Thermal Insulation pilot. An alternative approach would be to use the incineration with energy recovery and to deduct the corresponding amounts of heat and electricity produced, taking into consideration the LHV and the efficiency of the process. However, for a simplification of the process the first alternative was selected.
    The following datasets were used for the modelling:
    - Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27 S – for some plastic materials which are not in the list below and do not have specific datasets available;
    - Waste incineration of wood products (OSB, particle board), EU-27 S – for wooden products;
    - Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27;
    - Waste incineration of plastics (rigid PVC), EU-27 S – for vinyl tiles;
    - Waste incineration of plastics (PE, PP, PS, PB), EU-27 – for PE, PP, PS and PB related materials;
    - Waste incineration of plastics (PET, PMMA, PC), EU-27 S

- ***ED***
  - Following the largely used approach across the draft PEFCRs these parameters was modelled with the ELCD datasets for landfill. The following datasets were used for modelling of the disposal of various materials:
    - Landfill of ferro metals EU-27 – for all metals (copper, copper alloy, steel, electronic circuits, various metal based appliances/machinery);
    - Landfill of plastic waste EU-27 – for all types of plastics but also materials such as paints and others);
    - Landfill of glass/inert waste EU-27 – for all inert type of materials such as concrete, mineral wool, glass);
    - Landfill of wood products (OSB, particle board) EU-27 – for wooden products);
    - Landfill of municipal solid waste, landfill including landfill gas utilisation and leachate treatment, without collection, transport and pre-treatment, BE, DK technology mix, at landfill site EU-27 – for products such as acrylic binder, bulb, lamp, led.
  - More specific datasets per material type should be developed to allow a more accurate calculation of the impacts.

[15] To be noted that the currently available ELCD datasets do not have a consistent approach in naming (S or without S do not keep their meaning for the incineration of the various materials).

4.4. LEARNINGS RELATED TO LC INVENTORY– TO FEED THE TASK 3

The following learnings related to datasets are identified:

- Dataset should allow the application of the CFF formula;
- Type of datasets necessary for a proper modelling at building level:
  - Specific datasets for large category of products used in a building:
    - To develop an extended list of products necessary for modelling an entire building;
    - Develop generic datasets for the modelling the beginning of the system boundaries (PEF_A1 to A3) in a flexible way. Such generic datasets should be the basis for developing company specific datasets for such products:
      - To allow the distinction of the virgin material input (Ev);
      - To allow the distinction of the recycled content input (Erecycled);
      - To allow the distinction of the transportation of the raw materials in a transparent manner (per raw material and source – virgin/recycled);
      - To allow the distinction of the manufacturing process related inputs and outputs;
      - To allow the application of the CFF formula by integrating the PEF parameters (A, B, R1, R2, R3);
      - To integrate the default scenarios from the PEFCR of the respective product category (such as transportation related scenario's but not only, as applicable);
    - Develop generic datasets for modelling the EoL of various categories of products used in buildings. Such datasets can be at European level but also country specific:
      - These datasets should allow the distinction of the various CFF formula parts: E^*_v, $E_{recyclingEoL}$ (a range of possible EoL recycling scenarios to be developed per category of products), ED and E_{ER} (with $\mathbf{X_{ER,heat}}$, $\mathbf{X_{ER,elec}}$, $\mathbf{E_{SE,heat}}$, $\mathbf{E_{SE,elec}}$, **and LHV).**

CHAPTER 5 ACTIVITY 1.4: LIFE CYCLE IMPACT ASSESSMENT

5.1. PEF RESULTS

The aim of this PEF4Buildings project is to test the applicability of the PEF method (and the latest versions available of the related guidance documents developed in the framework of the Environmental Footprint pilot test phase) to a new office building, and to provide an overview of pros and cons of alternative possible approaches to the definition of the benchmark and classes of performance for the typology of buildings within the scope of the study. With this goal in mind the aim is not to focus on the PEF results for the two office building as such but to learn from the assessment in terms of pros and cons when applying the PEF method to office building and to develop some recommendations for future developments in this area. The results in this chapters are presented and interpreted with this overall goal in mind.

As this project does not intend to focus on the absolute vlaues and results obtained, but aims at understanding the methodological aspects of calculating a PEF of an office building, only a limited number of the results are reported in the following paragraphs. These are included to illustrate what the model allows to extract directly as results from the LCA software. The results for the life cycle stages and elements which are not elaborated here, can however be directly extracted from the model that will be shared with the EC at the end of the contract.

The LCIA results of both case studies were calculated according to the PEF Guide. These are slightly different than the ones mentioned in the Guidance document v6.1/v6.2. As the latter were however not yet available in the SimaPro software, we could not assess the case studies according to this latest version. More specifically, the impact categories as mentioned in Table 12 were assessed.

Table 12 Impact categories and related indicators (PEF Guide)

Impact category	Indicator
Climate change	kg CO2 eq
Ozone depletion	kg CFC-11 eq
Non-cancer human health effects	CTUh
Cancer human health effects	CTUh
Particulate matter/Respiratory inorganics	kg PM2.5 eq
Ionizing radiation, HH	kBq U235 eq
Photochemical ozone formation, HH	kg NMVOC eq
Acidification terrestrial and freshwater	mol H+ eq
Eutrophication terrestrial	mol N eq
Eutrophication freshwater	kg P eq
Eutrophication marine	kg N eq
Ecotoxicity freshwater	CTUe
Land use	kg C deficit
Water resource depletion	m^3 water eq
Mineral, fossil and ren resource depletion	Kg Sb eq

The impact assessment has been done at the level of the characterised values (sections 5.2.1 and 4.3.1) and at the level of the normalised and weighted results (sections 5.2.2 and 4.3.2). For the latter the normalisation factors EC-JRC Global (2010 or 2013), per person have been used (see Table 13).

Table 13 Normalisation factors (EC-JRC Global (2010 or 2013), per person)

Impact category	Normalisation	Indicator
Climate change	7,07E+03	kg CO2 eq
Ozone depletion	1,22E-02	kg CFC-11 eq
Non-cancer human health effects	1,55E-04	CTUh
Cancer human health effects	1,24E-05	CTUh
Particulate matter/Respiratory inorganics	5,07E+00	kg PM2.5 eq
Ionizing radiation, HH	2,41E+02	kBq U235 eq
Photochemical ozone formation, HH	4,53E+01	kg NMVOC eq
Acidification terrestrial and freshwater	5,61E+01	molc H+ eq
Eutrophication terrestrial	1,64E+02	molc N eq
Eutrophication freshwater	6,54E+00	kg P eq
Eutrophication marine	3,04E+01	kg N eq
Ecotoxicity freshwater	5,20E+06	CTUe
Land use	3,74E+03	kg C deficit
Water resource depletion	6,89E+01	m^3 water eq
Mineral, fossil and ren resource depletion	1,93E-01	Kg Sb eq

The weighting set is based on the weighting set included in the Guidance document v6.2. The weighting factors from the Guidance document however have been rescaled as these include the impact categories ‘resource use, mineral’ and ‘resource use, energy carriers’ as two separate ones, while our set of impact categories solely includes one indicator ‘mineral, fossil and renewable resource depletion’. For the rescaling the two resource indicators have been considered as one indicator, receiving the weight of ‘7,55’, equal to the weighting of the indicator ‘resource use, mineral’ in the Guidance document v 6.2. The rescaled weighting factors are summarised in Table 14.

Table 14 Weighting factors: rescaled weighting factors from the Guidance document v6.2

Impact category	Weighting set: GD v6.2 rescaled	Indicator
Climate change	0,22971	kg CO2 eq
Ozone depletion	0,06883	kg CFC-11 eq
Non-cancer human health effects	0,02007	CTUh
Cancer human health effects	0,02323	CTUh
Particulate matter/Respiratory inorganics	0,09773	kg PM2.5 eq
Ionizing radiation, HH	0,05465	kBq U235 eq
Photochemical ozone formation, HH	0,05214	kg NMVOC eq
Acidification terrestrial and freshwater	0,06763	molc H+ eq
Eutrophication terrestrial	0,04047	molc N eq
Eutrophication freshwater	0,03054	kg P eq
Eutrophication marine	0,03229	kg N eq
Ecotoxicity freshwater	0,02094	CTUe
Land use	0,08661	kg C deficit
Water resource depletion	0,09282	m^3 water eq
Mineral, fossil and ren resource depletion	0,08235	Kg Sb eq

Finally, the hotspots have been identified (sections 5.2.3 and 4.3.3) in line with the Guidance document v6.1. The hotspots were analysed in terms of most relevant impact categories, life cycle stages and processes.

5.2. PEF RESULTS FOR BELORTA BUILDING

5.2.1. CHARACTERISED RESULTS

For the BelOrta building, the characterised results have been calculated at the level of:

- the building: indicating the contribution of each life cycle stage;
- the life cycle stage: indicating the contribution of each element;
- the element: indicating the contribution of each processed material.

As this project does not intend to focus on the absolute results obtained, but aims at understanding the methodological aspects of calculating a PEF of an office building, only a limited number of the results are reported in the subsequent paragraphs. These are included to illustrate what the model allows to extract directly as results from the LCA software. The results for the life cycle stages and elements which are not elaborated here, can however be directly extracted from the model that will be shared with the EC at the end of the contract.

Characterised results - building

Figure 21 graphically represents the characterized results at the building level, indicating the contribution of each life cycle stage. From the graph it is clear that the use phase and the pre-processing phase are the most important life cycle stages. Environmental benefits are clearly visible as well during the end-of-life stage of the building. In the subsequent section, the two most important life cycle stages are focused on.

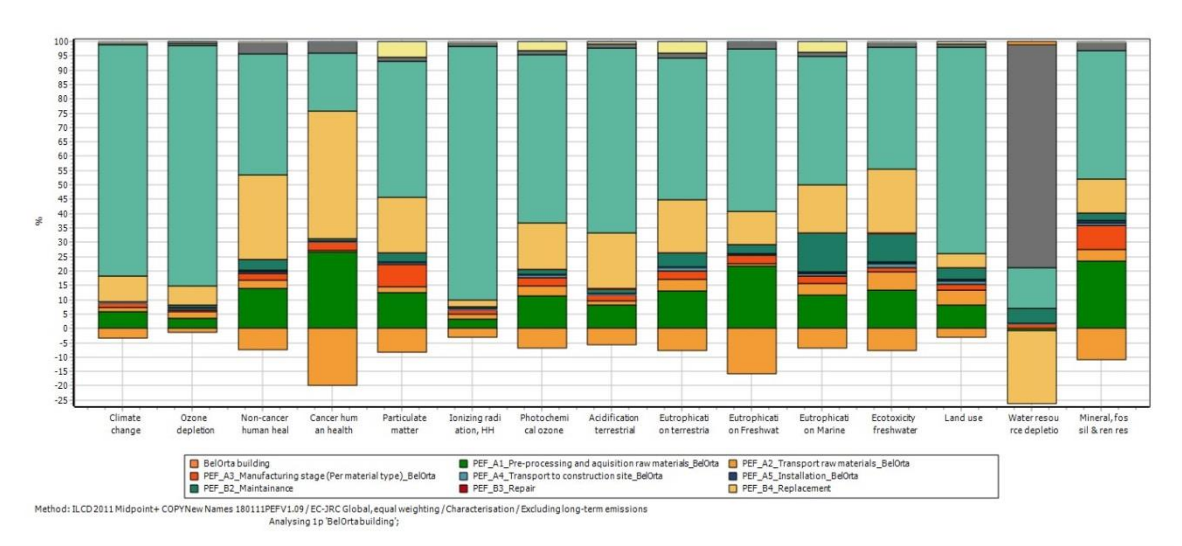

Figure 21: BelOrta – Characterised results of the building

Characterised results – Life cycle stage PEF_A1 (pre-processing and raw material acquisition)

The characterised results shown in for the life cycle stage PEF_A1 provides insight in the contribution of the various elements the building consists of. The elements that contribute most to each of the impact categories can be identified and further analysed in a subsequent step. For the BelOrta building we can see that the element contribution varies over the various impact categories. Three elements have been selected for further analysis (to illustrate the potential of the model): (1) PEF_A1_FL01_Concrete floor on earth, (2) PEF_A1_RO01_Roof construction 76,5 cm and (3) PEF_A1_FL02_Concrete storey floor 45 cm (see further).

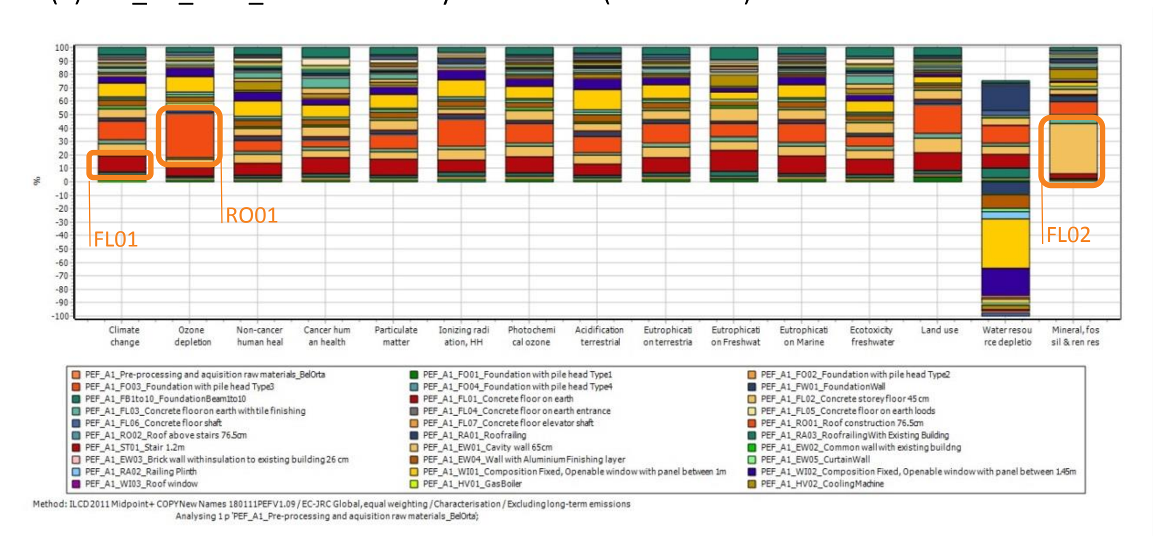

Figure 22: BelOrta - characterised results for life cycle stage PEF_A1

Characterised results – Life cycle stage PEF_B1-B7 (use phase)

From a more in depth look at the life cycle stage PEF_B1-B7 (Figure 23) it is clear that the operational energy use during use phase contributes most to the majority of the impact categories. For the impact category ‘water resource depletion’, operational water use contributes most.

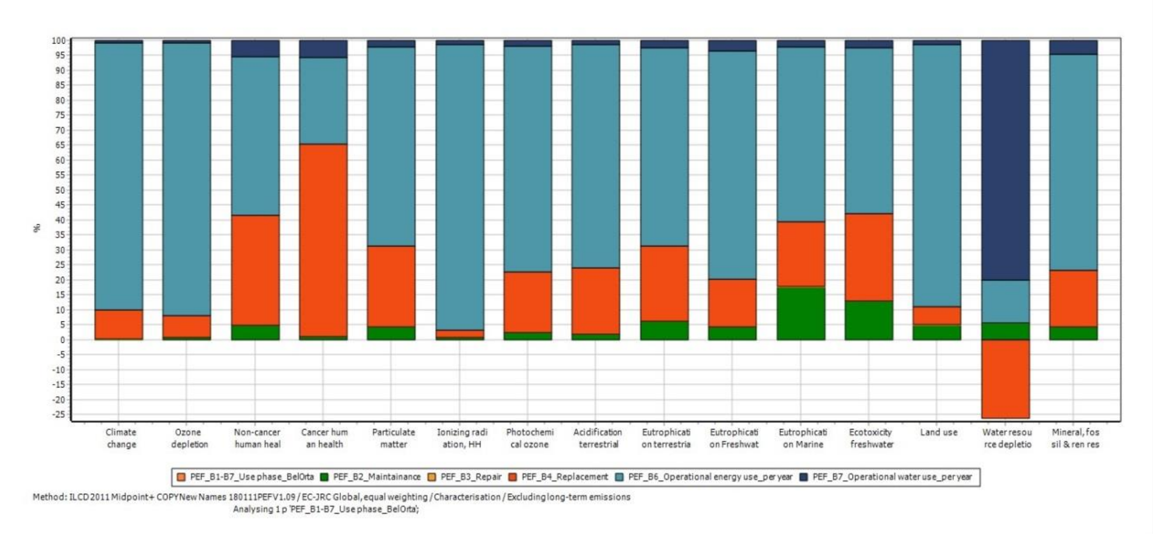

Figure 23: BelOrta - characterised results for life cycle stage PEF_B1-B7

Characterised results PEF_A1 – Floor 01

To illustrate the results that can be extracted directly from the SimaPro model at building element level, the results are shown in Figure 24 for the life cycle stage PEF_A1 for the floor 01 – Concrete floor on earth. The results provide insight in the contribution of the various processed materials present in the building. The results for the floor 01 show that the contribution depends on the impact category, but clearly the reinforcing steel and the in situ concrete contribute to an important extent for the majority of the impact categories.

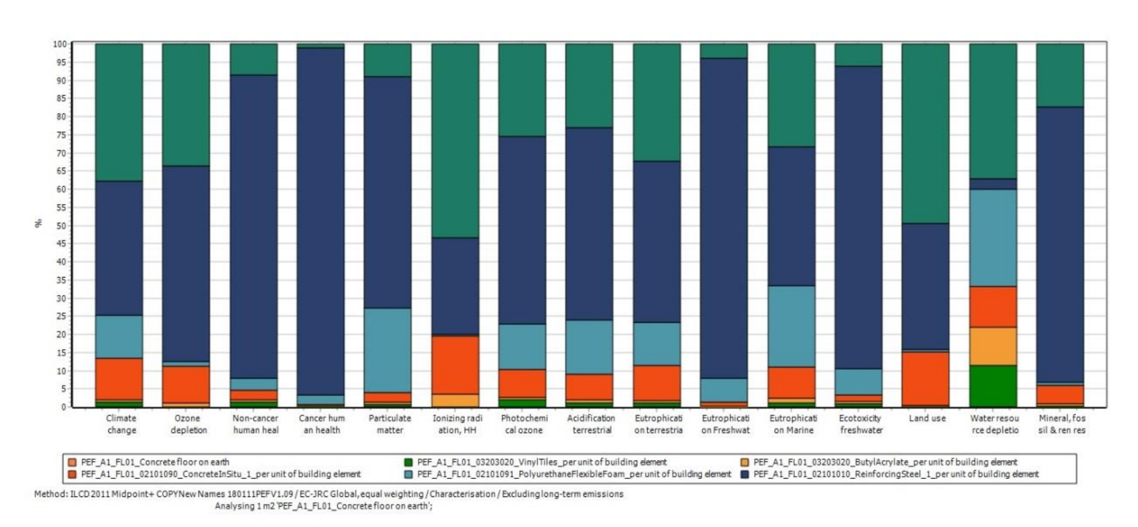

Figure 24: BelOrta – characterised results PEF_A1_FL01_concrete floor on earth

Characterised results PEF_A1 – Roof 01

The further analysis of the Roof 01 reveals that the high impact for ozone depletion (as shown in Figure 22) is caused by the PIR insulation (see Figure 25).

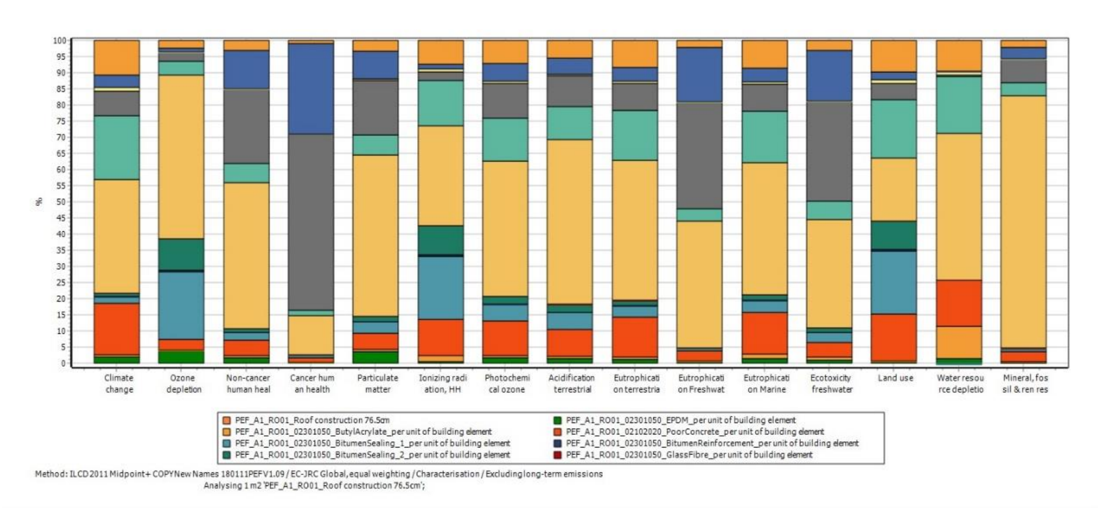

Figure 25: BelOrta – characterised results PEF_A1_RO01_ construction 76,5 cm

Characterised results PEF_A1 – Floor 02

The further analysis of the floor 02 reveals that the high impact for mineral, fossil and ren resource depletion (as shown in Figure 22) is caused by the finishing layer in ceramic tiles (see Figure 26).

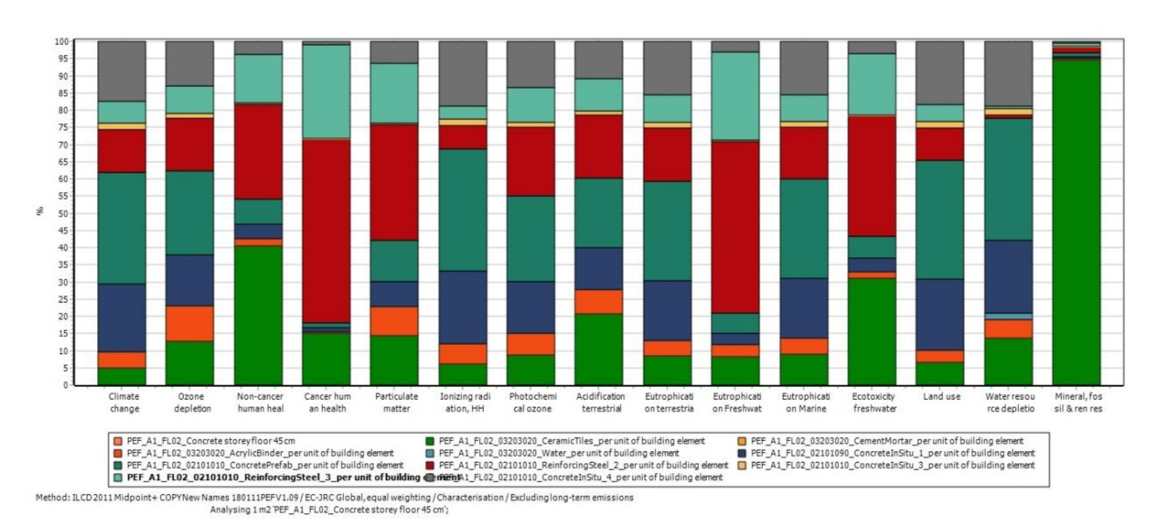

Figure 26: BelOrta – characterised results PEF_A1_FL02_ Concrete storey floor 45 cm

Characterised results – operational energy use (PEF_B6)

The environmental impact due to operational energy use is mainly caused by heating the building (gas boiler) and electricity use.

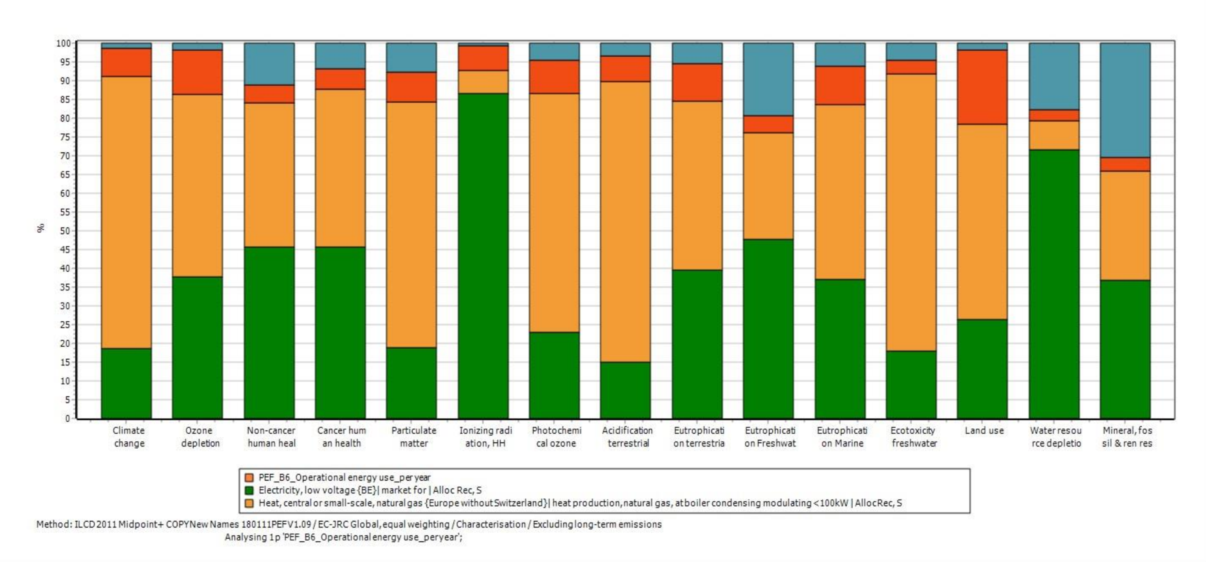

Figure 27: BelOrta – characterised results life cycle stage PEF_B6 (operational energy use)

5.2.2. NORMALISED AND WEIGHTED RESULTS

Normalised results

Figure 28 shows the normalised results for the BelOrta building, considering the whole building and its full life cycle.

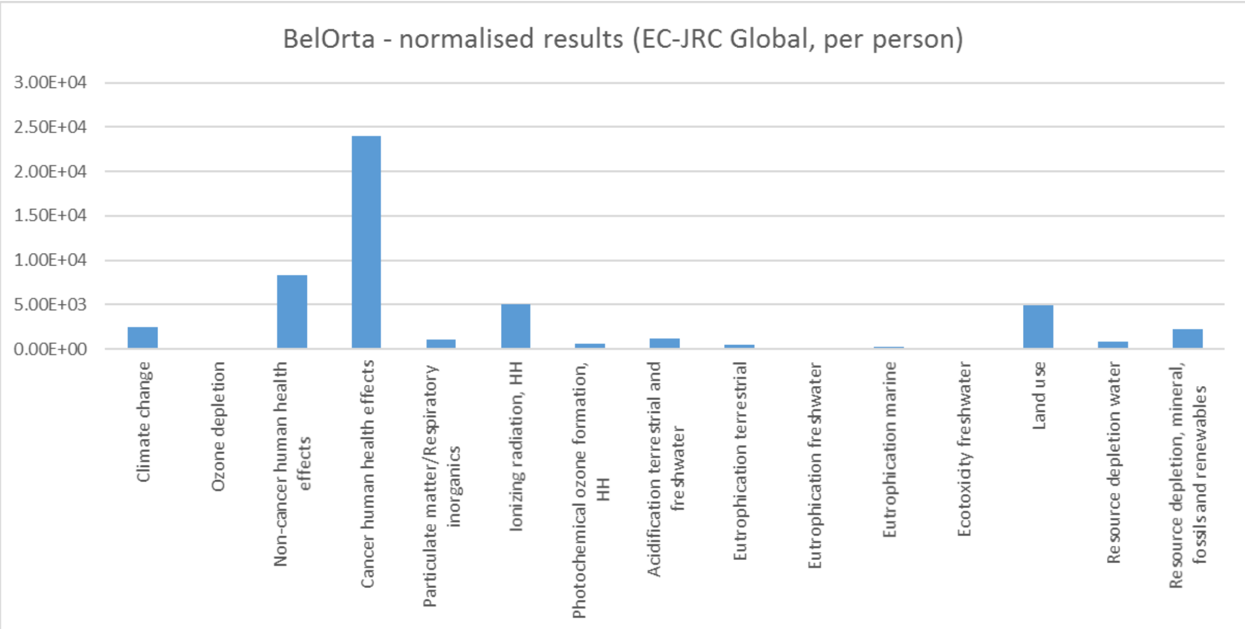

Figure 28: BelOrta – normalised results

Weighted results

Figure 29 shows the weighted results for the BelOrta building, considering the whole building and its full life cycle. The results show that excluding toxicity leads to lower overall environmental impacts.

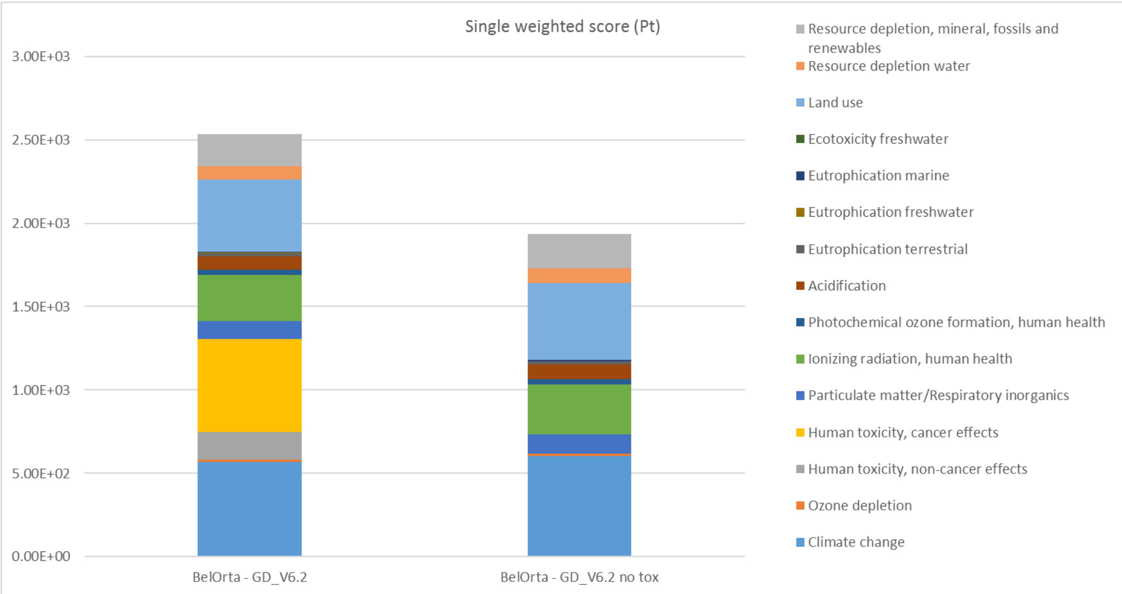

Figure 29: BelOrta – weighted results

5.2.3. HOTSPOTS

The hotspots are defined at the level of the most relevant impact categories, most relevant life cycles stages and most relevant processes.

a) Most relevant impact categories

The most relevant impact categories are identified based on the normalised and weighted results of the PEF screening study. The following rules from the Guidance document v6.2 were followed:

- At last three relevant impact categories shall be considered;
- The most relevant impact categories shall be identified as all impact categories that cumulatively contribute to at least 80% of the total environmental impact (excluding toxicity related impact categories);
- This should start from the largest to the smallest contributions.

The most relevant impact categories have been defined with and without toxicity (Figure 30). The results show that the most relevant impact categories vary depending considering toxicity or not. For the identification of the most relevant life cycle stages (subsequent section), we focused on the most relevant impact categories identified when using the weighting set of the Guidance document v6.2, excluding toxicity: i.e. climate change, land use and Ionizing radiation, HH. This is indicated with the orange box in Figure 30.

BelOrta - GD_V6.2		
Climate change	%	23%
Cancer human health effects	%	44%
Land use	%	62%
Ionizing radiation, HH	%	72%
Resource depletion, mineral, fossils and re	%	80%

BelOrta - GD_V6.2 no tox		
Climate change	%	31%
Land use	%	55%
Ionizing radiation, HH	%	70%
Resource depletion, mineral, fossils and renewables	%	81%

Figure 30: BelOrta – most relevant impact categories

b) Most relevant life cycle stages

The most relevant life cycle stages are identified based on the normalised and weighted results of the PEF screening study using the Guidance document v6.2 weighting factors, excluding toxicity.

The following rules from the Guidance document v6.2 were followed:

- Life cycle stages which together contribute to **at least 80% of any of the most relevant impact categories** identified;
- This should start from the largest to the smallest contributions.

The most relevant life cycle stages for the three most relevant impact categories identified are shown in Figure 31. The green highlighted life cycle stages are identified as the most relevant ones as these accumulated to at least 80% of the most relevant impact categories.

Climate change	
PEF_B6_Operational energy use_per year	78%
PEF_B4_Replacement	9%
PEF_A1_Pre-processing and aquisition raw materials_BelOrta	6%
PEF_C3-C4_EoL stage (Per material type)_BelOrta	3%
PEF_A2_Transport raw materials_BelOrta	1%
PEF_A3_Manufacturing stage (Per material type)_BelOrta	1%
PEF_B7_Operational water use_per year	1%
PEF_C1_Dismantling_BelOrta Building	0%
PEF_A4_Transport to construction site_BelOrta	0%
PEF_B2_Maintainance	0%
PEF_A5_Installation_BelOrta	0%
PEF_C2_Transport per tkm to all EoL scenarios_BelOrta	0%
PEF_B3_Repair	0%

Ionizing Raditation, HH	
PEF_B6_Operational energy use_per year	86%
PEF_A1_Pre-processing and aquisition raw materials_BelOrta	3%
PEF_C3-C4_EoL stage (Per material type)_BelOrta	3%
PEF_B4_Replacement	2%
PEF_A3_Manufacturing stage (Per material type)_BelOrta	2%
PEF_A2_Transport raw materials_BelOrta	1%
PEF_B7_Operational water use_per year	1%
PEF_B2_Maintainance	1%
PEF_C1_Dismantling_BelOrta Building	0%
PEF_A4_Transport to construction site_BelOrta	0%
PEF_A5_Installation_BelOrta	0%
PEF_C2_Transport per tkm to all EoL scenarios_BelOrta	0%
PEF_B3_Repair	0%

Land use	
PEF_B6_Operational energy use_per year	70%
PEF_A1_Pre-processing and aquisition raw materials_BelOrta	8%
PEF_A2_Transport raw materials_BelOrta	5%
PEF_B4_Replacement	5%
PEF_B2_Maintainance	4%
PEF_C3-C4_EoL stage (Per material type)_BelOrta	3%
PEF_A3_Manufacturing stage (Per material type)_BelOrta	2%
PEF_A4_Transport to construction site_BelOrta	1%
PEF_B7_Operational water use_per year	1%
PEF_C1_Dismantling_BelOrta Building	1%
PEF_A5_Installation_BelOrta	1%
PEF_C2_Transport per tkm to all EoL scenarios_BelOrta	0%
PEF_B3_Repair	0%

Mineral, fossil & ren resource depletion	
PEF_B6_Operational energy use_per year	41%
PEF_A1_Pre-processing and aquisition raw materials_BelOrta	62%
PEF_B4_Replacement	72%
PEF_C3-C4_EoL stage (Per material type)_BelOrta	82%
PEF_A3_Manufacturing stage (Per material type)_BelOrta	90%
PEF_A2_Transport raw materials_BelOrta	93%
PEF_B7_Operational water use_per year	96%
PEF_B2_Maintainance	98%
PEF_A4_Transport to construction site_BelOrta	99%
PEF_A5_Installation_BelOrta	100%
PEF_C2_Transport per tkm to all EoL scenarios_BelOrta	100%
PEF_C1_Dismantling_BelOrta Building	100%
PEF_B3_Repair	100%

Figure 31: BelOrta – most relevant life cycle stages

c) Most relevant processes

In line with the Guidance document v6.2, the most relevant processes have been defined for each of the most relevant impact categories identified. The identification of the most relevant processes is done according to Table 15 (Guidance Document v6.2, p. 33) at level-1. The definition of level-1 can be found in section 3.1.1.

Table 15 Criteria to select at which life cycle stage level to identify the most relevant processes (Guidance Document v6.2: p.33)

Contribution of the use stage to the total impact	Most relevant processes identified at the level of
≥ 50%	· Whole life cycle excluding use stage, and · Use stage
< 50%	· Whole life cycle

As the use phase in our study is contributing more than 50%, the most relevant processes are identified both at the level of the use stage and the whole life cycle, excluding use phase. The most relevant processes are those that collectively contribute at least with 80% to any of the most relevant impact categories identified.

The most relevant processes identified are summarised in Figure 32**Error! Reference source not found.** for the whole life cycle excluding use phase and in Figure 33 for the use phase.

Climate Change	
IW06MAT_03101090_AluminiumFrame_A1	5.5%
WI01_02202020_FrameA_A1	2.5%
IW01_02201020_concretePrefab_A1	2.1%
RO01MAT_02102090_PolyurethaneRigidFoam_A1	2.0%
EW01_02201020_concretePrefab_A1	1.9%
FL01MAT_02101010_ConcreteInSitu_2_A1	1.9%
FL01MAT_02101010_ReinforcingSteel_1_A1	1.8%
WI01_02202020_FrameA_C3/C4	1.7%
FL01MAT_02101010_ReinforcingSteel_1_C3/C4	1.6%
RO01_02102010_PrefabElement_A1	1.5%
FL02_02101010_PrefabFloorElement_A1	1.5%
WI02_02202020_FrameA_A1	1.5%
FL01MAT_02101010_ConcreteInSitu_2_A2	1.4%
LI01_04504050_Fixture_C3/C4	1.3%
IW01_02201020_concretePrefab_C3/C4	1.3%
WI01_02202020_FrameA_A3	1.2%
EW01_02201020_concretePrefab_C3/C4	1.2%
EW01MAT_02201020_ReinforcingSteel_A1	1.1%
EW04MAT_02201010_Aluminium_A1	1.0%
WI02_02202020_FrameA_C3/C4	1.0%
EW01MAT_02201010_Brick_A3	0.9%
RO01MAT_02102020_PoorConcrete_A1	0.9%
RA01MAT_02102090_Aluminium_1_A1	0.8%
IW03MAT_03101010_GalvanisedSteel_A3	0.8%
LI01MAT_04504090_T5Bulb_C3/C4	0.8%
RO01_02102010_PrefabElement_A2	0.8%
FL02_02101010_PrefabFloorElement_A2	0.8%
EW04MAT_02201010_Aluminium_C3/C4	0.8%
FL01MAT_02101010_ConcreteInSitu_2_C1	0.7%
WI02_02202020_FrameA_A3	0.7%
IW01_02201020_concretePrefab_A2	0.7%
RO01_02102010_PrefabElement_C3/C4	0.7%
FL02_02101010_PrefabFloorElement_C3/C4	0.7%
FL02MAT_02101090_ConcreteInSitu_1_A1	0.7%
RO01MAT_02102020_PoorConcrete_A2	0.7%
FO01MAT_01102015_ConcreteInSitu_2_A1	0.7%
EW01_02201020_concretePrefab_A2	0.6%
RA01MAT_02102090_Aluminium_1_C3/C4	0.6%
RO01MAT_02102010_ConcreteInSitu_2_A1	0.6%
FL02MAT_02101010_ConcreteInSitu_4_A1	0.6%
FL01MAT_02101091_PolyurethaneFlexibleFoam_A1	0.6%
PI05MAT_04303090_Steel_A1	0.6%
IW03MAT_03101010_GalvanisedSteel_A1	0.6%
FL01MAT_02101090_ConcreteInSitu_1_A1	0.6%
EW01MAT_02201081_PolyurethaneRigidFoam_A1	0.6%
FL01MAT_02101010_ConcreteInSitu_2_C3/C4	0.5%
EW04MAT_02201010_Aluminium_A3	0.5%
EW05_02202030_AluminiumFrame_C3/C4	0.5%
FL02MAT_02101090_ConcreteInSitu_1_A2	0.5%
EL03MAT_04503050_GalvanisedSteel_A3	0.5%
PI05MAT_04303090_Steel_C3/C4	0.5%
FO01MAT_01102015_ConcreteInSitu_2_A2	0.5%
RA02MAT_02201080_Aluminium_A1	0.5%
IW03MAT_03101010_GalvanisedSteel_C3/C4	0.5%
RO01MAT_02102010_ConcreteInSitu_2_A2	0.4%
FL02MAT_02101010_ConcreteInSitu_4_A2	0.4%
RA01MAT_02102090_Aluminium_1_A3	0.4%
FB01to10MAT_01102080_ReinforcingSteel_1to10_15_A1	0.4%
FL01MAT_02101090_ConcreteInSitu_1_A2	0.4%
DO04MAT_03103010_AluminiumFrame_A1	0.4%
HV02MAT_04303010_CoolingMachine_A1	0.4%
RO01_02102010_PrefabElement_C1	0.4%
FL02_02101010_PrefabFloorElement_C1	0.4%
FB01to10MAT_01102080_ReinforcingSteel_1to10_15_C3/C4	0.4%
RA02MAT_02201080_Aluminium_C3/C4	0.4%
PI03MAT_04201020_ZincSteelPipe_A1	0.4%
PI03MAT_04201020_ZincSteelPipe_A1	0.4%
FL03MAT_02101010_ConcreteInSitu_2_A1	0.4%
IW01_02201020_concretePrefab_C1	0.4%
EW02_02201020_concretePrefab_A1	0.4%
FL03MAT_02101010_ReinforcingSteel_1_A1	0.3%
EW05_02202030_AluminiumFrame_A3	0.3%
EW05_02202030_AluminiumFrame_A1	0.3%
EL03MAT_04503050_GalvanisedSteel_A1	0.3%
EW01_02201020_concretePrefab_C1	0.3%
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A1	0.3%
EL02_04503050_Cableholder_A1	0.3%
FL03MAT_02101010_ReinforcingSteel_1_C3/C4	0.3%
LI02_04504050_Fixture_C3/C4	0.3%
IW06MAT_03101020_GlazingLaminated_A1	0.3%
EL03MAT_04503050_ZincSteel_A1	0.3%
RO01MAT_02102020_PoorConcrete_C1	0.3%
PI03MAT_04201020_ZincSteelPipe_C3/C4	0.3%
PI03MAT_04201020_ZincSteelPipe_C3/C4	0.3%
PI08MAT_04306010_SteelPipe_A1	0.3%
EL03MAT_04503050_GalvanisedSteel_C3/C4	0.3%
FL02MAT_03203020_CeramicTiles_A3	0.3%
FL02MAT_03203020_AcrylicBinder_C3/C4	0.3%
LI01_04504050_Fixture_A1	0.3%
EW04MAT_02201020_ReinforcingSteel_A1	0.3%
FL03MAT_02101010_ConcreteInSitu_2_A2	0.3%
WI01MAT_02202020_Aluminium_1_A1	0.3%
WI01_02202010_FrameAp_A1	0.3%
IW06MAT_03101090_AluminiumFrame_A5	0.3%
FL01MAT_02101010_ConcreteInSitu_2_A4	0.3%
FO02MAT_01102015_ConcreteInSitu_2_A1	0.3%
RO01MAT_02102020_PoorConcrete_C3/C4	0.2%
FL02MAT_02101090_ConcreteInSitu_1_C1	0.2%
IW06MAT_03101090_AluminiumFrame_C3/C4	0.2%
RA02MAT_02201080_Aluminium_A3	0.2%
FO01MAT_01102015_ConcreteInSitu_2_C1	0.2%
FL01MAT_02101010_ReinforcingSteel_1_A3	0.2%
LI03_04504050_Fixture_C3/C4	0.2%
RO01MAT_02102090_PolyurethaneRigidFoam_C3/C4	0.2%
EW05MAT_02202030_GlazingDouble_A1	0.2%
HV02MAT_04303010_CoolingMachine_C3/C4	0.2%
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A2	0.2%
EW04MAT_02201020_ReinforcingSteel_C3/C4	0.2%
PI08MAT_04306010_SteelPipe_C3/C4	0.2%
EL03MAT_04503050_ZincSteel_C3/C4	0.2%
WI01_02202010_FrameBp_A1	0.2%
RO01MAT_02102010_ConcreteInSitu_2_C1	0.2%
FL02MAT_02101010_ConcreteInSitu_4_C1	0.2%
RO01MAT_02102010_ReinforcingSteel_2_A1	0.2%
FL02MAT_02101010_ReinforcingSteel_3_A1	0.2%
EW04MAT_02201020_ConcretePrefab_A1	0.2%
EW02_02201020_concretePrefab_C3/C4	0.2%
WI02_02202010_FrameAp_A1	0.2%
FL01MAT_02101090_ConcreteInSitu_1_C1	0.2%
IW06MAT_03101020_GlazingLaminated_C3/C4	0.2%
FO01MAT_01102070_ReinforcingSteel_1_A1	0.2%
DO06MAT_03103010_AluminiumFrame_A1	0.2%
FL01MAT_03203020_VinylTiles_C3/C4	0.2%
WI01MAT_02202020_Aluminium_1_C3/C4	0.2%
FL02MAT_02101090_ConcreteInSitu_1_C3/C4	0.2%
RO01_02102010_PrefabElement_A4	0.2%
FO01MAT_01102015_ConcreteInSitu_2_C3/C4	0.2%
RO01MAT_02102010_ReinforcingSteel_2_C3/C4	0.2%
FL02_02101010_PrefabFloorElement_A4	0.2%
FL02MAT_02101010_ReinforcingSteel_3_C3/C4	0.2%
FO02MAT_01102015_ConcreteInSitu_2_A2	0.2%
WI01MAT_02202020_GlazingDouble2_A1	0.2%
LI02MAT_04504090_T5Bulb_C3/C4	0.2%
WI02_02202010_FrameBp_A1	0.2%
EW01MAT_02201010_Brick_A2	0.2%
FO01MAT_01102070_ReinforcingSteel_1_C3/C4	0.2%
FO03MAT_01102015_ConcreteInSitu_2_A1	0.2%
WI01_02202020_Uprofile_A1	0.2%
LI03MAT_04504090_TCTLamp_C3/C4	0.2%
RO01MAT_02102010_ConcreteInSitu_2_C3/C4	0.2%
IW01_02201020_concretePrefab_A3	0.2%
WI01_02202010_FrameAp_C3/C4	0.2%
FL02MAT_02101010_ConcreteInSitu_4_C3/C4	0.2%
Total	**80.2%**

Land use	
FL01MAT_02101010_ConcreteInSitu_2_A2	3.2%
FL01MAT_02101010_ConcreteInSitu_2_A1	2.3%
IW01_02201020_concretePrefab_A1	2.2%
EW01_02201020_concretePrefab_A1	2.0%
IW06MAT_03101090_AluminiumFrame_A1	2.0%
RO01_02102010_PrefabElement_A2	1.9%
FL02_02101010_PrefabFloorElement_A2	1.9%
RO01_02102010_PrefabElement_A1	1.8%
FL02_02101010_PrefabFloorElement_A1	1.8%
FL01MAT_02101010_ReinforcingSteel_1_A1	1.6%
IW01_02201020_concretePrefab_A2	1.6%
RO01MAT_02102020_PoorConcrete_A2	1.5%
RO01MAT_02102090_PolyurethaneRigidFoam_A1	1.5%
EW01_02201020_concretePrefab_A2	1.5%
RO01MAT_02301050_BitumenSealing_1_A1	1.5%
FL02MAT_03203020_CeramicTiles_A3	1.4%
FL01MAT_02101010_ReinforcingSteel_1_C3/C4	1.4%
FL02MAT_02101090_ConcreteInSitu_1_A2	1.1%
FO01MAT_01102015_ConcreteInSitu_2_A2	1.1%
FL01MAT_02101010_ConcreteInSitu_2_C1	1.1%
RO01MAT_02102020_PoorConcrete_A1	1.1%
RO01MAT_02102010_ConcreteInSitu_2_A2	1.0%
FL02MAT_02101010_ConcreteInSitu_4_A2	1.0%
FL01MAT_02101090_ConcreteInSitu_1_A2	1.0%
IW01_02201020_concretePrefab_C3/C4	1.0%
EW01MAT_02201020_ReinforcingSteel_A1	1.0%
EW01_02201020_concretePrefab_C3/C4	0.9%
WI01_02202020_FrameA_A3	0.9%
FL02MAT_02101090_ConcreteInSitu_1_A1	0.8%
FO01MAT_01102015_ConcreteInSitu_2_A1	0.8%
WI01_02202020_FrameA_A1	0.8%
RO01MAT_02102010_ConcreteInSitu_2_A1	0.7%
RA01MAT_02102090_Plywood_1_A1	0.7%
FL02MAT_02101010_ConcreteInSitu_4_A1	0.7%
FL01MAT_02101090_ConcreteInSitu_1_A1	0.7%
RO01MAT_02301050_BitumenSealing_2_A1	0.7%
PI05MAT_04303090_Steel_A1	0.6%
FL03MAT_02101010_ConcreteInSitu_2_A2	0.6%
LI01_04504050_Fixture_C3/C4	0.6%
RO01_02102010_PrefabElement_C1	0.6%
FL02_02101010_PrefabFloorElement_C1	0.6%
FL01MAT_02101010_ConcreteInSitu_2_A4	0.6%
IW01_02201020_concretePrefab_C1	0.6%
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A2	0.6%
PI05MAT_04303090_Steel_C3/C4	0.5%
EW01_02201020_concretePrefab_C1	0.5%
WI01_02202020_FrameA_C3/C4	0.5%
WI02_02202020_FrameA_A3	0.5%
RO01MAT_02102020_PoorConcrete_C1	0.5%
WI02_02202020_FrameA_A1	0.5%
RO01_02102010_PrefabElement_A4	0.4%
FL03MAT_02101010_ConcreteInSitu_2_A1	0.4%
FL02_02101010_PrefabFloorElement_A4	0.4%
FO02MAT_01102015_ConcreteInSitu_2_A2	0.4%
HV02MAT_04303010_CoolingMachine_A1	0.4%
RO01_02102010_PrefabElement_C3/C4	0.4%
FL02_02101010_PrefabFloorElement_C3/C4	0.4%
EW01MAT_02201010_Brick_A2	0.4%
LI01MAT_04504090_T5Bulb_C3/C4	0.4%
PI03MAT_04201020_ZincSteelPipe_A1	0.4%
PI03MAT_04201020_ZincSteelPipe_A1	0.4%
EW01MAT_02201010_Brick_A3	0.4%
FL02MAT_02101090_ConcreteInSitu_1_C1	0.4%
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A1	0.4%
FO01MAT_01102015_ConcreteInSitu_2_C1	0.4%
EW04MAT_02201010_Aluminium_A3	0.4%
FB01to10MAT_01102080_ReinforcingSteel_1to10_15_A1	0.4%
RO01MAT_02102020_PoorConcrete_A4	0.4%
IW01_02201020_concretePrefab_A4	0.4%
EW02_02201020_concretePrefab_A1	0.4%
EW04MAT_02201020_ConcretePrefab_A2	0.4%
RO01MAT_02102010_ConcreteInSitu_2_C1	0.4%
FL02MAT_02101010_ConcreteInSitu_4_C1	0.4%
EW01MAT_02201010_Brick_A1	0.4%
EW01_02201020_concretePrefab_A4	0.3%
FL01MAT_02101090_ConcreteInSitu_1_C1	0.3%
EW04MAT_02201010_Aluminium_A1	0.3%
FB01to10MAT_01102080_ReinforcingSteel_1to10_15_C3/C4	0.3%
EL03MAT_04503050_ZincSteel_A1	0.3%
RA01MAT_02102090_Aluminium_1_A3	0.3%
FL03MAT_02101010_ReinforcingSteel_1_A1	0.3%
WI02_02202020_FrameA_C3/C4	0.3%
FO02MAT_01102015_ConcreteInSitu_2_A1	0.3%
PI03MAT_04201020_ZincSteelPipe_C3/C4	0.3%
PI03MAT_04201020_ZincSteelPipe_C3/C4	0.3%
FO03MAT_01102015_ConcreteInSitu_2_A2	0.3%
FL01MAT_02101010_ConcreteInSitu_2_A5	0.3%
EW03MAT_02201020_ConcreteBlock_A2	0.3%
EW02_02201020_concretePrefab_A2	0.3%
FL02MAT_03203020_CeramicTiles_A4	0.3%
EW04MAT_02201020_ConcretePrefab_A1	0.3%
FL02MAT_03203020_CeramicTiles_A1	0.3%
FL03MAT_02101010_ReinforcingSteel_1_C3/C4	0.3%
RA01MAT_02102090_Aluminium_1_A1	0.3%
HV02MAT_04303010_CoolingMachine_C3/C4	0.3%
IW06MAT_03101020_GlazingLaminated_A1	0.3%
EW05_02202030_AluminiumFrame_A3	0.3%
PI08MAT_04306010_SteelPipe_A1	0.2%
FO04MAT_01102015_ConcreteInSitu_2_A2	0.2%
EL03MAT_04503050_ZincSteel_C3/C4	0.2%
EW04MAT_02201020_ReinforcingSteel_A1	0.2%
EW04MAT_02201010_Aluminium_C3/C4	0.2%
FL03MAT_03203020_CeramicTiles_A3	0.2%
EW05MAT_02202030_GlazingDouble_A1	0.2%
DO05MAT_03103010_Plywood_A1	0.2%
FO03MAT_01102015_ConcreteInSitu_2_A1	0.2%
FL03MAT_02101010_ConcreteInSitu_2_C1	0.2%
FL02MAT_02101090_ConcreteInSitu_1_A4	0.2%
IW01_02201020_concretePrefab_A3	0.2%
FL01MAT_02101010_ConcreteInSitu_2_A3	0.2%
EW04MAT_02201020_ReinforcingSteel_C3/C4	0.2%
FO01MAT_01102015_ConcreteInSitu_2_A4	0.2%
EW03MAT_02201020_ConcreteBlock_A1	0.2%
PI08MAT_04306010_SteelPipe_C3/C4	0.2%
EL02_04503050_Cableholder_A1	0.2%
RO01MAT_02102010_ReinforcingSteel_2_A1	0.2%
RA01MAT_02102090_Aluminium_1_C3/C4	0.2%
FL02MAT_02101010_ReinforcingSteel_3_A1	0.2%
FO01MAT_01102070_ConcreteInSitu_1_A2	0.2%
EW01_02201020_concretePrefab_A3	0.2%
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_C1	0.2%
RO01MAT_02102010_ConcreteInSitu_2_A4	0.2%
RO01_02102010_PrefabElement_A5	0.2%
FL03MAT_02101090_ConcreteInSitu_1_A2	0.2%
FL02MAT_02101010_ConcreteInSitu_4_A4	0.2%
FL02_02101010_PrefabFloorElement_A5	0.2%
FO01MAT_01102070_ReinforcingSteel_1_A1	0.2%
FL01MAT_02101010_ConcreteInSitu_2_C3/C4	0.2%
RA02MAT_02201080_Aluminium_A3	0.2%
IW06MAT_03101020_GlazingLaminated_C3/C4	0.2%
FL01MAT_02101010_ReinforcingSteel_1_A3	0.2%
FL01MAT_02101090_ConcreteInSitu_1_A4	0.2%
FO04MAT_01102015_ConcreteInSitu_2_A1	0.2%
WI01MAT_02202020_GlazingDouble2_A1	0.2%
DO03_03103010_Panel_A1	0.2%
Total	**80.1%**

Ionizing radiation, HH	
LI01_04504050_Fixture_C3/C4	4.6%
LI01MAT_04504090_T5Bulb_C3/C4	3.3%
IW03MAT_03101010_GalvanisedSteel_A3	2.8%
WI01_02202020_FrameA_A1	2.4%
RO01MAT_02102090_PolyurethaneRigidFoam_A1	1.9%
FL01MAT_02101010_ConcreteInSitu_2_A2	1.9%
WI01_02202020_FrameA_C3/C4	1.8%
EL03MAT_04503050_GalvanisedSteel_A3	1.7%
FL01MAT_02101010_ConcreteInSitu_2_A1	1.4%
WI02_02202020_FrameA_A1	1.4%
EL02_04503050_Cableholder_A1	1.3%
IW06MAT_03101090_AluminiumFrame_A1	1.3%
RO01MAT_02301050_BitumenSealing_1_A1	1.2%
IW01_02201020_concretePrefab_A1	1.2%
RO01_02102010_PrefabElement_A2	1.1%
FL02_02101010_PrefabFloorElement_A2	1.1%
FL02MAT_03203020_CeramicTiles_A3	1.1%
EW01_02201020_concretePrefab_A1	1.1%
WI02_02202020_FrameA_C3/C4	1.0%
LI02_04504050_Fixture_C3/C4	1.0%
EW04MAT_02201010_Aluminium_A1	1.0%
RO01_02102010_PrefabElement_A1	1.0%
FL02_02101010_PrefabFloorElement_A1	1.0%
RO01MAT_02102090_PolyurethaneRigidFoam_C3/C4	1.0%
IW01_02201020_concretePrefab_A2	0.9%
LI03_04504050_Fixture_C3/C4	0.9%
RO01MAT_02102020_PoorConcrete_A2	0.9%
FL01MAT_02101010_ConcreteInSitu_2_C1	0.9%
EW01_02201020_concretePrefab_A2	0.9%
RA01MAT_02102090_Aluminium_1_A1	0.8%
EW04MAT_02201010_Aluminium_C3/C4	0.8%
LI02MAT_04504090_T5Bulb_C3/C4	0.7%
FL01MAT_02101010_ReinforcingSteel_1_A1	0.7%
LI03MAT_04504090_TCTLamp_C3/C4	0.7%
RO01MAT_02102020_PoorConcrete_A1	0.7%
FL02MAT_02101090_ConcreteInSitu_1_A2	0.7%
FO01MAT_01102015_ConcreteInSitu_2_A2	0.7%
RA01MAT_02102090_Aluminium_1_C3/C4	0.6%
RO01MAT_02102010_ConcreteInSitu_2_A2	0.6%
FL02MAT_02101010_ConcreteInSitu_4_A2	0.6%
LI06_04504050_Fixture_C3/C4	0.6%
FL01MAT_02101090_ConcreteInSitu_1_A2	0.6%
RO01MAT_02301050_BitumenSealing_2_A1	0.6%
FL01MAT_02101010_ReinforcingSteel_1_C3/C4	0.5%
EW05_02202030_AluminiumFrame_C3/C4	0.5%
FL02MAT_02101090_ConcreteInSitu_1_A1	0.5%
FO01MAT_01102015_ConcreteInSitu_2_A1	0.5%
FB01to10MAT_01102080_XPS_1to10_10_A1	0.5%
EW01MAT_02201010_Brick_A3	0.5%
WI01_02202020_FrameA_A3	0.5%
RA02MAT_02201080_Aluminium_A1	0.5%
RO01_02102010_PrefabElement_C1	0.5%
FL02_02101010_PrefabFloorElement_C1	0.5%
RO01MAT_02102010_ConcreteInSitu_2_A1	0.5%
FL02MAT_02101010_ConcreteInSitu_4_A1	0.5%
FB01to10MAT_01102080_XPS_1to10_10_C3/C4	0.5%
IW01_02201020_concretePrefab_C1	0.4%
FL01MAT_02101090_ConcreteInSitu_1_A1	0.4%
EW01MAT_02201081_PolyurethaneRigidFoam_C3/C4	0.4%
EW01MAT_02201020_ReinforcingSteel_A1	0.4%
IW03MAT_03101010_PlasterBoards_A3	0.4%
IW01_02201020_concretePrefab_C3/C4	0.4%
EW01_02201020_concretePrefab_C1	0.4%
FL01MAT_02101091_PolyurethaneFlexibleFoam_C3/C4	0.4%
EW01_02201020_concretePrefab_C3/C4	0.4%
EW05_02202030_AluminiumFrame_A1	0.4%
IW02MAT_03101010_GalvanisedSteel_A3	0.4%
LI05_04504050_Fixture_C3/C4	0.4%
FL03MAT_02101010_ConcreteInSitu_2_A2	0.4%
RA02MAT_02201080_Aluminium_C3/C4	0.4%
RO01MAT_02102020_PoorConcrete_C1	0.4%

FL01MAT_02101010_ConcreteInSitu_2_A4
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A2
WI01_02202010_FrameAp_A1
EW03MAT_02201081_GlassWoolRigidFoam_A3
FL02MAT_02101090_ConcreteInSitu_1_C1
FO01MAT_01102015_ConcreteInSitu_2_C1
WI02_02202020_FrameA_A3
PI05MAT_04303090_Steel_A1
WI01_02202010_FrameBp_A1
FL03MAT_02101010_ConcreteInSitu_2_A1
RO01MAT_02102010_ConcreteInSitu_2_C1
FL02MAT_02101010_ConcreteInSitu_4_C1
LI01_04504050_Fixture_A1
FL01MAT_02101010_ConcreteInSitu_2_A3
RO01MAT_02301050_BitumenSealing_1_A3
WI02_02202010_FrameAp_A1
FL01MAT_02101090_ConcreteInSitu_1_C1
RO01_02102010_PrefabElement_A4
WI01MAT_02202020_Aluminium_1_A1
FL02_02101010_PrefabFloorElement_A4
FO02MAT_01102015_ConcreteInSitu_2_A2
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_A1
EW01MAT_02201010_Brick_A2
IW01_02201020_concretePrefab_A3
PI05MAT_04303090_Steel_C3/C4
WI02_02202010_FrameBp_A1
EW01_02201020_concretePrefab_A3
RO01MAT_02102020_PoorConcrete_A4
IW01_02201020_concretePrefab_A4
EW04MAT_02201010_Aluminium_A3
LI01_04504050_Fixture_A5
EL01_XVBCables_A1
EW04MAT_02201020_ConcretePrefab_A2
RO01_02102010_PrefabElement_C3/C4
IW03MAT_03101010_GalvanisedSteel_C3/C4
FL02_02101010_PrefabFloorElement_C3/C4
IW03MAT_03101010_GalvanisedSteel_A1
EW01_02201020_concretePrefab_A4
HV02MAT_04303010_CoolingMachine_A1
RO01MAT_02102090_PolyurethaneRigidFoam_A3
EW02_02201020_concretePrefab_A1
WI01MAT_02202020_Aluminium_1_C3/C4
RO01_02102010_PrefabElement_A3
FL02_02101010_PrefabFloorElement_A3
FO02MAT_01102015_ConcreteInSitu_2_A1
WI01_02202010_FrameAp_C3/C4
EL02_04503050_Cableholder_C3/C4
FL01MAT_02101010_ReinforcingSteel_1_A3
PI03MAT_04201020_ZincSteelPipe_A1
PI03MAT_04201020_ZincSteelPipe_A1
PI05MAT_04303090_LDPE_1_A1
FL03MAT_03203020_CeramicTiles_A3
FL01MAT_02101010_ConcreteInSitu_2_A5
RA01MAT_02102090_Aluminium_1_A3
FO03MAT_01102015_ConcreteInSitu_2_A2
EL01_XVBCables_C3/C4
WI01_02202010_Uprofile_A1
FB01to10MAT_01102080_ReinforcingSteel_1to10_15_A1
FL03MAT_02101010_ConcreteInSitu_2_C1
EW04MAT_02201020_ConcretePrefab_A1
EW03MAT_02201020_ConcreteBlock_A2
LI01MAT_04504090_T5Bulb_A5
EW02_02201020_concretePrefab_A2
WI01_02202010_FrameBp_C3/C4
IW06MAT_03101020_GlazingLaminated_A1
WI02_02202010_FrameAp_C3/C4
FB01to10MAT_01102080_ConcreteInSitu_1to10_13_C1
FL01MAT_02101010_ConcreteInSitu_2_C3/C4
FL02MAT_03203020_CeramicTiles_A1
WI02MAT_02202020_Aluminium_1_A1
Total

Mineral, fossil and renewable resource depletion	
Floor_CeramicTiles_A1	9.1%
Floor_CeramicTiles_C3/C4	7.5%
Lighting_Ballast_C3/C4	3.7%
ExteriorWindows_AluminiumFrameA_A3	3.5%
Roof_PolyurethaneRigidFoam_A1	3.3%
HVAC_CoolingMachine_A1	2.6%
Floor_ConcreteInSitu_A2	2.4%
InternalWalls_GalvanisedSteel_A3	1.8%
Floor_ReinforcingSteel_A1	1.6%
Floor_ReinforcingSteel_C3/C4	1.5%
ExternalWalls_Aluminium_A3	1.5%
Electrical_Cableholder_A1	1.5%
Floor_CeramicTiles_A3	1.4%
Roof_Plywood_A1	1.2%
Electrical_GalvanisedSteel_A3	1.2%
ExteriorWindows_AluminiumFrameA_A1	1.1%
ExternalWalls_PrefabConcreteWall_A1	1.0%
Lighting_Fixture_C3/C4	1.0%
InternalWalls_PrefabConcreteWall_A1	1.0%
InternalWalls_AluminiumFrame_A1	0.9%
Roof_Aluminium_A3	0.9%
HVAC_Steel_A1	0.8%
PileFoundation_ConcreteInSitu_A2	0.8%
ExteriorWindows_AluminiumFrameA_C3/C4	0.8%
Doors_Plywood_A1	0.8%
ExteriorWindows_GlazingSandblasted_A1	0.8%
Lighting_T5Bulb_C3/C4	0.8%
Stairs_CeramicTiles_A1	0.7%
ExternalWalls_PrefabConcreteWall_C3/C4	0.7%
HVAC_Steel_C3/C4	0.7%
Floor_ConcreteInSitu_A1	0.7%
Roof_PrefabConcreteElement_A2	0.7%
ExternalWalls_AluminiumFrame_A3	0.7%
InternalWalls_PrefabConcreteWall_C3/C4	0.7%
Floor_PrefabConcreteElement_A2	0.6%
ExternalWalls_PrefabConcreteWall_A2	0.6%
ExteriorWindows_Aluminium_A3	0.6%
InternalWalls_PrefabConcreteWall_A2	0.6%
HVAC_ZincSteelPipe_A1	0.6%
Sanitary_ZincSteelPipe_A1	0.5%
Roof_PoorConcrete_A2	0.5%
Floor_CeramicTiles_A5	0.5%
Roof_PrefabConcreteElement_A1	0.5%
Floor_PrefabConcreteElement_A1	0.5%
Floor_ConcreteInSitu_A4	0.5%
ExternalWalls_Aluminium_A1	0.4%
Electrical_ZincSteel_A1	0.4%
ExternalWalls_Brick_A1	0.4%
ExteriorWindows_AluminiumFrameAp_A3	0.4%
HVAC_ZincSteelPipe_C3/C4	0.4%
Sanitary_ZincSteelPipe_C3/C4	0.4%
Roof_ConcreteInSitu_A2	0.4%
ExteriorWindows_Plywood_A1	0.4%
Floor_ConcreteInSitu_A3	0.4%
Floor_ConcreteInSitu_A3	0.4%
PileFoundation_ReinforcingSteel_A1	0.4%
Stairs_CeramicTiles_C3/C4	0.4%
HVAC_CoolingMachine_C3/C4	0.4%
Floor_ConcreteInSitu_C3/C4	0.4%
ExternalWalls_Aluminium_C3/C4	0.4%
ExteriorWindows_AluminiumFrameBp_A3	0.3%
Doors_FireproofPanel_A1	0.3%
Electrical_ZincSteel_C3/C4	0.3%
PileFoundation_ReinforcingSteel_C3/C4	0.3%
HVAC_CondensingGasBoiler_A1	0.3%
FoundationBeams_ReinforcingSteel_A1	0.3%
Lighting_Fixture_A3	0.3%
Roof_BitumenSealing_A3	0.3%
Roof_Aluminium_A1	0.3%
FoundationBeams_ReinforcingSteel_C3/C4	0.3%
ExteriorWindows_Uprofile_A3	0.2%
HVAC_SteelPipe_A1	0.2%
PileFoundation_ConcreteInSitu_A1	0.2%
Electrical_XVBCable_A1	0.2%
Electrical_Cableholder_C3/C4	0.2%
Roof_Aluminium_C3/C4	0.2%
Floor_ConcreteInSitu_A5	0.2%
Lighting_Fixture2_C3/C4	0.2%
ExternalWalls_ReinforcingSteel_A1	0.2%
HVAC_SteelPipe_C3/C4	0.2%
FoundationBeams_ConcreteInSitu_A2	0.2%
Roof_PrefabConcreteElement_C3/C4	0.2%
ExteriorWindows_Aluminium_A1	0.2%
Floor_PrefabConcreteElement_C3/C4	0.2%
Electrical_XVBCable_C3/C4	0.2%
Electrical_SensorCeiling_A1	0.2%
ExternalWalls_ReinforcingSteel_C3/C4	0.2%
ExteriorWindows_GlazingDouble2_A1	0.2%
ExternalWalls_Brick_C3/C4	0.2%
ExteriorWindows_AluminiumFrameB_A3	0.2%
Roof_ReinforcingSteel_A1	0.2%
Roof_PrefabConcreteElement_A4	0.2%
ExternalWalls_AluminiumFrame_C3/C4	0.2%
Floor_PrefabConcreteElement_A4	0.2%
PileFoundation_ConcreteInSitu_A4	0.2%
Lighting_TCTLamp_C3/C4	0.1%
Roof_PoorConcrete_A1	0.1%
ExternalWalls_Brick_A2	0.1%
HVAC_CoolingMachine_A5	0.1%
Roof_PolyurethaneRigidFoam_A3	0.1%
ExternalWalls_PrefabConcreteWall_A4	0.1%
Roof_ReinforcingSteel_C3/C4	0.1%
ExteriorWindows_Aluminium_C3/C4	0.1%
InternalWalls_GlazingLaminated_A1	0.1%
Roof_PoorConcrete_A4	0.1%
ExteriorWindows_AluminiumFrameAp_A1	0.1%
InternalWalls_PrefabConcreteWall_A4	0.1%
Total	**80.1%**

Figure 32: BelOrta – most relevant processes on level -1 for the whole life cycle excluding use phase

Climate Change	
Heat, heat prodcution, natural gas, at boiler condensing modulating <100kW_B6	69.00%
Electricity, low voltage_B6	17.79%
Total	**86.79%**

Ionizing radiation, HH	
Electricity, low voltage_B6	70.45%
Heat, heat prodcution, natural gas, at boiler condensing modulating <100kW_B6	5.10%
Heat, other than natural gas, heat prodcution,Light fuel oil, at boiler 10kW condensing, non modulating_B6	5.34%
Total	**80.88%**

Land Use	
Heat, heat prodcution, natural gas, at boiler condensing modulating <100kW_B6	46.97%
Electricity, low voltage_B6	23.86%
Heat, other than natural gas, heat prodcution,Light fuel oil, at boiler 10kW condensing, non modulating_B6	18.05%
Total	**88.88%**

Mineral, fossil and renewable resource depletion	
Electricity, low voltage_B6	27.82%
Electricity, low voltage, electricity production, photovoltaic, 3kWp roof installation_B6	22.97%
Heat, heat production, natural gas, at boiler condensing modulating<100kW_B6	22.05%
Tap Water_B7	4.86%
Heat, other than natural gas, heat production, Light fuel oil, at boiler 10kW condensing, non modulating_B6	2.70%
Total	**80.40%**

Figure 33: BelOrta – most relevant processes on level -1 for the use phase

5.3. PEF RESULTS FOR BE2226 BUILDING

5.3.1. CHARACTERISED RESULTS

For the BE2226 building, the characterised results have been calculated at the level of:

- the building: indicating the contribution of each life cycle stage;
- the life cycle stage: indicating the contribution of each element.

In the subsequent paragraphs, the same methodological aspects of calculating a PEF of a building as in chapter 4.1 are presented.

Characterised results - building

Figure 34 illustrates the contribution of each life cycle stage by the characterized results at the building level. The most important life cycle stages for the majority of the impact categories of BE2226 are the use phase (even for NZEB building) and the pre-processing phase. Environmental benefits are clearly visible as well during the end-of-life stage of the building. In the subsequent section, the two most important life cycle stages are focused on.

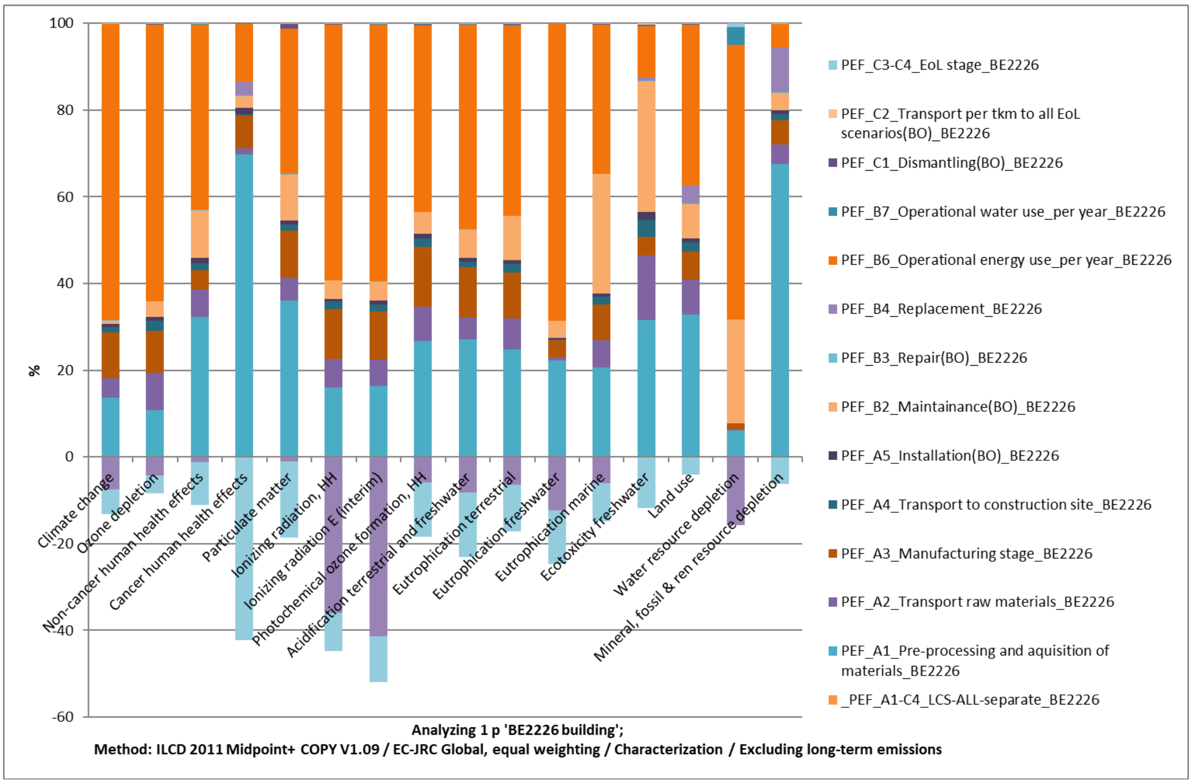

Figure 34: BE2226 - characterised results of the building

Characterised results – Life cycle stage A1

The characterised results shown for the life cycle stage PEF_A1 provides insight in the contribution of the various elements the building consists of. The elements that contribute most to each of the impact categories can be identified and further analysed in a subsequent step. For the BE2226 building we can see that the element contribution varies over the various impact categories.

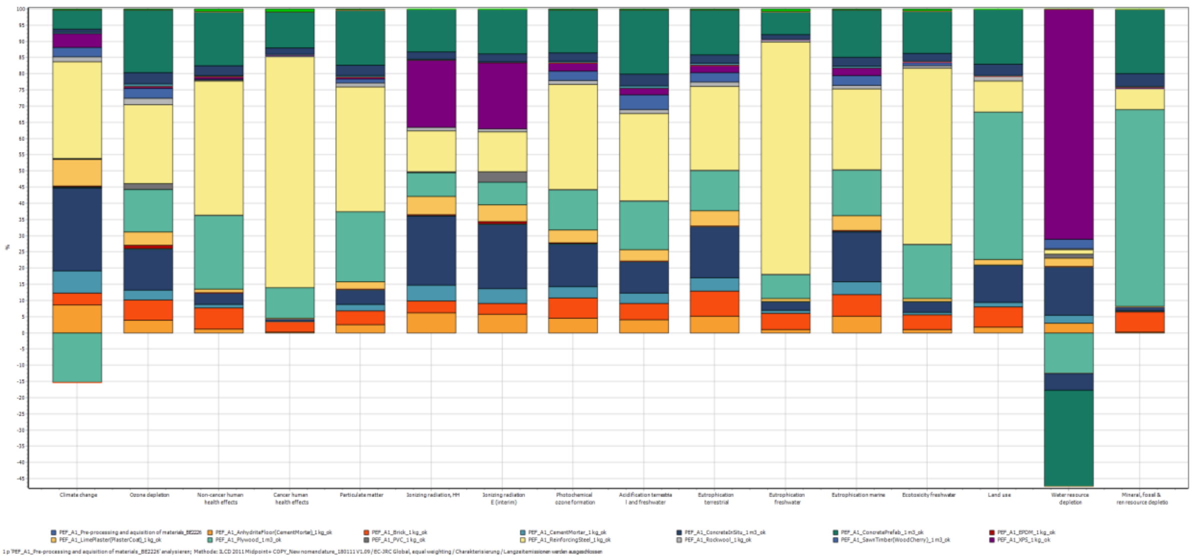

Figure 35: BE2226 - characterised results for life cycle stage PEF_A1

Characterised results – Life cycle stage PEF_B1-B7 (use phase)

To analyse the use phase of the building, a more in depth look at the life cycle stage PEF_B1-B7 is shown in Figure 36. It is clear that the operational energy use during use phase contributes most to the majority of the impact categories. For the impact category ‘Water resource depletion’, operational water use contributes most.

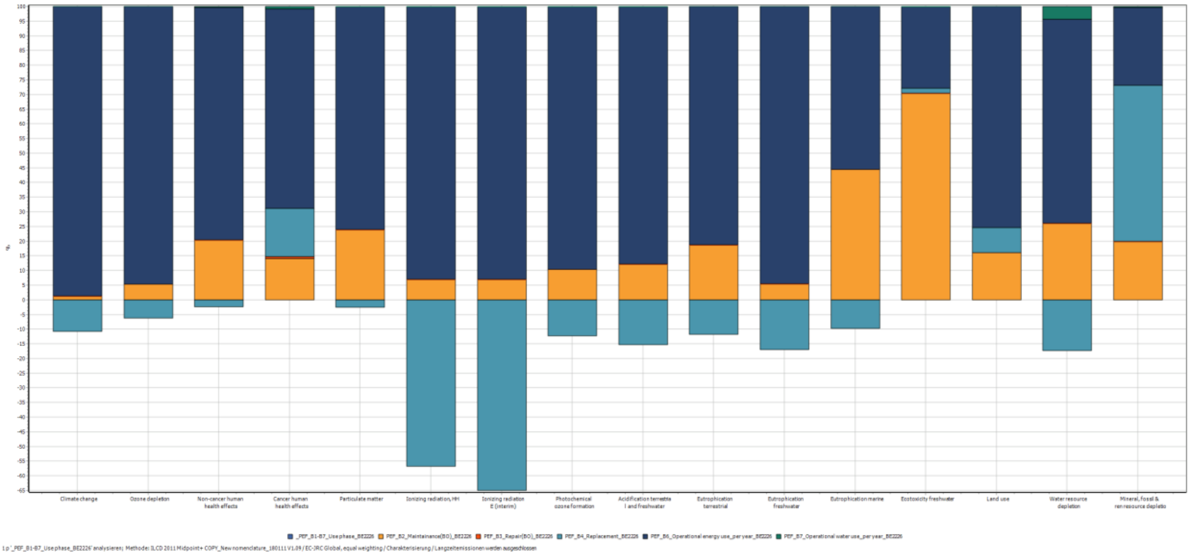

Figure 36: BE2226 - characterised results for life cycle stages PEF_B1-B7

5.3.2. NORMALISED AND WEIGHTED RESULTS

Normalised results

The normalised results for the BE2226 building are shown in Figure 37, considering the whole building and its full life cycle. Human health effects (both for non-cancer and cancer effects) is dominating the normalised results.

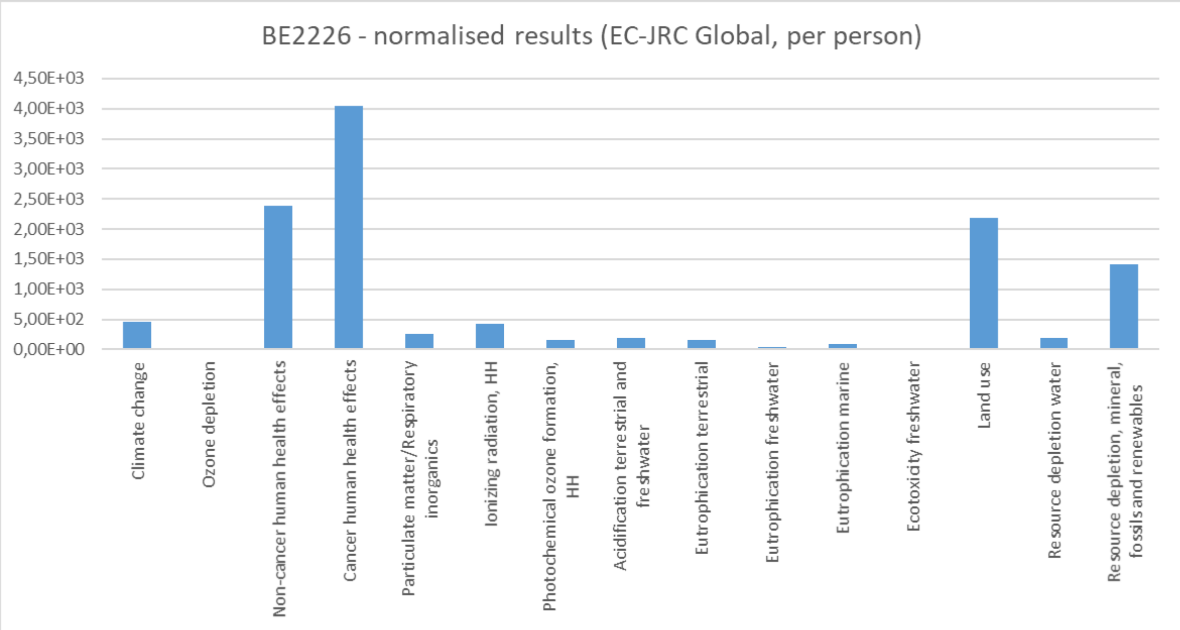

Figure 37: BE2226 - normalised results

Weighted results

The weighted results for the BE2226 building are shown in Figure 38, considering the whole building and its full life cycle. The results show, similar to the results from the BelOrta case study, that excluding toxicity leads to lower overall environmental impacts.

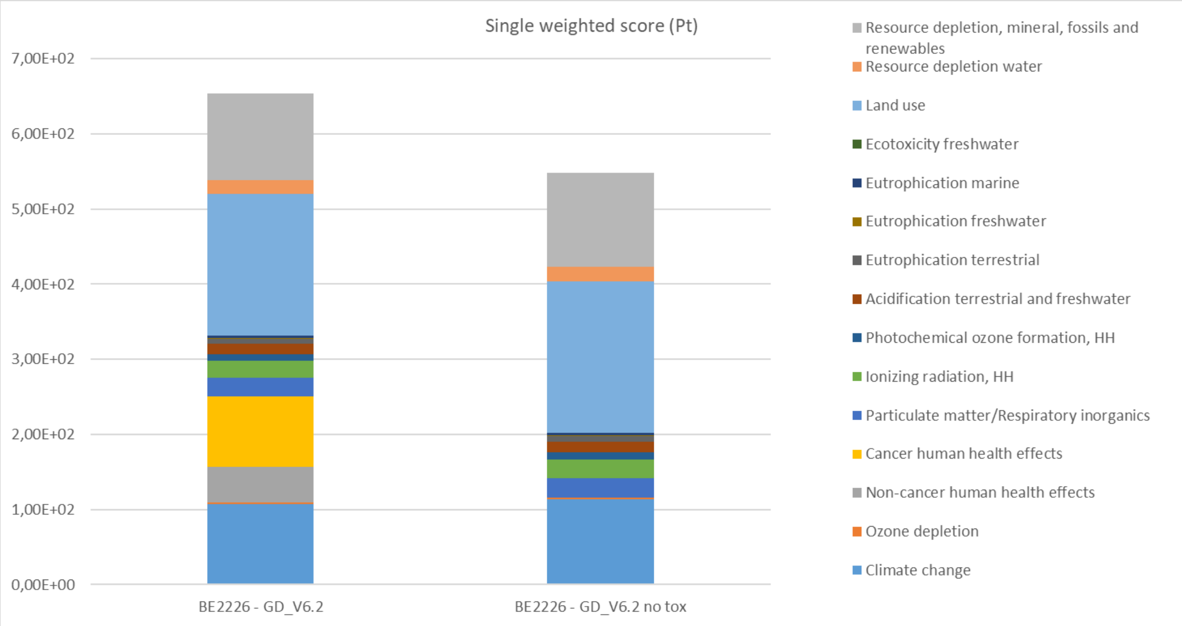

Figure 38: BE2226 - weighted results

5.3.3. Hotspots

The hotspots are defined at the level of the most relevant impact categories, most relevant life cycles stages and most relevant processes.

a) Most relevant impact categories

The most relevant impact categories are identified based on the normalised and weighted results of the PEF screening study. The following rules from the Guidance document v6.2 were followed:

- At last three relevant impact categories shall be considered;
- The most relevant impact categories shall be identified as all impact categories that cumulatively contribute to at least 80% of the total environmental impact (excluding toxicity related impact categories);
- This should start from the largest to the smallest contributions.

The most relevant impact categories have been defined with and without toxicity (Figure 39). The results show that the most relevant impact categories vary depending on considering toxicity or not. For the identification of the most relevant life cycle stages (subsequent section), we focused on the most relevant impact categories identified for BE2226 when using the weighting set of the Guidance document v6.2, excluding toxicity: i.e. 'Land use' and 'Resource depletion minerals, fossils and renewables' and 'Climate Change'. This is highlighted with the orange box in Figure 39.

BE2226 - GD_V6.2	
Land use	29%
Resource depletion, mineral, fossils and renewables	47%
Climate change	63%
Cancer human health effects	77%
Non-cancer human health effects	85%

BE2226 - GD_V6.2 no tox	
Land use	37%
Resource depletion, mineral, fossils and renewables	60%
Climate change	80%

Figure 39: BE2226 – most relevant impact categories

b) Most relevant life cycle stages

The most relevant life cycle stages are identified based on the normalised and weighted results of the PEF screening study using the Guidance document v6.2 weighting factors, excluding toxicity. The following rules from the Guidance document v6.2 were followed:

- Life cycle stages which together contribute to **at least 80% of any of the most relevant impact categories** identified;
- This should start from the largest to the smallest contributions.

The most relevant life cycle stages for the three most relevant impact categories identified are shown in Figure 40 with their accumulated contribution. The green highlighted life cycle stages are identified as the most relevant ones as these represent at least 80% of the overall impact for these categories.

Land use	
PEF_B6_Operational energy use_per year_BE2226	36%
PEF_A1_Pre-processing and aquisition of materials_BE2226	67%
PEF_A2_Transport raw materials_BE2226	75%
PEF_B2_Maintainance(BO)_BE2226	82%
PEF_A3_Manufacturing stage_BE2226	89%
PEF_B4_Replacement_BE2226	93%
PEF_C3-C4_EoL stage_BE2226	97%
PEF_A4_Transport to construction site_BE2226	99%
PEF_A5_Installation(BO)_BE2226	100%
PEF_C2_Transport per tkm to all EoL scenarios(BO)_BE2226	100%
PEF_C1_Dismantling(BO)_BE2226	100%
PEF_B3_Repair(BO)_BE2226	100%
PEF_B7_Operational water use_per year_BE2226	100%

Resource depletion, mineral, fossils and renewables	
PEF_A1_Pre-processing and aquisition of materials_BE2226	64%
PEF_B4_Replacement_BE2226	74%
PEF_C3-C4_EoL stage_BE2226	79%
PEF_A3_Manufacturing stage_BE2226	85%
PEF_B6_Operational energy use_per year_BE2226	90%
PEF_A2_Transport raw materials_BE2226	94%
PEF_B2_Maintainance(BO)_BE2226	97%
PEF_A4_Transport to construction site_BE2226	99%
PEF_A5_Installation(BO)_BE2226	100%
PEF_C2_Transport per tkm to all EoL scenarios(BO)_BE2226	100%
PEF_B3_Repair(BO)_BE2226	100%
PEF_B7_Operational water use_per year_BE2226	100%
PEF_C1_Dismantling(BO)_BE2226	100%

Climate change	
PEF_B6_Operational energy use_per year_BE2226	60%
PEF_A1_Pre-processing and aquisition of materials_BE2226	72%
PEF_A3_Manufacturing stage_BE2226	82%
PEF_B4_Replacement_BE2226	88%
PEF_C3-C4_EoL stage_BE2226	93%
PEF_A2_Transport raw materials_BE2226	97%
PEF_A4_Transport to construction site_BE2226	98%
PEF_B2_Maintainance(BO)_BE2226	99%
PEF_A5_Installation(BO)_BE2226	100%
PEF_C2_Transport per tkm to all EoL scenarios(BO)_BE2226	100%
PEF_B3_Repair(BO)_BE2226	100%
PEF_C1_Dismantling(BO)_BE2226	100%
PEF_B7_Operational water use_per year_BE2226	100%

Figure 40: BE2226 – most relevant life cycle stages

c) Most relevant processes

In line with the Guidance document v6.2, the most relevant processes have been defined for each of the three most relevant impact categories (see Figure 30). The identification of the most relevant processes is done according to Table 15 (Guidance Document v6.2, p. 33) at level-1. The definition of level-1 can be found in section 3.1.1. For the most important impact categories 'Land use' and 'Resource depletion minerals, fossils and renewables' the most relevant processes are evaluated for the whole building life cycle, i.e. including use phase. As for the impact in category 'Climate change' the use phase in the BE2226 case study is contributing more than 50%, the most relevant processes in this category had to be calculated accordingly: For the whole life cycle, excluding use phase as well as for the use stage only.

- The most relevant processes are **those that collectively contribute at least with 80% to any of the most relevant impact categories identified**;

Figure 41 shows the most relevant processes for 'Land use' and 'Resource depletion minerals, fossils and renewables' for the whole life cycle (incl. use phase). The most relevant processes identified for 'Climate change' are presented in Figure 42 for the whole life cycle excluding use phase and in Figure 43 for the use phase only.

Land use	
PEF_B6_Electricity, medium voltage (AT), market	35%
FL02_031010_Plywood	13%
WE02_022020_Exterior Window UF	11%
PEF_B2_Cleaning_VacuumWaterSoap	7%
FS01_021010_ConcreteInSitu	5%
EW01_022010_Brick	3%
PEF_B4_Replacement_Lighting	3%
FL01_031060_Plywood	3%
Total	81%

Resource depletion minerals, fossils and renewables	
FL02_031010_Plywood	32%
WE02_022020_Exterior Window UF	26%
PEF_B4_Replacement_Lighting	7%
FL01_031060_Plywood	7%
WE01_022020_Exterior Window GF	5%
PEF_B6_Electricity, medium voltage (AT), market	5%
Total	81%

Figure 41: BE2226 –most relevant processes on level -1 for the whole life cycle (incl. use phase) for 'Land use' and 'Resource depletion minerals, fossils and renewables'

Climate change	
EW01_022010_Brick	18%
FS01_021010_ConcreteInSitu	12%
IW01_031010_Brick	8%
FL02_032030_CementMortar	6%
EW01_022010_CementMortar	6%
WE02_022020_Exterior Window UF	6%
PEF_A5_Losses_A1	4%
FN01_021020_ConcreteInSitu	4%
FL02_032030_Rockwool	3%
FS01_021010_ReinforcingSteel	3%
FN02_014020_ConcreteInSitu	3%
PEF_A5_Losses_C3-C4	3%
RF01_032030_XPS	2%
RS01_021020_ConcreteInSitu	2%
FL02_031010_SawnTimber	2%
Total	82%

Figure 42: BE2226 – most relevant processes on level -1 for the whole life cycle excl. use phase for 'Climate change'

Climate change	
PEF_B6_Electricity, medium voltage (AT), market	88%
Total	88%

Figure 43: BE2226 – most relevant processes on level -1 for the use phase for 'Climate change'

5.4. COMPARISON OF OUTCOMES OF THE TWO CASES

Although the intention of the two assessments of the two cases is not to compare their LCIA results in detail, some important outcomes can be highlighted.

Firstly, looking at the overall weighted score of the two buildings (Figure 29 and Figure 38), we notice a significant difference in overall impact. The results for BE2226 building clearly show a lower impact than the BelOrta building. The latter is moreover the case when toxicity is considered or not. This was expected as the second case (BE2226) is an advanced building (NZEB) while the first case (BelOrta) is a business-as-usual case. However, it should be noted that the building control system (including sensors, control panels…) and piping is not modelled for the second case. Furthermore, the two buildings have the same use and a similar size in terms of floor area but represent different building typologies.

Secondly, the most relevant impact categories identified differ between the two cases. For both cases climate change and land use are identified as most relevant impact categories, but in a different order of importance. In addition, 'Ionizing radiation, HH' is identified as third most relevant impact category for the BelOrta case, while 'Resource depletion minerals, fossils and renewables' is identified as second most relevant impact category for the BE2226 case. The most relevant impact categories hence clearly depend on the building (energy performance and materials used), but also on the location (electricity mix). We can furthermore conclude that several of the most relevant impact categories are 'additional' impact categories which are not included in the current version of the EN 15804 and EN 15978.

Thirdly, for both buildings the PEF_A6 (operational energy use) and PEF_A1 (pre-processing of raw materials) phase have been identified being amongst the most relevant life cycle stages. However, for the BelOrta building, the use phase contributes significantly more to the life cycle impact than for the BE2226 building (the whole use phase causes 78% of the impact of the building on 'Climate hange' for BelOrta and around 60% for BE2226), which was expected. As the use phase in the BE2226 building causes lower impacts than in the BelOrta building, additional life cycle stages become more relevant. For the three most relevant impact categories these additional life cycle stages are: PEF_A2 (transport raw materials) and PEF_B2 (only for BE2226) for impact category 'Land use'; PEF_A3 (manufacturing stage) for both the impact categories 'Climate change' and 'Resource depletion minerals, fossils and renewables' for BE2226; PEF_B4 for the impact category 'Climate change' for BelOrta and the impact category 'Resource depletion minerals, fossils and renewables' for BE2226 and PEF_C3/C4 for 'Resource depletion minerals, fossils and renewables'. From these findings it can be concluded that for highly energy efficient buildings other life cycle stages become more relevant in relation. As indicated before, the location of the building potentially also influences the relative importance of the life cycle stages (e.g. due to differences in climate and thus operational energy demand, electricity mix, transport distances, etc.).

Finally, the identification of the most relevant processes leads to a different set of most relevant processes for both buildings. This was to be expected as both buildings consist of different materials and elements, but are also located in a different location and hence a different electricity mix is used during the important use phase of the building. To explore methodological difference in analysing the assessment results we chose two options to present the most important processes. While for BelOrta we present most relevant processes per sub-element and life cycle stage separately, the processes for BE2226 are aggregated across life cycle stages to show the sub-elements' contribution to life cycle impacts.

For both buildings however, the use phase was contributing for more than 50% for the majority (four out of six) of identified most important impact categories. Thus, the most relevant processes had to be identified for the use phase and the full life cycle (excluding use phase) separately. From this, we can conclude that for buildings, which generally have a relatively long and uncertain life span, it is recommended to always require the identification of the most relevant processes for both the whole life cycle (including the use phase) and for the use phase and the remaining life cycle stages separately.

5.5. LEARNINGS RELATED TO LCIA ASSESSMENT– TO FEED THE TASK 3

From the LCA assessment, we can summarise the following learnings.

The **models** of the two cases allowed to assess the building in a fairly easy way:

For the **BelOrta building** the results as presented in this chapter and the hotspot analysis as required by the PEF method could be directly extracted from the SimaPro model, except for the process contribution of the processes in the life cycle stages PEF_A2 and PEF_A4. These life cycle stages were modelled in SimaPro in an aggregated way and had to be disaggregated to the level of the building materials in excel first, before we could determine the transport of each building material separately and then identify the most relevant processes. For the hotspot analysis, it would be helpful if these life cycle stages are modelled in a disaggregated form (i.e. transport per building material) in the SimaPro model, however modelling it as such is very time consuming, while in excel it can be quite easily done. The BelOrta SimaPro model allows to **directly extract the LCIA results at the level of the building, at the level of the life cycle stage, at the level of the element in each life cycle stage, and at the level of the material/process**.

For the **BE2226 Building** the modelling in SimaPro was done on material level for all main building elements (foundation, walls, floors, etc.), as the required total quantities for this could be directly extracted from the BIM model with the required accuracy. Secondary elements, like windows and doors, were **modelled as aggregated datasets** combining the materials contained within one piece of element. This modular approach allowed for a detailed modelling of these elements and offers an **efficient way of modelling** that could as well be used for a changing number of elements e.g. windows **during a design process**. Results derived from SimaPro could thus directly be used for the analysis of most relevant life cycle stages and impact categories. For most relevant processes the same issues as mentioned for BelOrta already were faced, as transport had to be disaggregated in excel afterwards – this limitation however can be overcome when modelling these life cycle stages accordingly, with material-specific transport values.

To analyse the impact of a certain building element, e.g. one square meter of floor, for BE2226 the results from SimaPro had to be taken back to the spreadsheet where information to make this dis/aggregation on the level of building elements is available already and could thus be executed with limited effort. As this information, of impact of a certain building element, is important especially during a building design process, it is suggested to consider this for future models.

The above-mentioned modelling aspects are in part related to the applied workflow and software solutions and may well be different in other cases.

The inclusion/exclusion of the toxicity impact category clearly influences the results to a significant extent, especially for the second case study. As weighting adds an **additional level of uncertainty** to the LCIA, it is **recommended to investigate the influence of the weighting to the results**. This can be done either by testing the robustness of the results when several weighting sets are used, or either by extending the identification of the most relevant life cycle stages and processes to a longer list of impact categories (not limiting it to the most relevant impact categories or increasing the minimum level of three impact categories as now required by the PEF Guidance document v6.2). The results of the two cases moreover revealed that several of the most relevant impact categories identified are **'additional' impact categories** which are not included in the current version of the standards EN 15804 and EN 15978.

The **identification of the most relevant impact categories, life cycle stages and processes** was done in excel after exporting the LCIA results from the SimaPro software. Macro's were developed in excel (visual basic) to identify the most relevant impact categories, life cycle stages and processes in order to avoid time consuming manual work. **It would be helpful if in future the LCA software would allow to do this directly in the software**.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1. METHODOLOGICAL ASPECTS

At the start of the project, **several basic documents** (PEF Guide, PEF guidance document v 6.1 and draft PEFCRs for construction products) were screened in order to ensure that our PEF study at building level is in line with all the PEF requirements. The requirements and guidelines in these documents were found very helpful for modelling our two cases in a consistent way. Nevertheless, it was time consuming to screen all documents and make sure that all requirements were met. Although two of the three project partners were very familiar with the PEF method and several of the PEF pilots for construction products, it still took quite a lot of time to ensure every document was carefully considered. This was even a bigger challenge for the third project partner who was less familiar with all the documents available related to the PEF method. We therefore want to recommend/confirm the importance of a PEFCR at building level in future.

When analysing the various **draft PEFCRs of construction products**, we noticed that these are not fully aligned in terms of definition of life cycle stages and scenarios. Also for this reason a PEFCR at building level that forms the base for all (new) PEFCRs for construction products is recommended. This PEFCR at building level should ensure:

- That life cycle stages are consistently defined across PEFCRs of all construction product categories;
- Alignment between PEFCR at building level and PEFCRs at the construction product level.

Furthermore, we want to highlight that the various draft PEFCRs for construction products supported a time efficient assessment at building level. We noticed that the modelling of the building materials for which such a draft PEFCR was available, was easier/required less time than the modelling of the other building materials. Besides the draft PEFCRs for construction products, we could benefit from the available **Belgian horizontal PCR for Buildings and MMG method** (national LCA methods for building elements) to define the life cycle scenarios for many of the materials/building elements for which no draft PEFCR was yet available. Even for products covered by a PEFCR, these national guidelines often gave more detailed/accurate information for the products produced in Belgium. This allowed to make a consistent analysis and to make the study to a high quality within the limited timeframe we had. It is recommended to include such national scenarios in the PEFCR for buildings in future.

The PEF studies done in this research were studies of **buildings that were designed and constructed already**. All design decisions were hence taken and measured data were available for the use phase of the building. This is however a completely different situation than when a PEF study needs to be made to support the design process/is required for a building permit. A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear **guidelines to model the use phase** are moreover crucial as this life cycle stage is assumed to be the most relevant one for the majority of the buildings. One important parameter in this context is the reference study period and related references service lives.

The challenges and issues that people meet while using LCA at the building level are also valid for PEF. PEF specific issues are mainly the availability of PEF compliant generic datasets and the quality of the existing generic datasets (not always PEF compliant).

Since the PEF endorses the use of the CFF formula it is recommended that all generic datasets allow the application of the CFF formula. This should be a recommendation for further development. The purchased PEF compliant datasets the Commission bought is already a first step in that direction.

6.2. DATA COLLECTION AND STRUCTURING

For the modelling of the building, we have chosen for a **hierarchical decomposition of the building** in line with the element method for cost control. It was found that this rigid hierarchical structuring was not only very helpful but seen as crucial in order to:

- Systematically model a building avoiding any data gaps and/or double counting;
- Easily exchange information between partners working on the same project;
- Exchange information between the various level in the model, i.e. building material, sub-elements, elements and buildings.

Once the structure of the model was defined, the **data collection process** could start. This proved to be an intensive process where a high level of detail is needed to enable an accurate assessment. This level of detail is currently not available as such in design documents. A quite extensive list of documents needed to be searched for and examined to find all the data needed for the PEF study. It is however expected, that if PEF studies of buildings become current practice in future, this data will be more readily available in a single or limited number of documents.

For both buildings a **Building Information Model (BIM)** was available and was an added value as it significantly reduced the time needed for data gathering. The following data were retrieved from the BIM models:

- Quantities for level 1 (elements), expressed as m², pieces, m³;
- Quantities for Level 2 (sub-elements/layers), expressed as m², pieces, m³;

For both cases, the BIM models were insufficient as single data source and several other sources had to be added, such as technical information sheets, building cost sheets, architectural plans. Although additional sources were needed for both buildings, the BIM model for building BE2226 has improvements considering data gathering in comparison to the BelOrta BIM model. While the BelOrta BIM model was developed during the design process by the architects, the BE2226 BIM model was modeled after building completion based on the final documentation and with the idea to extract data for LCA purposes. Moreover, attention was paid to the Level Of Geometry in the BE2226 model and to model the different building elements in a way suitable for accurate quantity take-off. Further, the BE2226 model includes more detailed material specifications, while these are mainly generic in the BelOrta model. One example is the information included about the insulation materials. While the BelOrta model will only define that the relevant layer is an insulation layer, the BE2226 model will specify the type and characteristics of insulation used, e.g. XPS insulation.

Following **learnings** can be formulated based on the data gathering process performed in this study:

- BIM was an important source with added value that made this study feasible within the foreseen timeframe;
- The risk for errors increases with the number of documents that need to be combined to find all the necessary data. The number of documents hence should be as limited as possible, ideally everything should be combined in one single document, e.g. a BIM model;
- Important aspects for a BIM model to be used for LCA:
  - Completeness and accuracy (modelled and un-modelled elements);
  - Level Of Geometry (LOG) for modelled elements;
  - Level Of Information (LOI) regarding specification of material information.

It is hence recommended to specific BIM requirements to allow a better data provision for PEF (LCA) purposes and identify ways of integrating LCA data into BIM.

With regard to **data needs requirements for PEF studies of buildings** no clear rules exist yet. In our study we assumed that the Product stage consists of processes in Situation 3, while Construction products stage and Use stage are mainly in Situation 1 and 2, as defined in DNM of the Guidance document. Considering that no products are directly produced at building level, the use of specific data is not mandatory. For the goal of this project it was considered in agreement with the Commission that there is no added value to put time and effort in collecting specific data as this would require a lot of time and endanger the other parts of the project. We nevertheless acknowledge that the use of specific data would enhance the data quality and should be used in future when specific PEF compliant datasets will be available for construction products.

It is recommended to include in a PEFCR for buildings a definition of processes that are / are not under operational control of the building commissioner. A more extended consultation with relevant stakeholders should take place related define how primary versus secondary data should be used when making PEF assessments at building level.

6.3. Modelling in Excel and SimaPro

As buildings are complex entities, also the PEF model was highly complex consisting of large amounts of data. Due to this complexity, the risks of errors are high and as mentioned before, a systematic approach is necessary. An important learning in this context, was using coding/naming conventions and systematically apply these to all elements, sub-elements and building materials in the building.

As LCA is an iterative approach and our model was a combination of Excel and SimaPro, parametrisation of the model was introduced in order to avoid manual remodelling during each iteration. This approach greatly supported the integration of the parameters of the CFF formula and was also useful for the development of the first case study, BelOrta. The concept of using element and material specific ratios, to describe density and proportion of a certain construction material contained within a sub-element or element, was very useful for both case studies. However, the use of parameters for total quantities of materials or elements in the building, i.e. to establish a link between BIM and the SimaPro model via Excel, applicable for different building case studies, was found not feasible in the time given as the two buildings assessed were still very different in terms of element composition, materials used, etc. and would thus require a more refined generic structure to establish such a link properly. Thus no parameters for material quantities were used in the BE2226 assessment, while the parameters introduced for the CFF formula were of great help also for this case study.

The complexity of the model implies a time consuming process to establish the model. A generic template for the data collection and modelling is therefore recommended if PEF studies of buildings should become mainstream.

Regarding the life cycle inventory, it was found that a more extended list of generic datasets is needed to model an entire building and that the current Ecoinvent datasets did not allow to apply the CFF formula without adapting them. It is therefore recommended to:

- provide a database with construction materials in line with PEF;
- Integrate the CFF formula in the datasets.

6.4. Interpretation of results

From the LCA assessment, we can summarise the following learnings.

Modelling

The models of the two cases allowed to assess the building in a fairly easy way.

For the *BelOrta building* the results as presented in this chapter and the hotspot analysis as required by the PEF method could be directly extracted from the SimaPro model, except for the process contribution of the processes in the life cycle stages PEF_A2 and PEF_A4. For the hotspot analysis, it would be helpful if these life cycle stages are modelled in a disaggregated form. The BelOrta SimaPro model allows to directly extract the LCIA results at the level of the building, at the level of the life cycle stage, at the level of the element in each life cycle stage, and at the level of the material/process.

For the *BE2226 building* the modelling in SimaPro was done on material level for all main building elements (foundation, walls, floors, etc.), as the required total quantities for this could be directly extracted from the BIM model with the required accuracy. Secondary elements, like windows and doors, were modelled as aggregated datasets combining the materials contained within one piece of element. This modular approach allowed for a detailed modelling of these elements and offers an efficient way of modelling that could as well be used for a changing number of elements e.g. windows during a design process. Results derived from SimaPro could thus directly be used for the analysis of most relevant life cycle stages and impact categories. For most relevant processes the same issues as mentioned for BelOrta already were faced, as transport had to be disaggregated in excel afterwards – this limitation however can be overcome when modelling these life cycle stages accordingly, with material-specific transport values.

The above mentioned modelling aspects are in part related to the applied workflow and software solutions and may well be different in other cases.

Method

The inclusion/exclusion of the toxicity impact category clearly influences the results to a significant extent, especially for the second case study. As weighting adds an additional level of uncertainty to the LCIA, it is recommended to investigate the influence of the weighting to the results. This can be done either by testing the robustness of the results when several weighting sets are used, or either by extending the identification of the most relevant life cycle stages and processes to a longer list of impact categories (not limiting it to the most relevant impact categories or increasing the minimum level of three impact categories as now required by the PEF Guidance document v6.2). The results of the two cases moreover revealed that several of the most relevant impact categories identified are 'additional' impact categories which are not included in the current version of the standards EN 15804 and EN 15978.

Hotspots

The identification of the most relevant impact categories, life cycle stages and processes was done in excel after exporting the LCIA results from the SimaPro software. Macro's were developed in excel (visual basic) to identify the most relevant impact categories, life cycle stages and processes in order to avoid time consuming manual work. It would be helpful if in future the LCA software would allow to do this directly in the software.

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ANNEXES

ANNEX 0-A – MINUTES OF THE 1ST STAKEHOLDER MEETING IN BRUSSELS, INCLUDING FEEDBACK OF STAKEHOLDERS

Date and location

PEF4Buildings - 1st Stakeholder Workshop
July 5th 2017
Brussels, EC Conference Centre Albert Borschette (Rue Froissart 36, 1040 Brussels, Belgium, Meeting room 0D)

Agenda

9:00-9:30 am - Registration and welcome coffee
9.30 - 9:45 am
Introduction on PEF method, PEF pilot phase and PEF4Building objectives by EC
9:45 – 10:00 am
PEF4Buildings project in a nutshell
- Project team
- Tasks
- Planning

10:00 – 10:30 am
Project framework and methodology
- General objective of the study
- System boundaries, scope, FU, scenarios
- Presenting the two building case studies
- PEF method and existing PEFCR for construction sector
- Benchmarking approach

10:30 – 10:45 am
Time for clarifying questions
10:45 – 11:15 am: Coffee break
11:15 – 12:00 am
PEF4Buildings project results
- Case 1
- Case 2
- Challenges

12:00 -12:15 pm
Conclusions and preliminary recommendations for steps forward
12:15 – 1:00 pm
Interactive discussion with stakeholders
Closing of the meeting

Representatives from the following organisations participated

AGC Glass Europe
ALIAXIS/ PEF pipes pilot
ArcelorMittal
Archipelago | ar-te
Architectenvennootschap ar-te
BASF
Belgian Brick Association
BIBM – Precast Concrete
Building Research Establishment (BRE)
CD2E
CEMBUREAU – The European Concrete Association
CEN SABE
CEN TC 650
CEPE
Cerame-Unie
Construction Products Association UK
Construction Products Europe
Ecomatters
Environmental Agency Austria
EUMEPS
Eurima
EUROFER – The European Steel Association
Eurogypsum
European Calcium Silicate Producers' Association
European Commission – DG Environment
European Commission, Joint Research Centre
Federal Ministry for Environment and Building, Germany
Hitachi
IBO GmbH
IBU
KU Leuven
Ministère de la transition écologique et solidaire/ Ministère de la cohésion des territories, France
NIBE
OVAM
PEP Ecopassport
PlasticsEurope
Politecnico di Milano
Rockwool
Saint Gobain
Schneider Electric
Solinnen
SPF Santé publique, sécurité de la chaine alimentaire et environnement, Belgium
Swiss Federal Office for the Environment
Technische Universitaet Berlin
Thinkstep AG
TU Graz
UECBV
VITO
Wienerberger

Minutes

- **Welcome by EC (Michele Galatola)**
- **Agenda (Carolin Spirinckx)**
- **Introduction to PEF by EC (Michele Galatola)**
- **PEF for buildings project in a nutshell (Carolin Spirinckx)**
- **Project Framework and methodology (Carolin Spirinckx)**
- **Clarifiying questions (moderated by Alexander Passer)**

1) Wienerberger:
   i) Impact categories and indicators: How will you deal with this in the project? Which indicators are used? How do take into account findings of TC350 about additional indicators?
      (1) A (P4B Team): Impact categories: Guidance 6.1 used, also taken into account additional categories TC350. Weighting set of Guidance 6.2
   ii) A1 default value 550 km of transport. Why so much? (bigger than Belgium)?
      (1) A: To have worst case scenario if no data is available – incentive to provide data.
   iii) Functional unit. One piece of building? Ignoring size of building? Questioning the definition of functional unit.
      (1) A (KU Leuven): Had discussion on that – atm not impact per sqm. Drawback is that impact is divided /lower for big building. Person-based metric is variable (different occupation). For benchmarking: Maybe division of buildings in size, classes of building types, discussion to be had.
      (2) A (DG ENV): Goal not to come up with the definite number, neither the ones used for assessment, nor for the results – no sense to discuss numbers today – Discussion of approach.
2) Environmental Agency (Umweltbundesamt Austria):
   i) Q: Possibility of using the existing datasets of transport (from tender) for this study?
      (1) A (DG ENV): All datasets tendered can be used by external users for implementation. Can be used by contractors for all studies. Technical problem for this study, datasets were still under improvement, thus not possible to implement them. Again, difference are numbers – this study focuses on the modelling, not the numbers.
3) Rockwool:
   i) Q: PCRs. In the Netherlands we have a method – which can be seen like PCR –which is available. For the purpose of your study you only used the Belgian horizontal PCR and the MMG method. Why? I would request to include other approaches/methods from other countries in a kind of literature list in your report.
      (1) A (VITO): As building is in Belgium, the Belgian PCRs were used. For benchmarking it can be interesting to include reference to other approaches/data/PCRs and we will look at them during task 2.
4) Insulation industry:
   i) Q: New office buildings, would it make sense to look into renovation scenarios? Biggest impact in use phase (of existing buildings). What are future possibilities to look into renovation scenarios?
      (1) A DG ENV: Pragmatic decision - opening in budget, possibility to do a (limited) study) – starting with scope on new building scenarios, then evolve to investigate refurbishment scenarios in other studies.
5) European Expanded Clay association:
   i) Q: RSP 50yrs seems short. Is it because it's an office, longer for housing?

(1) A (KU Leuven): 50 yrs is standard reference in most studies. Some countries do 60 yrs, range between 50-60 yrs.

6) Politecnico di Milano:
   i) Q: Why two case studies? Do you think that could be representative of European Situation?
      (1) A: Coming back to that in the next part of presentation.
7) German Ministry Environment, Germany:
   i) Q: Scope of study. Thought it should be combination of existing standards, now feels like EN 15804 should be replaced? All replaced by PEF? Why do we need a new system for benchmarking, how does it interfere with existing?
      (1) Q (DG ENV): Clarification of misunderstanding: No improvement of 15804 (product level), this study is on building level. Objective: What will be implication of doing a PEF study on building level. Similar information than what you get from CEN standard on building level. Not as replacement but to understand possibility of the approach put forward by JRC – Core indicators, additional indicators for performance of building – proposed indicators resulting from PEF study. Investigate what can be covered by PEF on building. If CEN fails to deliver what is in new mandate, EC will have to rely on PEF method – worst case scenario, hopefully not required.
   ii) Q: New mandate number?
      (1) A: Revision to existing mandate 350. Actively working since one year. Agreement to have first draft/technical agreement available end of Summer/October 2017.
8) Thinkstep
   i) Q: Functional unit: in DGNB m²FloorArea/a. Study with different sizes, no correlation for this study! – Recommendation towards benchmarking approach.
   ii) Q2: Use stage; what was included? Heating, cooling?
      (1) A (KU Leuven): Full energy bill from architects, averaged over 3 years. Energy consumption for existing building when calculating new building. If no specific data on use phase, different approach is required, later discussed.
9) Hitachi:
   i) Q1: Do you have a plan to develop a building PEFCR?
   ii) Q2: Do you want to have building PEFCR?
   iii) Q3: Data center (building typology) included scope?
      (1) A3 (VITO): Clarification? IT equipment not included. Energy consumption is included. (Karen): No inventory/datasets for building will be developed within this study.
      (2) A1: No PEFCR for buildings will be developed in this study. Recommendations for a draft will be given.
      (3) A2/3 (KU Leuven): Not in scope (scope new office buildings). Same principles may apply.
10) Eurima
   i) Q: Datasets from Ecoinvent. Will you have assessment of co-product allocation? How much this could make assessment on building level difficult? Especially for allocation rules for EoL of materials, that become visible on building level.
      (1) A (VITO): Current datasets to not allow look into allocation of co-products. To take this into consideration, more detailed datasets required. Currently existing datasets adapted to apply CFF, without alternating allocation in the background. Not possible to address this at this step. New datasets will have to allow this.
   ii) Add: Request to report findings on what it means for development of new datasets?

End of first session, Coffee break

- **PEF4Buildings project results (Karen Allacker) and Preliminary Conclusions/Take home messages (Alexander Passer)**
- **Interactive discussion with stakeholder (VITO moderated)**

1) <u>Thinkstep:</u>
   i) Q: Estimation whether it is feasible to do PEF study on building level based on recommendations in guidance document. Especially regarding data required?
      (1) A (KU Leuven): Difficult to generalize – Case studies chosen as we knew data would be available. Data gathering is time consuming now, but feasible and improvable– once datasets provided the application on building level, using these datasets, shall be feasible.
      (2) A (VITO): Might be included in building PEFCR. What processes are included, where to use primary/secondary data.
2) <u>PEF pilot “pipes”/ Aliaxis:</u>
   i) Q: Chapter 1.5: How to define the best way to report. Goal to discriminate buildings? Will you take into account existing building schemes or just PEF communication tools?
      (1) A (VITO): Will be part of next step: benchmarking. “communication” is not a separate task in this study.
      (2) A (DG ENV): Premature discussion, cannot discuss use of PEF before we know what PEF can/cannot do. Discussion on how to use assessment of building using PEF is too early. Interest is to understand if it’s feasible to do PEF on buildings in future. What to do with it then is beyond scope of this study.
3) <u>AGC Glass Europe:</u>
   i) Q: Intend to do with the results? Comparison of technologies? Comparison on materials?
      (1) A (KU Leuven): Intention not to compare materials or technologies, but to test application of method.
      (2) A (DG ENV): Depends on who is doing the study and for what purpose. If doing it to build building, you look into supply chain, identify hotspots and try to improve. At same time, once you have built you can communicate final performance. Two applications: 1) To improve performance of product and 2) to communicate results/performance of building.
   ii) Q2: Benchmarks: Do you have in mind to go for country-specific benchmarks? Use stage important?
      (1) A (VITO): Is to be discussed, will be presented in next workshop in November.
4) <u>CEN SABE:</u>
   i) Q: Link between the PEFCR of building and PEFCR for materials? Recommendations of what needs to be changed in existing draft PEFCR of materials.
      (1) A (KU Leuven): Checked consistency of draft PEFCRs of materials, not aligned.
      (2) A (VITO): PEFCRs on materials should be in line with scenarios defined on building level – potentially in PEFCR for building.
5) <u>German Ministry Environment:</u>
   i) Q: Relation of PEFCR to existing EN 15798 for building?
      (1) A: Looked at EN, noticed that when aim is to harmonize rules for PEF, EN rules are not specified strict enough. Thus rules have to be specified to align assumptions/rules of the assessment.
      (2) A (VITO): Goal of work of TC350 to work towards alignment, not just on product but on building level.

6) CEN SABE:
   i) EN 15978 stricter than EN 15804?
      (1) A (DG ENV): Don't expect so. In mandate: Whatever change is done in 15804 has to be kept consistent 15978. Not asked to make 15978 more strict – this would be voluntary.
7) European Ceramic Association, CERAME-UNIE
   i) Comment: PEFCR for office building should be in line with EN 150814 (EPDs for construction materials) and EN 15978 (for buildings)?
   ii) A (DG ENV): This is not/will not be a PEFCR for office buildings. If there will be such a thing, it will come afterwards. Careful with terminology: Today PEF and 15804 – through alignment will be as aligned as possible, won't be totally aligned (maximum compromise achievable), not fully compliant. In context of PEF, PCR of buildings (has to be compliant), then EPD (15804) will not be compliant. Crossroads: either go with 15804 or PEF. (?!)
8) Eurima:
   i) Comment: Congratulations on team for presentation.
   ii) Q: Hardly specifics about PEF noticeable, what difference to 15804. What is specific to PEF approach, what is specific to PEF LCA of buildings? Can be seen: good data for products required, BIM as data source to be developed, better data provision required (not one database throughout Europe). For assessment PEFCR on Belgium level was required – different for member states, "default" changes. Will conclusion cover these differences? Which relate to PEF, which are general for LCA?
      (1) A (KU Leuven): Confirms many issues are general for LCA of buildings. Specific challenges of application of PEF to be looked into more detail – check what was in national PEFCR and what wasn't. For data: yes, it should be there (available), once it is LCA will be more straight forward. Specific to PEF: data quality requirements – quality of results depend on it. Especially for benchmarking requirement to use primary data on Level -1 is crucial – different to other methods.
   iii) A (DG ENV): Not method, but in PEF required to use the same source of data for the inventory
   iv) A (VITO): What we see in 15804/15897, not in PEF, for all materials end of waste status has to be defined – very difficult, rule not clear, can differ from material to material. Added value of PEF, Using PEF/CFF it is aligned for all materials.
9) Rockwool:
   i) Q: Why so much effort in applying formula if it doesn't work with Ecoinvent? Is it easier to apply than end of waste status? Could you do it for several materials, how on national/international level? Assumption that material PEFCR could be aligned on European level (ignoring that special scenarios are different). What type of questions are to be answered with this study? Interesting to see study looking at contribution of elements/materials. What questions regarding application of PEF on building does it answer? Impressions that conclusions presented are not connected to PEF.
      (1) A (KU Leuven): Many questions general for LCA. If just done LCA study, would not have looked at PEFCR for construction materials. For many LCA on building level you don't investigate PEFCRs.
   ii) Q: When you want to do something for benchmarking on buildings, EN 15897 could be applied (?!). Nice learnings, but why study – specifics of application of PEF?
      (1) A (VITO), agrees to discuss later.
10) German Ministry Environment:
   i) Q: EN has "voluntary information", could be possible to integrate in PEF? Discussion on indoor air pollution is crucial. In evaluation system for sustainable buildings in GER its

becoming more and more mandatory in building standards. Fear of implementing it in EN, if EN might be lost/not used.

(1) A (DG ENV): In technical report, issue of indoor air pollution is included as one of the impact categories to be further analyzed. Ongoing discussion. Thus, not in list of mandatory impacts in PEF. In PEFCRs pilots are implementing voluntary/additional information. It will not be lost in case it is moved from EN to PEF framework – stresses again this is not the intention (to move)

11) Wienerberger:

i) Q: PCR, a number of prepared by EU, a number prepared by national institutions. Ongoing standardization in CEN – concrete finished, masonry, roofing under development. Certain amount of PCR available today. Recommendation of team to provide PEFCR of buildings as basis for PCR on products? Will PCRs have to be redone? Potential for increasing confusion with an additional scheme?

(1) A (VITO): With new mandate/new EN 15897 PCRs will have to be updated. Currently in a transition phase. Current PEFCRs an PCRs will anyhow need an update in time.

(2) A (DG ENV): Elaborated answer. In context of CEN and mandate, all PCRs have expiry date, have to be redone from time to time. When new standard available, PCRs have to be update – fundamentals in standard stay the same. Did not change fundamentals – looking forward to transition/concept to be allowed to use both systems. Regarding the potential confusion, not a complication of schemes: PEF started because proliferation of schemes and labels, member states told EC to do something for comparability/fair competition. PEF only has one (!) set of rules similar for all over Europe. If moving to PEF proliferation is solved, potentially not possible with existing system. Pragmatic approach, trying to find best solution with all stakeholders.

12) EUMEPS:

i) Q: Remarks about usefulness of PEFCRs when making the evaluation at building level? Will be given now or at end of project?

(1) A (KU Leuven): Clear difference in time needed. Clear benefit, much more difficult to define scenarios for materials without PEFCRs.

ii) Q: Difference between PEFCRs?

(1) A (KU Leuven): Analysis of LCS and scenarios of PEFCR done. Inconsistencies need to be solved. Not major inconsistencies, can be overcome.

13) European Steel Association:

i) Good study, liked different aggregation level (element, materials). Challenge of transforming BIM? into LCI. Requirement to develop tool to streamline this process? Application of BIM is not use for majority of projects, another tool required? Can a tool be developed to support this process? Implied changes to EPDs?

(1) A (KU Leuven): Method applicable at the moment. To make it more time efficient development of a tool would be very beneficial to make it common practice. However not specifically needed to make it applicable. Especially for small building process should be streamlined to be efficient. For EPDs, if everything changes you need a new EPD. If recipe is available (background data) it can be done efficiently. Didn't look at raw materials in this study, EPDs are fine.

14) Expanded Clay Association:

i) Congratulates on study, very interesting. Q: Transition phase. Will be other stakeholder involvement opportunities? Consultation when PEF developed and EPD revised?

(1) A (DG ENV): As said, between now and end of 2018, two important developments defined in Circular Economy action plan. Follow up PEF pilot and Sustainable

Product Policy Framework (SPPF) looking at products, if changed/new legislation is required. In this context, implications of using PEF or not will be checked – "building world" will be involved. Thus mandate of this work is sanctioned – need to know what will be done with 15804, CE marking, etc. Any of such decisions has to be anticipated by in depth impact assessment – includes consultation with stakeholders, will be consulted. Several occasions where this discussions will take place, e.g. conference after end of pilot pahse (maybe beginning 2018)

15) Politecnico di Milano:
    i) Q: Benchmark of buildings: Reference list of buildings (best practice) or reference values? Reference, target values?
        (1) A (KU Leuven): Make approach (!) on how to define benchmarks (methodology). No benchmark or classes of performance will be defined in this project.
        (2) A (VITO): If, benchmarks are fixed values (following PEF). If a range, then its performance class

16) BASF:
    i) Q: Applicability, is it more more less complicated as current LCA on building level? If so, why? Quality requirements? Difficulty of applying CFF cause of non-compliant datasets – CEN mandate does not require to align with CFF. Applicability of CFF on building level interesting?
        (1) A (DG ENV): PEF easier as current system? Looking for something more easy or more reliable? Not asking to implement CFF in CEN; would be to abandon end of waste, change system boundaries there – not the point if CFF is applicable to CEN. To what extent CFF is applicable if implementing a PEF on building level.

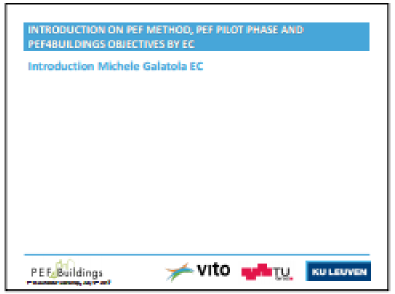
17) Environmental Agency Austria:
    i) Better data required. Then results can be looked at. Happy to see it can be applied. Many things to solve for wide applicability. Looking forward to benchmarking discussion. What kind of data is required in the long run; country specific data with different level of detail? How to provide this information? Need for database in the background to be used, non-commercial. Need to solve the data problem.
        (1) Remark (KU Leuven): Emphasis on data because we had to use non-compliant datasets. PEF compliant datasets needed.

18) Plastic Europe:
    i) Q: Benchmark for building would be compatible with benchmark on level of sub-elements?
        (1) A (DG ENV): Too early to say. Concept of benchmark for products is clear. "Performance of average project on market". Question is about a concept that could be compliant with PEF? Very preliminary aspect. Not at the step to provide answers to this question. First have to develop concept based on PEF requirements, then can check link to other concepts around.

- **Closing remarks (VITO):**

Feedback before End of July 2017 via Email

Slides used during workshop



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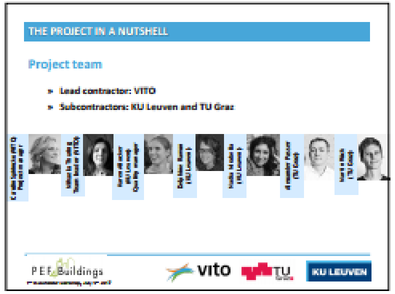
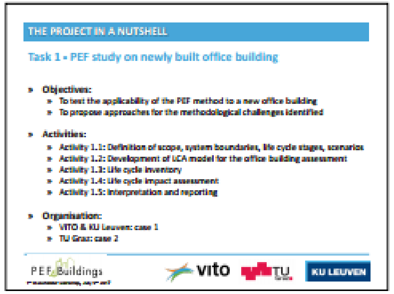
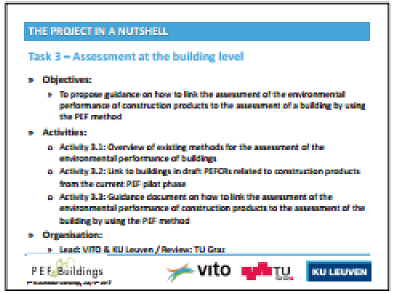
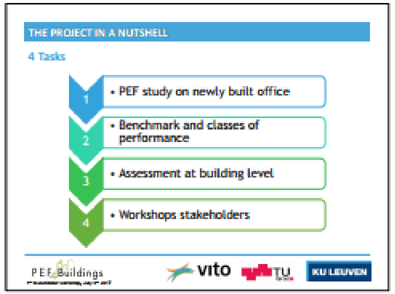
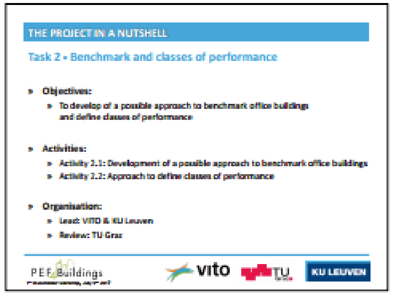

THE PROJECT IN A NUTSHELL
Project team
Lead contractor: VITO
Subcontractors: KU Leuven and TU Graz
PEF Buildings


THE PROJECT IN A NUTSHELL
Task 1 - PEF study on newly built office building
Objectives:
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
Activities:
Activity 1.1: Definition of scope, system boundaries, life cycle stages, scenarios
Activity 1.2: Development of LCA model for the office building assessment
Activity 1.3: Life cycle inventory
Activity 1.4: Life cycle impact assessment
Activity 1.5: Interpretation and reporting
Organisation:
VITO & KU Leuven: case 1
TU Graz: case 2
PEF Buildings


THE PROJECT IN A NUTSHELL
Task 3 – Assessment at the building level
Objectives:
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method
Activities:
Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings
Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Organisation:
Lead: VITO & KU Leuven / Review: TU Graz
PEF Buildings


THE PROJECT IN A NUTSHELL
4 Tasks
1
PEF study on newly built office
2
Benchmark and classes of performance
3
Assessment at building level
4
Workshops stakeholders
PEF Buildings


THE PROJECT IN A NUTSHELL
Task 2 - Benchmark and classes of performance
Objectives:
To develop of a possible approach to benchmark office buildings and define classes of performance
Activities:
Activity 2.1: Development of a possible approach to benchmark office buildings
Activity 2.2: Approach to define classes of performance
Organisation:
Lead: VITO & KU Leuven
Review: TU Graz
PEF Buildings


THE PROJECT IN A NUTSHELL
Task 4 – Workshops with stakeholders
Objectives: organisation of two workshops:
1. WS 1: to present the draft final results of the PEF studies (task 1)
2. WS 2: to present the proposed approach to develop a benchmark and classes of performance (task 2) and an approach for assessment at the building level (task 3)
Activities:
Activity 4.1: Workshop 1 – TODAY
Activity 4.2: Workshop 2 – November 2017 (week from 20/11 to 27/11 – specific date to be fixed and communicated)
Organisation:
VITO, KU Leuven and TU Graz
PEF Buildings

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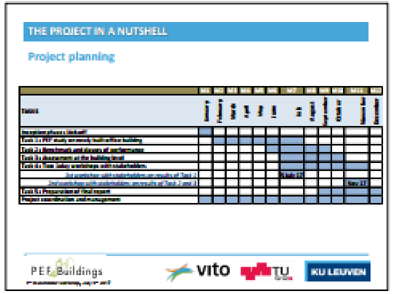
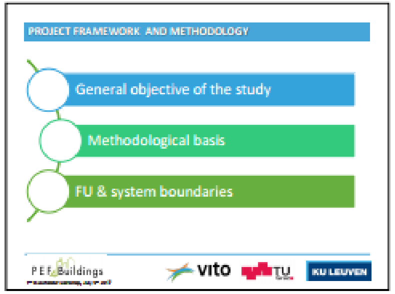
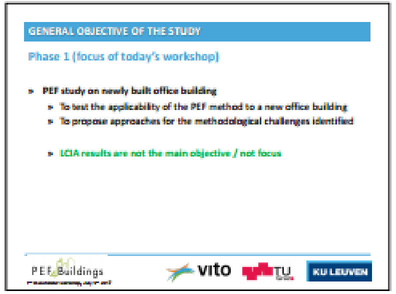
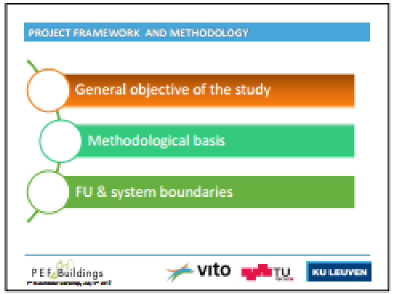
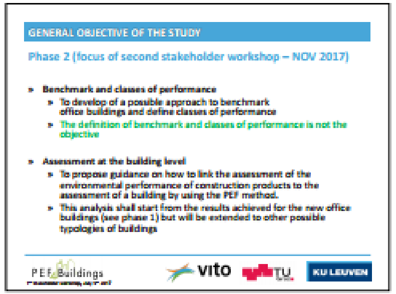

THE PROJECT IN A NUTSHELL
Project planning


PROJECT FRAMEWORK AND METHODOLOGY
General objective of the study
Methodological basis
FU & system boundaries


GENERAL OBJECTIVE OF THE STUDY
Phase 1 (focus of today's workshop)
PEF study on newly built office building
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
LCIA results are not the main objective / not focus


AGENDA FOR STAKEHOLDER'S WORKSHOP
Registration and welcome coffee (9:00-9:30 am)
Coffee break (10:45 – 11:15 am)
Closing of the meeting (1 pm)


PROJECT FRAMEWORK AND METHODOLOGY
General objective of the study
Methodological basis
FU & system boundaries


GENERAL OBJECTIVE OF THE STUDY
Phase 2 (focus of second stakeholder workshop – NOV 2017)
Benchmark and classes of performance
To develop of a possible approach to benchmark office buildings and define classes of performance
The definition of benchmark and classes of performance is not the objective
Assessment at the building level
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method.
This analysis shall start from the results achieved for the new office buildings (see phase 1) but will be extended to other possible typologies of buildings

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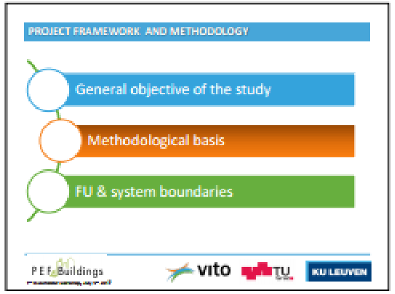
PROJECT FRAMEWORK AND METHODOLOGY
General objective of the study
Methodological basis
FU & system boundaries
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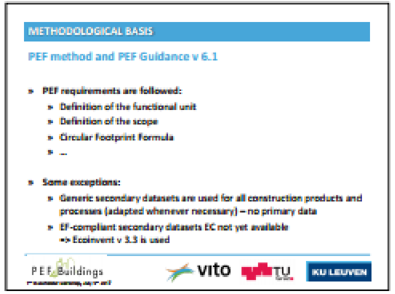
METHODOLOGICAL BASIS
PEF method and PEF Guidance v 6.1
PEF requirements are followed:
Definition of the functional unit
Definition of the scope
Circular Footprint Formula
…
Some exceptions:
Generic secondary datasets are used for all construction products and processes (adapted whenever necessary) – no primary data
EF-compliant secondary datasets EC not yet available
=> Ecoinvent v 3.3 is used
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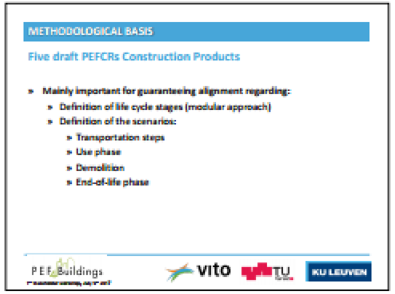
METHODOLOGICAL BASIS
Five draft PEFCRs Construction Products
Mainly important for guaranteeing alignment regarding:
Definition of life cycle stages (modular approach)
Definition of the scenarios:
Transportation steps
Use phase
Demolition
End-of-life phase
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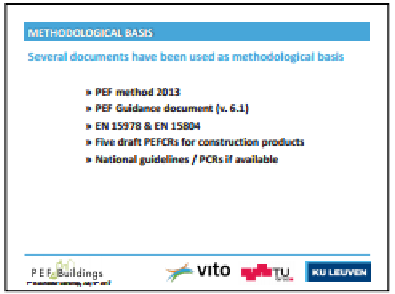
METHODOLOGICAL BASIS
Several documents have been used as methodological basis
PEF method 2013
PEF Guidance document (v. 6.1)
EN 15978 & EN 15804
Five draft PEFCRs for construction products
National guidelines / PCRs if available
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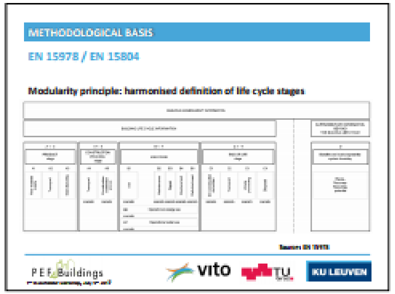
METHODOLOGICAL BASIS
EN 15978 / EN 15804
Modularity principle: harmonised definition of life cycle stages
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METHODOLOGICAL BASIS
Five draft PEFCRs Construction Products
Product Environmental Footprint
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METHODOLOGICAL BASIS
National guidelines
Not for all products draft PEFCRs are available
National guidelines/PCRs were consulted too
MMG method
+
Belgian PCR 4.1
OVAM
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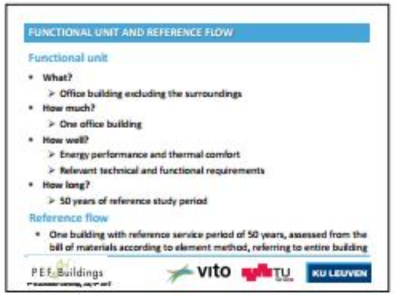
FUNCTIONAL UNIT AND REFERENCE FLOW
Functional unit
What?
Office building excluding the surroundings
How much?
One office building
How well?
Energy performance and thermal comfort
Relevant technical and functional requirements
How long?
50 years of reference study period
Reference flow
One building with reference service period of 50 years, assessed from the bill of materials according to element method, referring to entire building
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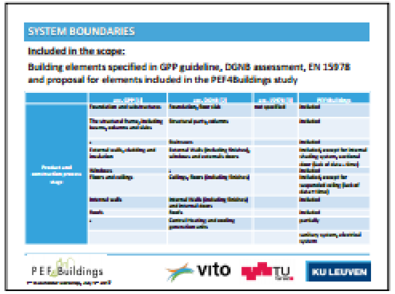
SYSTEM BOUNDARIES
Included in the scope:
Building elements specified in GPP guideline, DGNB assessment, EN 15978 and proposal for elements included in the PEF4Buildings study
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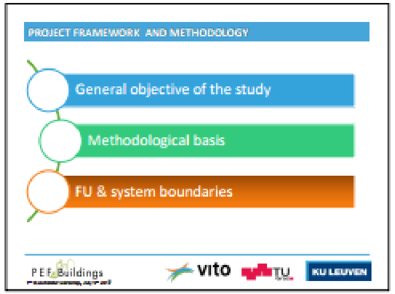
PROJECT FRAMEWORK AND METHODOLOGY
General objective of the study
Methodological basis
FU & system boundaries
PEF4Buildings
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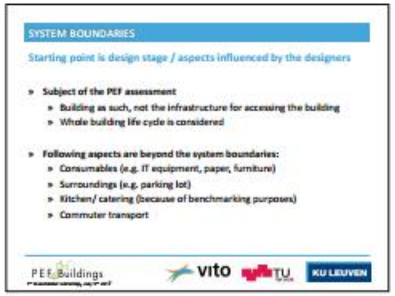
SYSTEM BOUNDARIES
Starting point is design stage / aspects influenced by the designers
Subject of the PEF assessment
Building as such, not the infrastructure for accessing the building
Whole building life cycle is considered
Following aspects are beyond the system boundaries:
Consumables (e.g. IT equipment, paper, furniture)
Surroundings (e.g. parking lot)
Kitchen/ catering (because of benchmarking purposes)
Commuter transport
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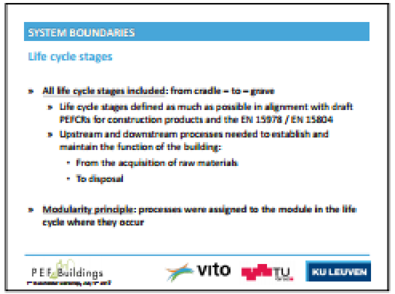
SYSTEM BOUNDARIES
Life cycle stages
All life cycle stages included: from cradle – to – grave
Life cycle stages defined as much as possible in alignment with draft PEFCRs for construction products and the EN 15978 / EN 15804
Upstream and downstream processes needed to establish and maintain the function of the building:
From the acquisition of raw materials
To disposal
Modularity principle: processes were assigned to the module in the life cycle where they occur
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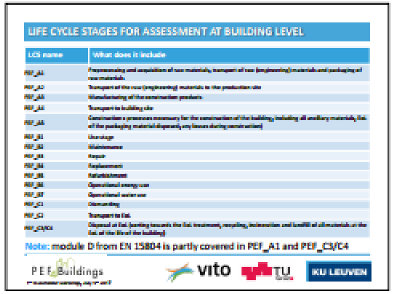
LIFE CYCLE STAGES FOR ASSESSMENT AT BUILDING LEVEL
LCS name
What does it include
Transport of the raw (engineering) materials to the production site
Manufacturing of the construction products
Transport to building site
Use stage
Maintenance
Repair
Replacement
Refurbishment
Operational energy use
Operational water use
Dismantling
Transport to EoL
Note: module D from EN 15804 is partly covered in PEF_A1 and PEF_C3/C4
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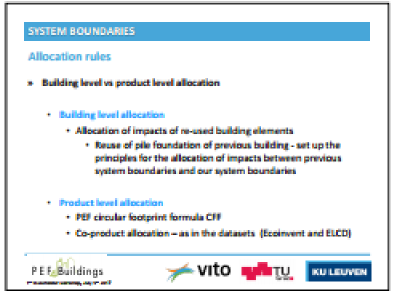
SYSTEM BOUNDARIES
Allocation rules
Building level vs product level allocation
Building level allocation
Allocation of impacts of re-used building elements
Reuse of pile foundation of previous building - set up the principles for the allocation of impacts between previous system boundaries and our system boundaries
Product level allocation
PEF circular footprint formula CFF
Co-product allocation – as in the datasets (Ecoinvent and ELCD)
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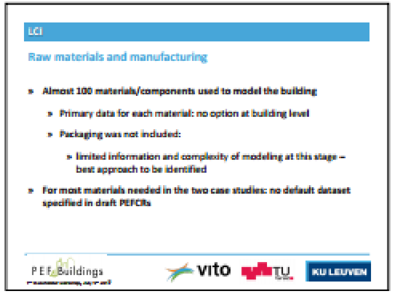
LCI
Raw materials and manufacturing
Almost 100 materials/components used to model the building
Primary data for each material: no option at building level
Packaging was not included:
limited information and complexity of modeling at this stage – best approach to be identified
For most materials needed in the two case studies: no default dataset specified in draft PEFCRs
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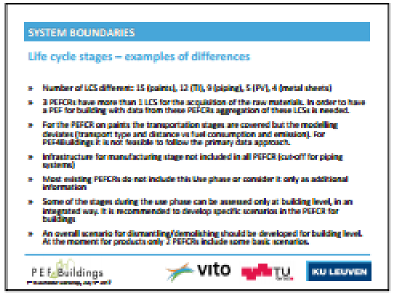
SYSTEM BOUNDARIES
Life cycle stages – examples of differences
Number of LCS different: 15 (paints), 12 (TI), 9 (piping), 5 (PV), 4 (metal sheets)
3 PEFCRs have more than 1 LCS for the acquisition of the raw materials. In order to have a PEF for building with data from these PEFCRs aggregation of these LCSs is needed.
For the PEFCR on paints the transportation stages are covered but the modelling deviates (transport type and distance vs fuel consumption and emission). For PEF4Buildings it is not feasible to follow the primary data approach.
Infrastructure for manufacturing stage not included in all PEFCR (cut-off for piping systems)
Most existing PEFCRs do not include this Use phase or consider it only as additional information
Some of the stages during the use phase can be assessed only at building level, in an integrated way. It is recommended to develop specific scenarios in the PEFCR for buildings
An overall scenario for dismantling/demolishing should be developed for building level. At the moment for products only 2 PEFCRs include some basic scenarios.
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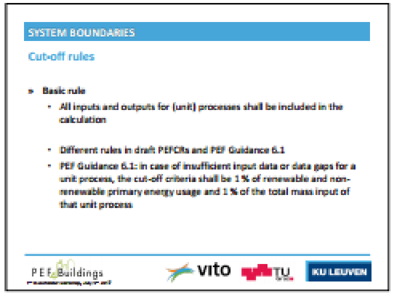
SYSTEM BOUNDARIES
Cut-off rules
Basic rule
All inputs and outputs for (unit) processes shall be included in the calculation
Different rules in draft PEFCRs and PEF Guidance 6.1
PEF Guidance 6.1: in case of insufficient input data or data gaps for a unit process, the cut-off criteria shall be 1 % of renewable and non-renewable primary energy usage and 1 % of the total mass input of that unit process
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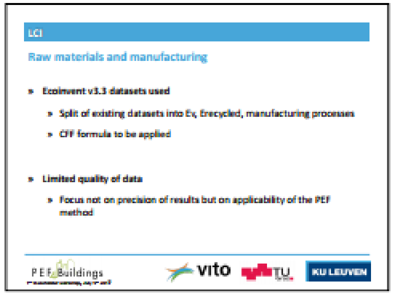
LCI
Raw materials and manufacturing
Ecoinvent v3.3 datasets used
Split of existing datasets into Ev, Erecycled, manufacturing processes
CFF formula to be applied
Limited quality of data
Focus not on precision of results but on applicability of the PEF method
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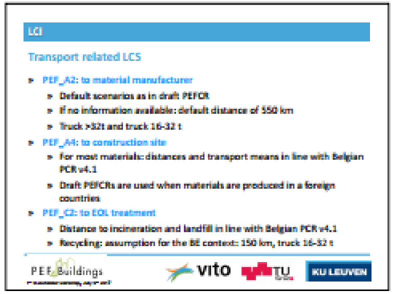
LCI
Transport related LCS
PEF_A2: to material manufacturer
Default scenarios as in draft PEFCR
If no information available: default distance of 550 km
Truck >32t and truck 16-32 t
PEF_A4: to construction site
For most materials: distances and transport means in line with Belgian PCR v4.1
Draft PEFCRs are used when materials are produced in a foreign countries
PEF_C2: to EOL treatment
Distance to incineration and landfill in line with Belgian PCR v4.1
Recycling: assumption for the BE context: 150 km, truck 16-32 t
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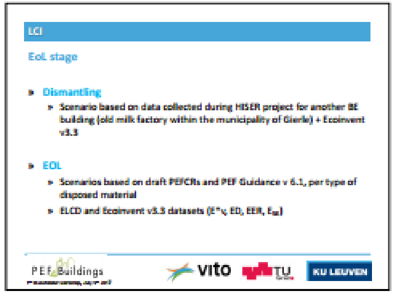
LCI
EoL stage
Dismantling
Scenario based on data collected during HISER project for another BE building (old milk factory within the municipality of Gierle) + Ecoinvent v3.3
EOL
Scenarios based on draft PEFCRs and PEF Guidance v 6.1, per type of disposed material
ELCD and Ecoinvent v3.3 datasets (E*v, ED, EER, ESE)
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QUESTIONS STAKEHOLDERS
Time for clarifying questions
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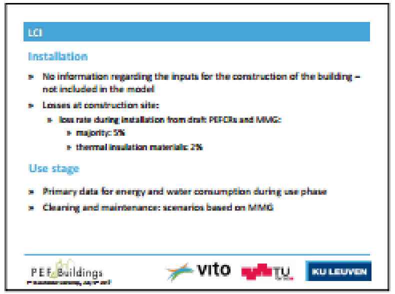
LCI
Installation
No information regarding the inputs for the construction of the building – not included in the model
Losses at construction site:
loss rate during installation from draft PEFCRs and MMG:
majority: 5%
thermal insulation materials: 2%
Use stage
Primary data for energy and water consumption during use phase
Cleaning and maintenance: scenarios based on MMG
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AGENDA FOR STAKEHOLDER'S WORKSHOP
Registration and welcome coffee (9:00-9:30 am)
Time for clarifications (10:30 am – 10:45 am)
Coffee break (10:45 – 11:15 am)
Closing of the meeting (1 pm)
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AGENDA FOR STAKEHOLDER'S WORKSHOP
Registration and welcome coffee (9:00-9:30 am)
Coffee break (10:45 – 11:15 am)
Closing of the meeting (1 pm)
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COFFEE BREAK
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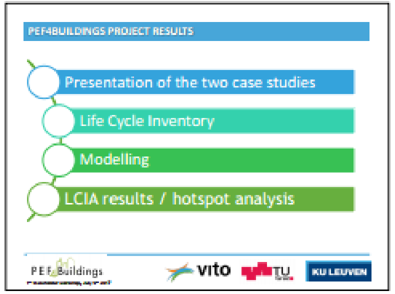
PEF4BUILDINGS PROJECT RESULTS
Presentation of the two case studies
Life Cycle Inventory
Modelling
LCIA results / hotspot analysis
PEF4Buildings
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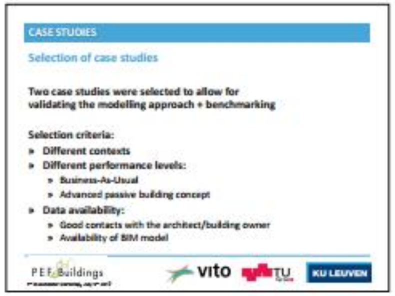
CASE STUDIES
Selection of case studies
Two case studies were selected to allow for validating the modelling approach + benchmarking
Selection criteria:
Different contexts
Different performance levels:
Business-As-Usual
Advanced passive building concept
Data availability:
Good contacts with the architect/building owner
Availability of BIM model
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AGENDA FOR STAKEHOLDER'S WORKSHOP
Registration and welcome coffee
PEF4Buildings project results (11:15 am – 12:00 am)
Closing of the meeting (1 pm)
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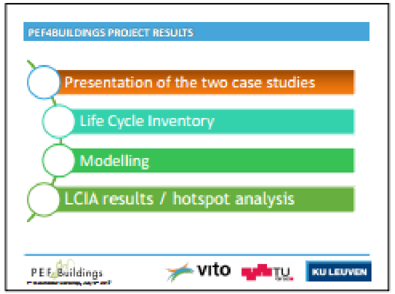
PEF4BUILDINGS PROJECT RESULTS
Presentation of the two case studies
Life Cycle Inventory
Modelling
LCIA results / hotspot analysis
PEF4Buildings
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CASE STUDIES
Case study 1 – Belgium: BelOrta
Architect: AR-TE
Client: BelOrta scrl
Construction year: 2014
Context: suburban (St-Katelijne-Waver)
Net floor surface: 3000 m²
Represents: BAU office, in use
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CASE STUDIES
Case study 1 – Belgium: BelOrta
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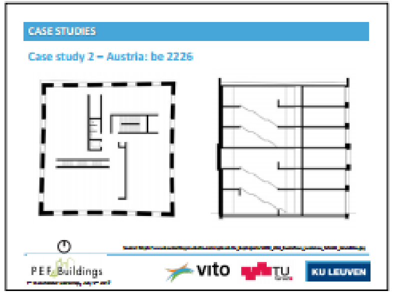
CASE STUDIES
Case study 2 – Austria: be 2226
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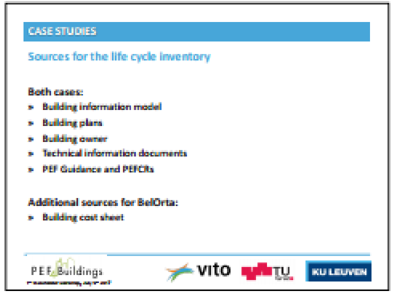
CASE STUDIES
Sources for the life cycle inventory
Both cases:
Building information model
Building plans
Building owner
Technical information documents
PEF Guidance and PEFCRs
Additional sources for BelOrta:
Building cost sheet
PEF Buildings
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CASE STUDIES
Case study 2 – Austria: be 2226
Architect: Baumschlager & Eberle
Client: AD Vermietung OG
Construction year: 2013
Context: suburban
(Millennium Park, Lustenau)
Net floor area: 2400 m²
Heating demand: 8 W/m² (covered by waste heat from users and appliances)
Represents: advanced building concept (passive, no heating/cooling)
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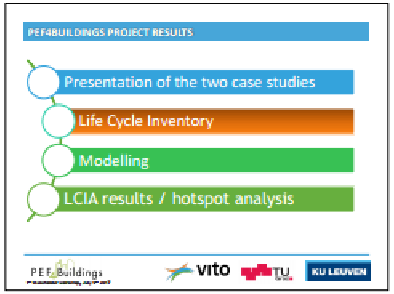
PEF4BUILDINGS PROJECT RESULTS
Presentation of the two case studies
Life Cycle Inventory
Modelling
LCIA results / hotspot analysis
PEF Buildings
vito
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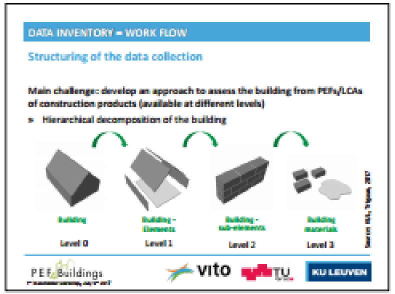
DATA INVENTORY – WORK FLOW
Structuring of the data collection
Main challenge: develop an approach to assess the building from PEFs/LCAs of construction products (available at different levels)
Hierarchical decomposition of the building
Level 0
Level 1
Level 2
Level 3
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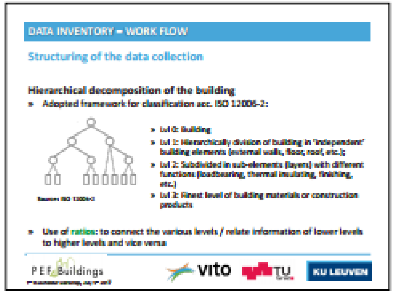
DATA INVENTORY – WORK FLOW
Structuring of the data collection
Hierarchical decomposition of the building
Adopted framework for classification acc. ISO 12006-2:
Lvl 0: Building
Lvl 1: Hierarchically division of building in 'independent' building elements (external walls, floor, roof, etc.);
Lvl 2: Subdivided in sub-elements (layers) with different functions (loadbearing, thermal insulating, finishing, etc.)
Lvl 3: Finest level of building materials or construction products
Use of ratios: to connect the various levels / relate information of lower levels to higher levels and vice versa
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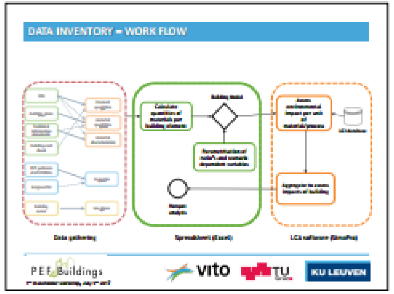
DATA INVENTORY – WORK FLOW
Data gathering
Spreadsheet (Excel)
LCA software (SimaPro)
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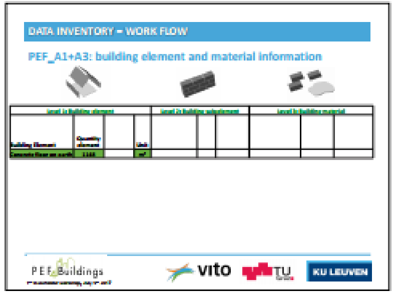
DATA INVENTORY – WORK FLOW
PEF_A1+A3: building element and material information
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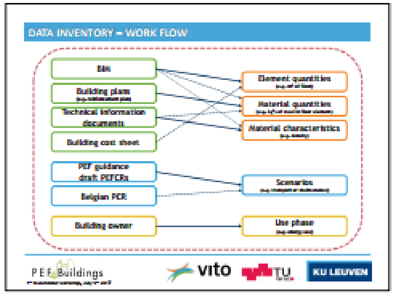
DATA INVENTORY – WORK FLOW
BIM
Building plans
Technical information documents
Building cost sheet
PEF guidance draft PEFCRs
Belgian PCR
Building owner
Element quantities
Material quantities
Material characteristics
Scenarios
Use phase
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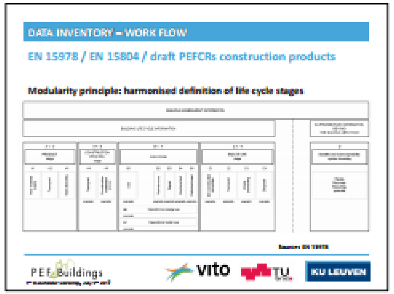
DATA INVENTORY – WORK FLOW
EN 15978 / EN 15804 / draft PEFCRs construction products
Modularity principle: harmonised definition of life cycle stages
Source: EN 15978
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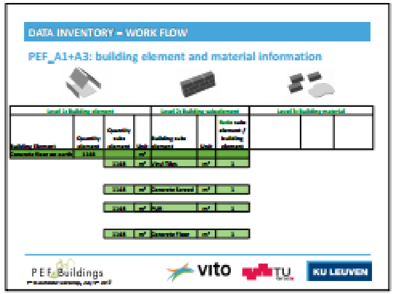
DATA INVENTORY – WORK FLOW
PEF_A1+A3: building element and material information
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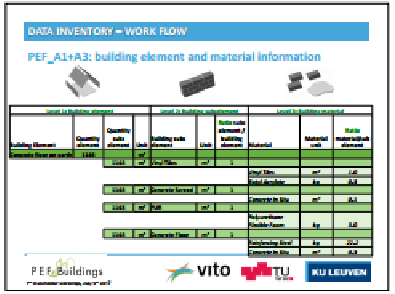
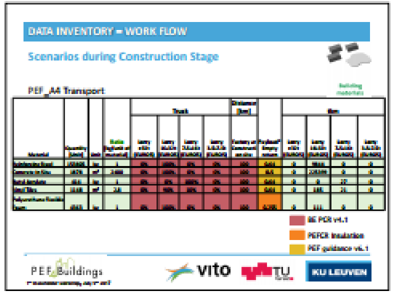
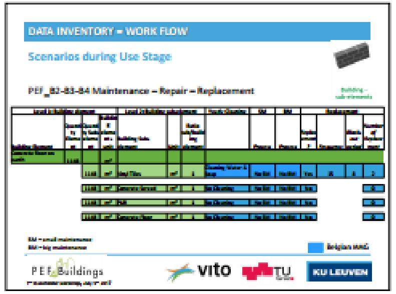
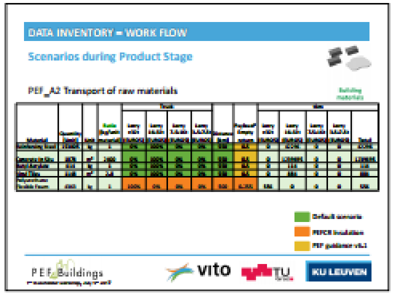
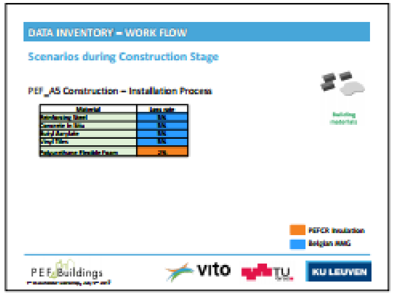
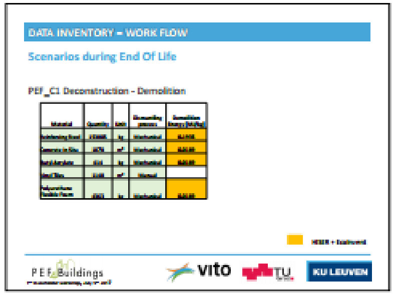

DATA INVENTORY – WORK FLOW
PEF_A1+A3: building element and material information


DATA INVENTORY – WORK FLOW
Scenarios during Construction Stage
PEF_A4 Transport


DATA INVENTORY – WORK FLOW
Scenarios during Use Stage
PEF_B2-B3-B4 Maintenance – Repair – Replacement


DATA INVENTORY – WORK FLOW
Scenarios during Product Stage
PEF_A2 Transport of raw materials


DATA INVENTORY – WORK FLOW
Scenarios during Construction Stage
PEF_A5 Construction – Installation Process


DATA INVENTORY – WORK FLOW
Scenarios during End Of Life
PEF_C1 Deconstruction - Demolition

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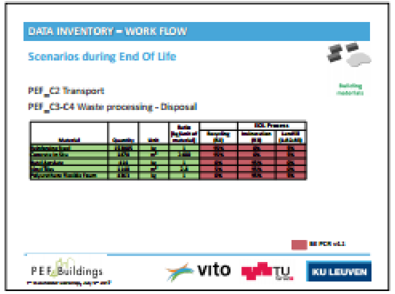
DATA INVENTORY – WORK FLOW
Scenarios during End Of Life
PEF_C2 Transport
PEF_C3-C4 Waste processing - Disposal
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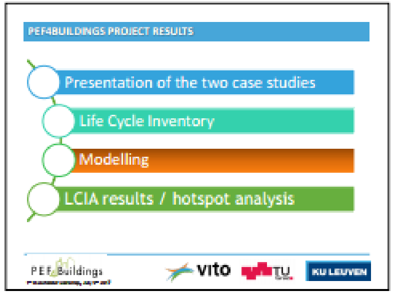
PEF4BUILDINGS PROJECT RESULTS
Presentation of the two case studies
Life Cycle Inventory
Modelling
LCIA results / hotspot analysis
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DATA INVENTORY – WORK FLOW
Simapro – Model and Coding Conventions
Identical hierarchical decomposition of the building
Tree-like structure
Code of building elements and materials (excel) maintained in SimaPro
Examples:
@ building level: many parameters => link with excel to improve the workflow
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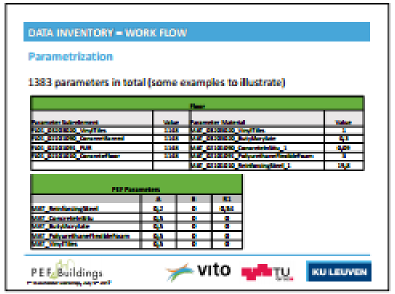
DATA INVENTORY – WORK FLOW
Parametrization
1383 parameters in total (some examples to illustrate)
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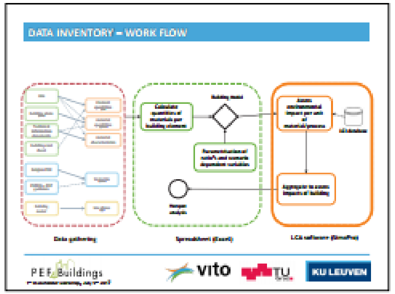
DATA INVENTORY – WORK FLOW
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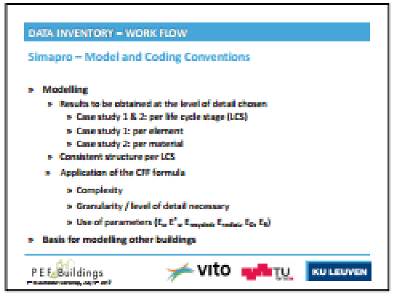
DATA INVENTORY – WORK FLOW
Simapro – Model and Coding Conventions
Modelling
Results to be obtained at the level of detail chosen
Case study 1 & 2: per life cycle stage (LCS)
Case study 1: per element
Case study 2: per material
Consistent structure per LCS
Application of the CFF formula
Complexity
Granularity / level of detail necessary
Basis for modelling other buildings
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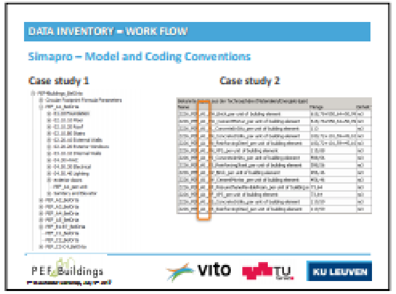
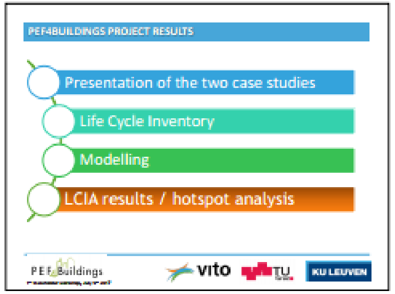
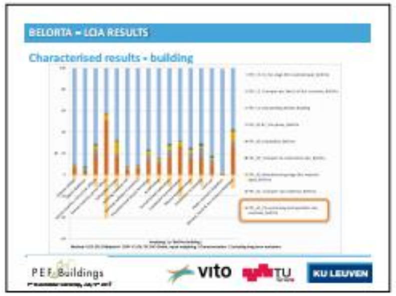
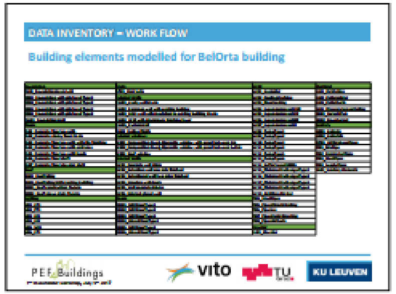
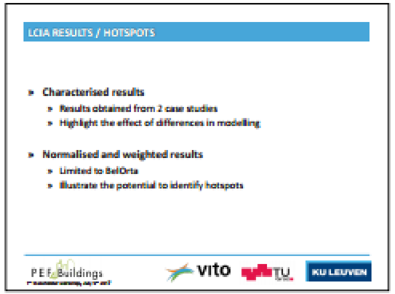
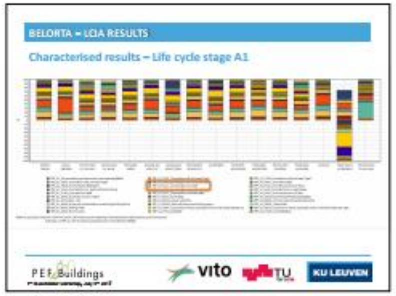

DATA INVENTORY – WORK FLOW
Simapro – Model and Coding Conventions
Case study 1
Case study 2


PEF4BUILDINGS PROJECT RESULTS
Presentation of the two case studies
Life Cycle Inventory
Modelling
LCIA results / hotspot analysis


BELORTA – LCIA RESULTS
Characterised results - building


DATA INVENTORY – WORK FLOW
Building elements modelled for BelOrta building


LCIA RESULTS / HOTSPOTS
Characterised results
Results obtained from 2 case studies
Highlight the effect of differences in modelling
Normalised and weighted results
Limited to BelOrta
Illustrate the potential to identify hotspots


BELORTA – LCIA RESULTS
Characterised results – Life cycle stage A1

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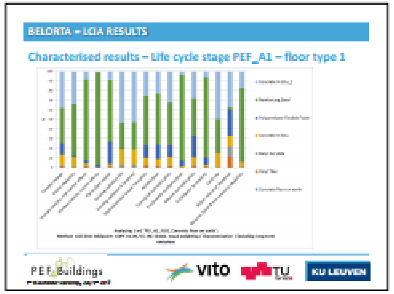
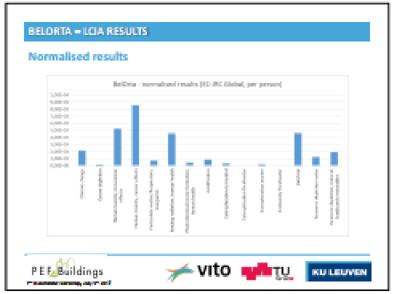
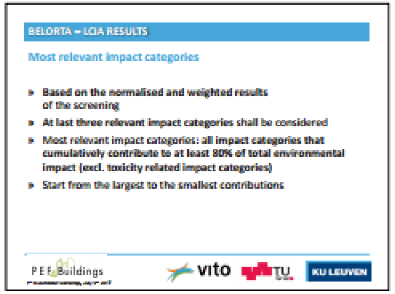
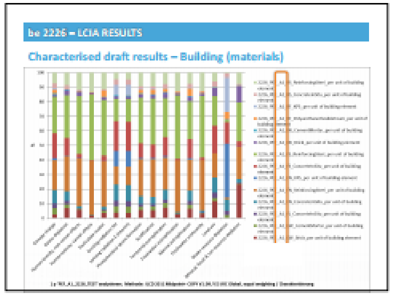
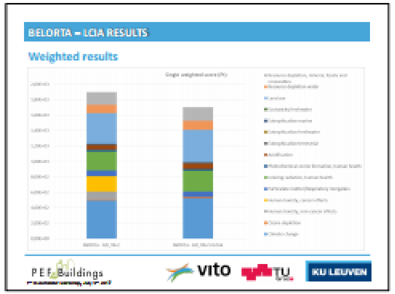
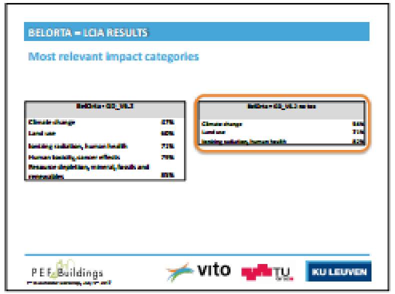

BELORTA – LCIA RESULTS
Characterised results – Life cycle stage PEF_A1 – floor type 1


BELORTA – LCIA RESULTS
Normalised results


BELORTA – LCIA RESULTS
Most relevant impact categories
Based on the normalised and weighted results of the screening
At last three relevant impact categories shall be considered
Most relevant impact categories: all impact categories that cumulatively contribute to at least 80% of total environmental impact (excl. toxicity related impact categories)
Start from the largest to the smallest contributions


be 2226 – LCIA RESULTS
Characterised draft results – Building (materials)


BELORTA – LCIA RESULTS
Weighted results


BELORTA – LCIA RESULTS
Most relevant impact categories

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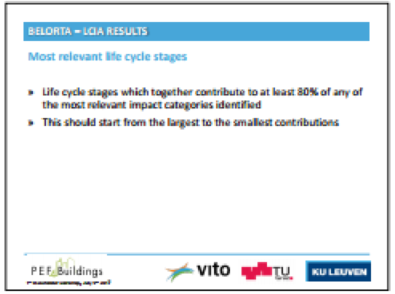
BELORTA – LCIA RESULTS
Most relevant life cycle stages
Life cycle stages which together contribute to at least 80% of any of the most relevant impact categories identified
This should start from the largest to the smallest contributions
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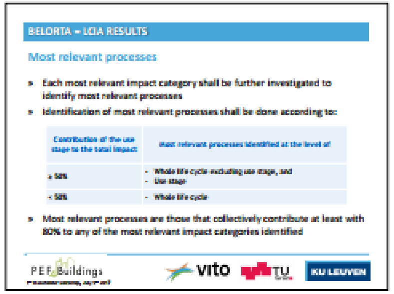
BELORTA – LCIA RESULTS
Most relevant processes
Each most relevant impact category shall be further investigated to identify most relevant processes
Identification of most relevant processes shall be done according to:
Most relevant processes are those that collectively contribute at least with 80% to any of the most relevant impact categories identified
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AGENDA FOR STAKEHOLDER'S WORKSHOP
Coffee break (10:45 – 11:15 am)
Closing of the meeting (1 pm)
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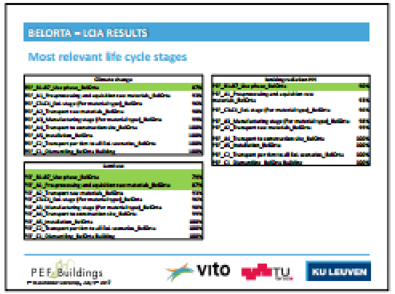
BELORTA – LCIA RESULTS
Most relevant life cycle stages
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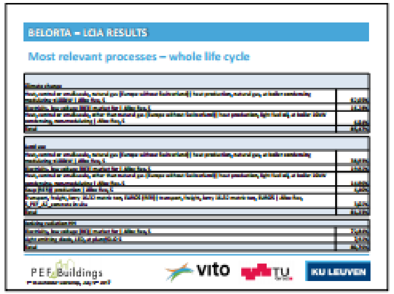
BELORTA – LCIA RESULTS
Most relevant processes – whole life cycle
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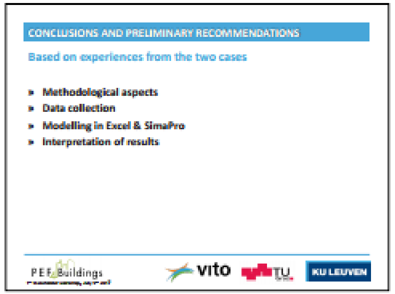
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Based on experiences from the two cases
Methodological aspects
Data collection
Modelling in Excel & SimaPro
Interpretation of results
PEF Buildings
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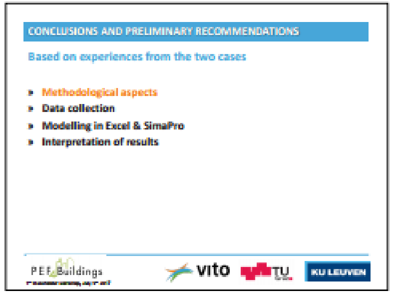
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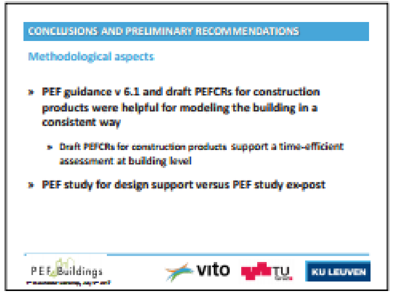
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
PEF guidance v 6.1 and draft PEFCRs for construction products were helpful for modeling the building in a consistent way
Draft PEFCRs for construction products support a time-efficient assessment at building level
PEF study for design support versus PEF study ex-post
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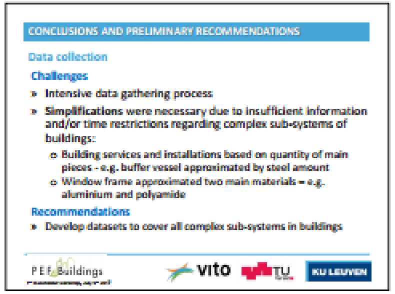
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Data collection
Challenges
Intensive data gathering process
Simplifications were necessary due to insufficient information and/or time restrictions regarding complex sub-systems of buildings:
Building services and installations based on quantity of main pieces - e.g. buffer vessel approximated by steel amount
Window frame approximated two main materials – e.g. aluminium and polyamide
Recommendations
Develop datasets to cover all complex sub-systems in buildings
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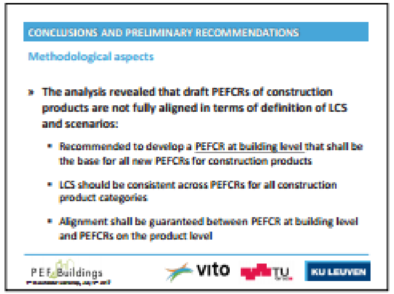
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
The analysis revealed that draft PEFCRs of construction products are not fully aligned in terms of definition of LCS and scenarios:
Recommended to develop a PEFCR at building level that shall be the base for all new PEFCRs for construction products
LCS should be consistent across PEFCRs for all construction product categories
Alignment shall be guaranteed between PEFCR at building level and PEFCRs on the product level
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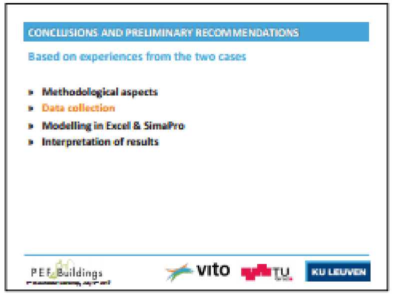
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
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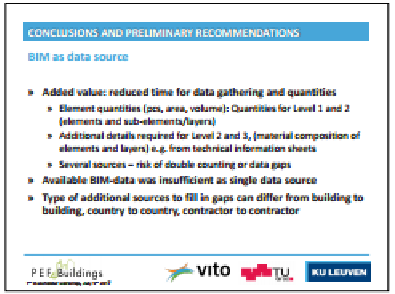
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
BIM as data source
Added value: reduced time for data gathering and quantities
Element quantities (pcs, area, volume): Quantities for Level 1 and 2 (elements and sub-elements/layers)
Additional details required for Level 2 and 3, (material composition of elements and layers) e.g. from technical information sheets
Several sources – risk of double counting or data gaps
Available BIM-data was insufficient as single data source
Type of additional sources to fill in gaps can differ from building to building, country to country, contractor to contractor
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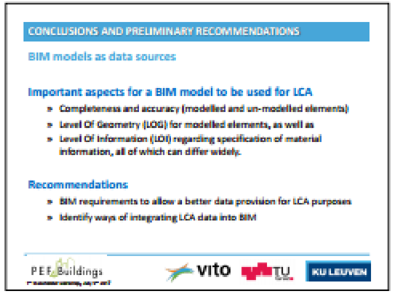
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
BIM models as data sources
Important aspects for a BIM model to be used for LCA
Completeness and accuracy (modelled and un-modelled elements)
Level Of Geometry (LOG) for modelled elements, as well as
Level Of Information (LOI) regarding specification of material information, all of which can differ widely.
Recommendations
BIM requirements to allow a better data provision for LCA purposes
Identify ways of integrating LCA data into BIM
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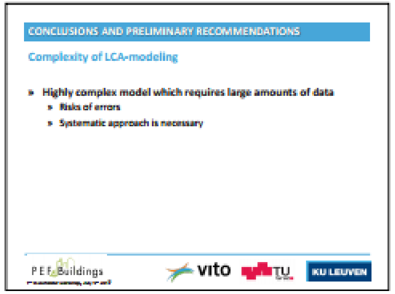
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Complexity of LCA-modeling
Highly complex model which requires large amounts of data
Risks of errors
Systematic approach is necessary
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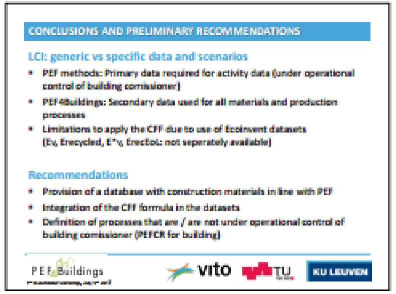
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
LCI: generic vs specific data and scenarios
PEF methods: Primary data required for activity data (under operational control of building comissioner)
PEF4Buildings: Secondary data used for all materials and production processes
Limitations to apply the CFF due to use of Ecoinvent datasets (Ev, Erecycled, E*v, ErecEoL: not seperately available)
Recommendations
Provision of a database with construction materials in line with PEF
Integration of the CFF formula in the datasets
Definition of processes that are / are not under operational control of building comissioner (PEFCR for building)
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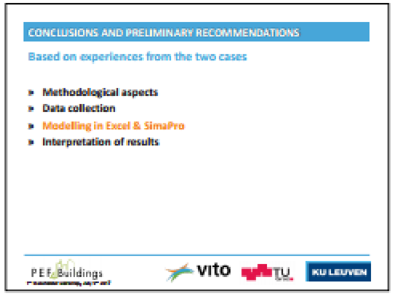
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
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Interpretation of results
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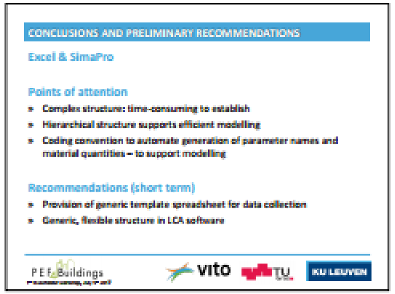
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Excel & SimaPro
Points of attention
Complex structure: time-consuming to establish
Hierarchical structure supports efficient modelling
Coding convention to automate generation of parameter names and material quantities – to support modelling
Recommendations (short term)
Provision of generic template spreadsheet for data collection
Generic, flexible structure in LCA software
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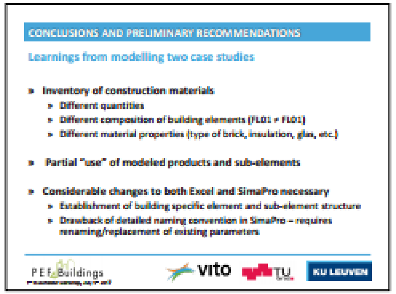
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Learnings from modelling two case studies
Inventory of construction materials
Different quantities
Different composition of building elements (FL01 ≠ FL01)
Different material properties (type of brick, insulation, glas, etc.)
Partial "use" of modeled products and sub-elements
Considerable changes to both Excel and SimaPro necessary
Establishment of building specific element and sub-element structure
Drawback of detailed naming convention in SimaPro – requires renaming/replacement of existing parameters
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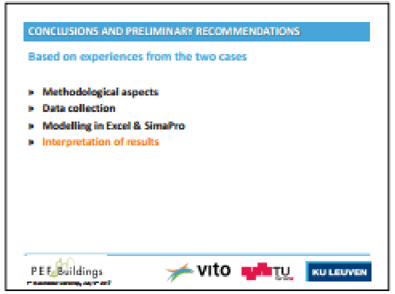
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Based on experiences from the two cases
Methodological aspects
Data collection
Modelling in Excel & SimaPro
Interpretation of results
PEF Buildings
vito
TU
KU LEUVEN


AGENDA FOR STAKEHOLDER'S WORKSHOP
Registration and welcome coffee(9:00-9:30 am)
Coffee break (10:45 – 11:15 am)
Closing of the meeting (1 pm)
PEF Buildings
vito
TU
KU LEUVEN


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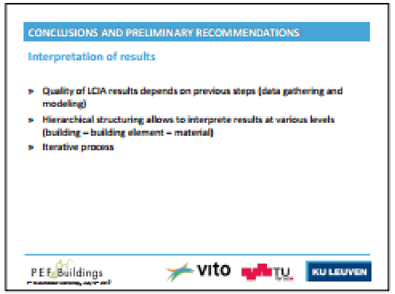
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Interpretation of results
Quality of LCIA results depends on previous steps (data gathering and modeling)
Hierarchical structuring allows to interprete results at various levels (building – building element – material)
Iterative process
PEF Buildings
vito
TU
KU LEUVEN


INTERACTIVE DISCUSSION WITH STAKEHOLDERS
FEEDBACK & Questions from stakeholders
PEF Buildings
vito
TU
KU LEUVEN


Thank you for your attention!
Please send feedback to:
carolin.spirinckx@vito.be
CC: karen.allacker@kuleuven.be
CC: alexander.passer@tugraz.at
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Additional feedback from stakeholders after stakeholder meeting

In Italic grey: comments from respective stakeholders.
After each comment: feedback from project team.

Rockwool International
Comment 1:
Link to "PRODUCT CATEGORY RULES (PCR) - DRAFT - DATE 2017-06-02 - BUILDINGS -PRODUCT CATEGORY CLASSIFICATION: UN CPC 531 - DRAFT VERSION 2.0 FOR OPEN CONSULTATION VALID UNTIL: DRAFT. DO NOT USE OR CITE" – Could be interesting to check for task 2.
Comment 2:
Once again thanks for the workshop. The project team is delivering an immense task in the PEF4buildings project. In order to get the most valuable outcome of the project, please find below some suggestions.
The goal of the project as presented in the workshop, is "To test the applicability of the PEF method to a new office building" and "To propose approaches for the methodological challenges identified". To my understanding the focus is therefor on the specific PEF issues (i.e. doing an LCA with the purpose of benchmarking within a product group; and specific methodological issues regarding allocation and indicators). During the workshop there was a lot of focus on generic LCA issues for LCAs of buildings, like the hierarchical decomposition of a building (nothing specific in PEF compared to normal LCA), the fact that you need product data that are aligned with the system boundaries on building level, etc.. Many of the conclusions are already well-known, both in TC350 (therefor there is the structure of EN15978 for buildings, building on product data from EN15804) and in existing "whole building LCA" tools.
Doing an LCA for a new office building brings nothing specifically new, except for showing - once more - that whole building LCA is feasible – whatever LCA calculation rules you use. The added value of doing the PEF exercise is to show which type of rules are required both on product as well as building level and to explain what rules should be elaborated in a PEFCR in addition to the generic LCA-rules, in order to make benchmarking possible for buildings.
Of course I recommend to include the Dutch "Bepalingsmethode", also available in English at https://www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf and the latest changes https://www.milieudatabase.nl/index.php?q=laatste-nieuws&t=108, which clearly show which rules and scenarios are necessary for the building level in addition to the generic EPD rules for products, to allow benchmarking of buildings. Comparing those rules with the ones you identify for your PEF exercise, could result in recommendations for stakeholders drafting PCRs for building (either being a PEFCR or a PCR based on EN15804 and EN15978).
Knowing the high knowledge level in your team, I have no doubts about the contents and calculations. It's probably a matter of my expectations of the study – not knowing exactly what the Commission has asked for - and the way it was presented during the workshop (with a lot of explanation on how the LCA was carried out). My suggestion would be to clearly distinguish between LCA in general and the specific PEF issues, and to specify the question to be answered before elaborating issues.
For the next step, rules for benchmarking, I recommend to have a look at:

- *the Dutch legal requirements for GPP new built office buildings with levels and classes for the environmental performance of a building. See Annex 1 (bijlage 1) in https://www.pianoo.nl/sites/default/files/documents/documents/milieucriteriadocumentkantoorgebouwennieuwbouw-maart2017.pdf*
- *the Dutch building Code with performance based requirements for new built houses and office building see "Afdeling 5.2. Milieu, nieuwbouw" http://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012/hfd5*

Feedback from project team:

- Comment 1: This will be considered when writing report D4 on benchmarking and potential classes of performance.
- Comment 2:
    - Comments are indeed relevant and when moving to the next stage of the project we will ensure checking the information and integrating it whenever appropriate with the context of this project.
    - This stage was mainly focused on the actual exercise of developing such a study/model, which was in itself a huge undertaking. However more specific learnings are to be discussed in the next stage. If the case we will revert back to Rockwool International for clarifications regarding the information she provided.
    - We highlighted specific PEF issues in report D3;
    - Different LCA methods have different requirements. PEF is also a LCA method, so many recommendations/issues are related to LCA assessment of buildings in general. Some are very specific to the PEF method and approach. The scope of this project was not to compare different LCA methods but to test if the PEF method is applicable to building and the challenges met and lessons learnt (see paragraphs 4.4 and 4.5 and chapter 5).
    - The Dutch methods the commenter is referring to will be considered when writing report D4 on benchmarking and potential classes of performance.
    - LCA general and PEF specific: did we make distinction in the report:
        - PEF specific learnings for LCI: paragraph 3.4;
        - PEF hotspot analysis: paragraph 4.5.

Public Waste Agency for Flanders, Belgium

Thanks for the invitation to come to the workshop yesterday. It was definitely a fascinating session for me to follow. Based on the comments heard, I conclude that there are still many questions about the 'course' running at EC (DG Grow & DG Environment), but you can't help that as an executive team.

The following (general) matters may still be useful to the further consider during your study and completion of the report:

- *Clearly outline the context of your study and emphasize what is indeed 'in scope' of the study and what's out of scope. I think it is very important to include this in the final report in order to correctly meet the stakeholders' expectations (I noticed a lot of confusion in the room during the workshop). As a consequence, you presented the 'preliminary results' (which resulted in very general recommendations, but maybe that's just the (only) scope of this study). For some people in the room this was a little disappointing ...*
- *In your presentation it was clearly stated that the figures themselves are not so important, or the "process" in order to achieve an impact assessment at the building level. This has certainly been stressed enough.*
- *During the discussion, DG Environment also suggested that EC is looking for a more (or most) reliable way of modelling the impact of buildings. Personally, I think this is the way to go to justify your studies and efforts. KU Leuven indicated at one point that the use of the PEFCRs of the 5 products worked very well, given that these products did not require a substantive discussion and, in combination with the PEF method, smoothly (and especially!!) leads to results unambiguously. Thus, the current mode of operation and the shortcomings (too vague provisions) within EN15978 (in addition to incomplete images due to insufficient indicators) also provide too little guidance to make it clear on a building-level calculation. Emphasizing this aspect (and further illustrating on the basis of concrete experiences in your process / study) may then also be an important insight for many*

stakeholders. I know your study is not about a comparison of PEF and EN but implicitly emphasizing these benefits at PEF (without mentioning EN) may be useful. It seems to me one of the many puzzle pieces that can facilitate the road to switch to PEF …

Feedback project team:

- We defined the scope from the designers perspective and clearly indicated that during the workshop and in the report D3;
- Both the PEF guide as well as the PEF guidance documents have been used. The LCIA results show/confirm the relevance of the additional impact categories.

Eurima – European Insulation Manufacturers Association

- *Comment 1: P11 (upper slide): some exceptions are made on the PEF requirements. It would be good to explain the consequences of these exceptions in the conclusions.*
- *Comment 2: P14 (upper slide): The functional unit defined as 1 building will have quite some consequences in the further tasks of this report. It would be good to assess other possibilities.*
- *Comment 3: P15 (upper slide): it is confusing to add a column on EN15978 as it creates the impression that nothing has to be taken into account following the standard, while this is not at all the reality.*
- *Comment 4: P31-33: Some of the hypotheses behind the results seem to come from the PEFCR on thermal insulation in pitched roofs, while here we speak about thermal insulation in floorings. The hypotheses could be very different. This shows the difficulty on how to use the existing PEFCR.*
- *Comment 5: P46-53: most of the conclusions seem to be related to the principle of making LCA at the building level. It would be interesting to split the conclusions which are related to make an LCA at the building level (independently of the methodology (PEF/EN15978) used) and the conclusions related to the PEF methodology specifically.*
- *Comment 6: Most of the conclusions seem currently aligned with the way the TC350 standards are used by some member states to make LCA of buildings.*

Feedback project team:

- Comment 1: No primary data were used to do the PEF modelling. For the rest we followed the PEF method and the PEF guidelines (mainly version 6.1, for the impact assessment 6.3). This is clearly mentioned in the report. Consequences however can't be foreseen yet:
    - Consequences modelling: more complex than other existing LCA methods due to the fact that the generic datasets available are not developed to be used in combination with the PEF Circular Footprint Formula (CFF);
    - Consequences on results: can't be foreseen yet.
- Comment 2: Functional unit is for task 1 expressed at building level and not per m² floor area for instance as we do not compare buildings amongst each other in task 1. For the benchmarking and classes of performance (task 2 – reported in D4) the FU will be more crucial and thus we will consider this in the second phase of the project (benchmarking – task 2).
- Comment 3: Not specified doesn't mean not to be included during the modelling. The EN15978 doesn't give clear guidelines on how and what to include specifically for each life cycle stage.
- Comment 4: For the insulation materials in the floors, we used the horizontal guidelines and rules from the draft PEFCR (independent from the application) and not the vertical rules for pitched roofs. The 2% of losses at the construction site are the same for all insulation materials.
- Comment 5: We highlighted specific PEF issues in report D3, also in the conclusions ((see paragraphs 4.4 and 4.5 and chapter 5).
- Comment 6: We highlighted specific PEF issues in report D3, also in the conclusions ((see paragraphs 4.4 and 4.5 and chapter 5).

BASF Group

Thanks for the stakeholder workshop and the presentations. It is very clear.
As stated during the meeting, I recommend to distinguish in the conclusion what is related to the applicability of LCA at building level in general and what is PEF specific. Also, several aspects are related to the current availability of data and tools and should therefore only be considered a temporary issue (e.g. the applicability of the Circular Footprint Formula).
Additionally, I have following comment when reading the slides again: the selection of most relevant impact categories may create some issues. In the example of BelOrta, it appears that the most relevant impact categories are all related to the energy consumption of the building. This should not be a criteria to select the relevant impact categories for the construction products. I would always recommend to declare all impact categories for construction products.

Feedback project team:

- Indeed the first workshop dealt more with the step of modelling according to the LCA/PEF rules an entire office building. It will be for the next stage of the project to reflect deeper to the PEF specific aspects, like benchmark, hotspots, and other.
- Impact categories: similarly as in the PEF studies at product level, all impact categories are to be reported. However the most relevant impact categories must be calculated following the PEF rules. In this situation the use phase (or the energy use part only) has a predominant impact, which is why it influences the impact categories that turn to be most relevant. This is not incorrect per se, but discussion must take place obviously regarding the results when including/excluding the use phase. No primary data were used to do the PEF modelling. For the rest we followed the PEF
    - To define the most relevant impact categories: based on weighting;
    - To define the most relevant processes (both with and without the use phase): only for most relevant impact categories and so indirectly only determined by the weighting;
    - This is reported in the D3 report in the learnings from the LCIA (paragraph 4.5).

BIBM - European Federation for Precast Concrete

COMMENT
If I understand correctly, the input for the construction process at the building site was not included in the model (see second slide on page 19 of the circulated presentation).
This may result in a major flaw when you compare "normal construction" (e.g. concrete cast on site, with all the needs in terms of energy, ancillary materials like molds etc. …) with "industrialized construction" (e.g. elements or parts of buildings manufactured in a plant and transported on site for assembly), the latter being heavily penalized.
The (environmental) impacts at construction site are not negligible on the whole life cycle assessment and should be somehow accounted for.
QUESTIONS

1. *It was mentioned that "Module D is split between modules A and C". Can you please develop a little bit more this process?*
2. *If I understood correctly, if "PEF for Buildings" are developed, environmental declarations for construction products based on a "convergent PEF/EN 15804" category rules cannot be used. Can you explain me the reason for this incompatibility?*

Feedback project team:

- Comment: the comment has been included in the conclusions and recommendations for data collection and structuring (paragraph 5.2).

- Question 1: Clarified in paragraph 1.2 on system boundaries): As the PEF method requires the application of the Circular Footprint Formula (CFF), module D from EN 15804 is partly covered in life cycle stage PEF_A1 and PEF_C3/C4. The CFF can be arranged in a modular way, to fit for example the structure of the EN 15804 standard (see figure 2 in the PEF guidance document version 6.2 where the CFF is presented and re-arranged in different modules).
- Question 2: PEFCR for construction products (finals ones – not yet) shall be compatible with possible PEFCR for buildings (same connectivity is needed as now with EN 15804 and EN 15798)

Ministère de la Transition écologique et solidaire - Ministère de la Cohésion des territoires

I wish to thank you for the invitation to the 1st PEF4Buildings workshop and as a feedback. I would like to share the French environmental initiative on new buildings (see the attached presentation).
In France, a large experimental trial was initiated in November 2016, called label "Energie Positive et Réduction Carbone" (or E+C-) which will enable to assess environmental performances (based on the LCA method and indicators (NF EN 15978)) of new buildings (residential and office) with the perspective of assessing and reducing their environmental footprint, meaning low energy consumption, low greenhouse gases emissions, inclusion of renewable energies, waste generation, ... The results of this trial will be the basis of the future French regulation in a few years (2 to 5 years). That's why French authorities are willing to share the results of this initiative at the European level since we think that it is particularly innovative and can feed your thought.

<u>Feedback project team:</u>

- We will have a look at it during the a possible approach for benchmark and classes of performance (in report D4).

Cerame Unie

1. *Comment 1: The functional unit needs to be more accurate to reflect buildings that have different size/storeys;*
2. *Comment 2: The environmental impact categories, methods and indicators from the CEN TR on additional indicators should be considered for this study*
3. *Comment 3: One of the recommendations of the study is to develop a PEFCR at building level. If this proposal goes forward, it is important to ensure that EPDs in line with the future amended EN15804 can be used for the environmental assessment of building using the PEF methodology for buildings. This would show that both methodologies are compatible.*

<u>Feedback project team:</u>

- Comment 1: : Functional unit is for task 1 expressed at building level and not per m² floor area for instance as we do not compare buildings amongst each other in task 1. For the benchmarking and classes of performance (task 2 – reported in D4) the FU will be more crucial and thus we will consider this in the second phase of the project (benchmarking – task 2).
- Comment 2: PEF guide is the one to be used: mandatory as posed by EC.
- Comment 3: Correct.

AFNOR Normalisation, France

French comments on 1st PEF4Buildings stakeholder workshop:
In the following comments, page ("p") indicates the page of the PDF, "top" indicates the top slide, "bottom" the bottom slide. Sorry for this approach that was driven by the fact that slides were not numbered.
Comment 1:

This is a general comment (also linked to what is seen on p27): during all the presentation, and in the questions from the public, the words "construction products" (e.g. window) and "construction materials" (e.g. steel) have been used indifferently by experts (since they are said to be "equivalent" as level 3 - indeed, they are not!), making the presentation difficult to follow, and introducing a bias in the exercise.
"Construction products" are the correct level of detail for people (e.g. architects) who model buildings: e.g. they access in an easy manner the number and nature of windows, they have no clue of the mass of wood (material) which has been used to produce these windows (including losses), and "no idea" about the processes which have been used.
And "Construction products" are also the correct level of detail for manufacturers, who know masses and processes for each of their windows.
Then, "Construction products" LCI are the correct data and level of detail when dealing with PEF applied to Buildings.
There is no need to go down to "materials" when dealing with PEF applied to buildings, as long as they have been used by a manufacturer to produce a "Construction product" which is delivered to a construction site. Of course, when a material is used on the construction site directly in the building (mortar, glue...), the LCI for this material is also needed.
More than this, the wish to go down to material level (as shown in the PowerPoint p31 top) would make PEF4buildings not feasible for an architect (no access to the information - it is already one of the conclusions, that was written long ago in some LCA reports in Europe), and would create inconsistencies between PEF studies (since everybody would make approximations in different manners - see the open question asked during the stakeholders meeting "can we get a tool to break down all construction products into materials ?" Such tool/database, integrating all composition data from all manufacturers, with specific process data, will never exist !).
Using "construction products" LCI is the only way to ensure consistency (of methodology, the update of EN 15804 is mainly done for that purpose!) and practicability for both architects and products manufacturers.
One can expect that precisions will be brought in the follow up of the PEF4building project regarding level 3, saying that, when dealing with PEF applied to buildings, the correct level of detail of LCI in the PEF model is the LCI which covers the "materials" or "construction products" that enter the construction site, elaborated in accordance with EN 15804 (updated according to M350), and that there is no point to provide the materials LCI of "construction products" with PEF applied to buildings projects.
Remark: this approach is the same for what is called "chemical products" used in PEF products during the PEF experimentation. "Chemical products" are similar to "Construction products" in terms of concept. The upstream material list for each "chemical product" used in the PEF experimentation is not requested, nor the process detailed impacts; only the LCI is expected.
Indeed, even if data issues are not the point of this PEF4building project as presented in the slides and during the meeting, one can expect that the next version of the PEF4building project will use "Construction products" EPD as a basis for calculations, and not Ecoinvent 3 data. Many are available: in fact, the number of European EPDs at usable (for PEF4building project) is of the same order of magnitude as the number of Ecoinvent LCI data sheets, and the methodology is as close (closer?) to PEF as the methodology used in the current Ecoinvent.
Following comments 2 and 3 are sub-comments to comment 1.
Comment 2
p11 top: it should be more clear in the project that EPDs prepared according to the future EN 15804 (after application of M350) will be accepted by DG ENV in the scope of the application of PEF to buildings (i.e. as such, and not requesting information from construction products related to material composition).
Comment 3:

p11 top: The use of Ecoinvent as default background data, "waiting for PEF compliant data sets", introduces a bias in the exercise, since all presentation focuses afterwards on "PEF for materials", such as CFF in p18 bottom applied to material. The decomposition of the building down to level 3 (in p27 bottom) is also interpreted in a "material" way, not from the "construction products" way.

The use of existing EPD data as default background data is possible (see what is done in France in the scope of PEBN) and introduces, in an appropriate manner, what should be done (with "updated" EPD according to the new EN 15804) afterwards when applying PEF to buildings.

Comment 4:

p18 bottom: During an exercise "PEF4building", CFF should be "developed" ("tested", "imagined") for a) "Construction products" and b) for parts of the building itself (i.e. end of life of entire parts of the building while keeping the rest of the building in use - hardly no building (far less than 5%) is destroyed after 50 years life in Europe).

CFF applied to materials is already (well) known (see PEF experimentation), there is no need to test it in this PEF4building project.

Feedback project team:

- Comment 1: Different levels are considered. Construction products can be either at the material level (steel) or at the product level (windows) as long as they are sold on the market one can call them "construction products". Building material is any material which is used for construction purposes. That is the way the terminology is used across the report. Level 3 in the table (for instance at page 31 of the hand-outs of the slides) are at the level of the building materials (most of them can also be called construction products, but not all of them). In a potential future PEFCR for (office) buildings a detailed and unambiguously definition shall be included. In a potential future update of the PEF calculations of the office buildings (out of scope of this project) the PEF compliant datasets that the European Commission purchased could be used and replace many Ecoinvent datasets.
- Comment 2: currently the project team can not endorse the fact that EPDs prepared according to the future EN 15804 (after application of the new mandate M350) will be accepted by DG ENV in the scope of the application of PEF to buildings (i.e. as such, and not requesting information from construction products related to material composition), as still this is work under development and we can't predict the outcome.
- Comment 3: existing EPDs are not PEF compliant so can't be integrated in the PEF for buildings exercise. The PEF compliant LCI generic datasets were not available at the time th project team started the modelling. It could be a recommendation to redo the modelling by using only PEF compliant datasets (however this action is out of the scope of the current project).
- Comment 4: PEF at material level is only tested for the following building related systems: insulation materials, paints, PV, piping systems for hot and cold and metal sheets. For most of the materials used in the two office buildings that we assessed in this project by using PEF, no PEF compliant data were available. Renovation was not part of the scope of the project but will for sure be an interesting additional topic to be assessed in future in the framework of applying PEF within the built environment.

Annex 0-B – Minutes of an additional stakeholder meeting in Vienna

Date and location

PEF4Buildings – Additional Stakeholder Workshop in Vienna
Date: Monday 25th of September 2017
Time: 11 am to 3 pm
Venue: Premises of WKO Vienna (Austria)

Agenda

- Registration and welcome coffee
- Objectives PEF4Buildings
- Update on CEN TC 350 – new mandate EN 15804
- PEF4Buildings project in a nutshell
- Project framework and methodology
- PEF4Buildings project results
- Conclusions and preliminary recommendations for steps forward
- Closing of the meeting

Representatives from the following organisations participated:

Baumassiv
BOKU Wien
Daxner & Merl
KU Leuven
PORR
TU Graz
Umweltbundesamt
VITO
Wienerberger
Wienerberger Belgium
WKO

Minutes

1 Welcome and tour de table

The Austrian Association for Building Materials & Ceramic Industries welcomed the stakeholders.

The stakeholders and the project team members that joined the meeting briefly introduced themselves.

VITO introduced the participants into the agenda. There was a request to add an additional point to the agenda: update of current status CEN TC350 (see agenda point 3).

2 Objectives PEF and PEF4Buildings

Presented by the Environmental Agency Austria (EAA)

Background of PEF:

- Historic background;
- “What is green?”;
- Comparability;
- Need for a single set of calculation rules building on existing standards and methods;
- Primary and secondary data (free availability);
- Still exploration phase: Development of sector specific/category rules, testing of rules;
- Currently 23 active EF pilots overall, a handful directly connected to building sector (insulation, metal sheets, pipes, etc.);
- Overview of active pilots, participation of industry and stakeholders (267 leading stakeholders in 23 active pilots);
- Outlook: policy discussion on follow-up planned for 2018-2020. Policies to be in place by from 2020 onwards. PEF is a tool which can be implemented to support policies. IPPSCP advisory group (Karin Hiller, Austrian representative) will be the follow up of PEF steering committee to discuss and advise on policy issues;
- Link of PEF, construction products and buildings.

Q (WKO): Involved in CEN TC350, were not “allowed” to do benchmarking, as this is political. Asks what aim of benchmarking in PEF is and how it is supposed to work. Schemes for benchmarking in place already (for other, non-construction material, PCR)?
A (EAA): Not yet clarified. Different methods can be applied (single number, weighting system, performance classes, etc.). Depends on what policy options the instrument support. Depends on how makes decision (consumer, businesses). Question of if there will be European benchmarks (e.g. highly affected by electricity mix), implications of producing in one-member state and selling to another. There was one scheme proposed by the JRC which is used in the pilots, but also other schemes could be used.
A (KU Leuven): Benchmarks only within one product category. Aim is to make environmental impact of products within categories comparable. However, as long as there are no rules for the product categories, benchmarking is not possible.
A (VITO): Question also is if there should be performance classes. Is it necessary, are benchmarks sufficient?

Q (Wienerberger Belgium): When considering CEN TC350 one can see that politics behind the pilot. Political pressure also from the PEF4Buildings project. New draft for EN 15804 asked by November 2017 – New standard by spring 2018. CEN should align with PEF - not about learning, but pushing for alignment”
A (EAA): Difficult to deliver in time as PEF development still in process - maybe too early to push CEN.

Q (Wienerberger): 1) A revision of PEF guide is missing, based on the learnings from pilots. Only then a CEN mandate should be required. 2) Benchmarking inside a product group. Who defines the product groups?
A (EAA): Long discussion in steering committee regarding level of granularity for product groups. E.g. pilot on “liquid laundry detergents” on one hand, on the other hand a broad scope for “retail services” – still learnings on that granularity. In the long term the industry will have to specify based on their interest of how much into detail a sector should be specified/grouped. Technical advisory boards will be in place to support industry. Guidance board dealing with governance and verification in place. Option for industry to propose to develop (new, additional, refined) category rules (i.e. define categories).

Q (Wienerberger): Mandate says that only modules A, C, D should be obligatory. From his perspective, Module B should be mandatory as well. Usage phase should be obligatory.
A (KU Leuven): No discussion within PEF4Buildings project as in PEF method all LCS should be included, thus Use Stage was included.

3 Update CEN TC 350 – new mandate EN 15804

(Off record: After several statements on PEF and CEN TC350 alignment it is proposed to have a brief update on CEN TC 350, provided by Wienerberger Belgium)

4 PEF4Buildings project in a nutshell

Presented by VITO:

- Aim of the project: testing application of PEF method on buildings. Report challenges, differences. In addition, testing possible approaches for development and application of benchmarks and classes of performance.
- Focus of today's presentation is on Task 1: PEF study on newly built office building.
- Presentation of tasks and activities.

Q (Wienerberger): Discussion on the size of the building affecting the benchmarking/classes of performance included?
A (VITO): Next workshop on benchmarks (date of which might be shifted to early 2018)

Action: Address discussion on size of building affecting benchmark/classes of performance.

Q (BOKU Wien): Why only office buildings?
A (VITO): Tender was asking new office buildings.

Q (PORR): Pipeworks included?
A (P4B team): Piping included. However, for some building elements assumptions had to be made where information was not available.

5 Project framework and methodology

Presented by TU Graz:

- Overview method, materials, relevant standards, five draft PCRs, national guidelines/PCRs where available;
- PEF requirements followed, required exceptions in this study;
- Modular approach, following EN 15804 with differences in module D;
- Overview of the five draft PEFCRs applied in this study; Additional national guidelines: MMG method (BE), PCR 4.1 (BE EPD program);
- Functional unit, reference flow;
- System boundaries and scope; Life cycle stages – differences for module D (included partially in PEF_A1 and PEF_C3/C4); Cut-off rules (1%);
- LCI: Raw material for manufacturing; scenarios for the different life cycle stages;
- Circular footprint formula.

C (VITO): Allocation on building level will be important discussion/challenge for e.g. renovation scenarios.

Q (BOKU Wien): Energy for appliances included but not raw materials?
A (KU Leuven): Yes, included in energy consumption during operation, but not in inventory of raw materials.

C (Wienerberger): Transport distance seems to high.
A (KU Leuven): Used the "worst case" as stated in relevant standards where no data was available. Recommendation to develop a PEFCR for buildings after this pilot study. A distinction per product group and per country is recommended for the future.

Q (Wienerberger Belgium): Definition of functional unit – "how well?" also ongoing discussion within CEN TC350. How is this defined in this project.
A (KU Leuven): A business as usual and nearly zero energy building are chosen for this project to take into account different building performances. The two different buildings will also help us in the benchmarking part of the project.

Q (BOKU Wien): Transport distance, where are values from?
A (KU Leuven): Distances from Belgian Standards, values from inquiry to industry.
Q2: What processes are in the 1% rule for cut-off criteria?
A (KU Leuven): Analyzed everything that is in the building (materials, systems). Where no data available proxies had to be used.

Q (Daxner & Merl): Goal and scope: who uses results of PEF. Planning team or client/consumer?
A (P4B team): PEF4Buildings is for the commission. In general, this relies on policies that will be decided on (see question earlier answered by Hanna Schreiber)

Q (Daxner & Merl): By using proxies for several products an underestimation may have happened for raw material impact, while using the data on energy consumption "overestimates".
A (P4B team): Goal of this study not results, but application of method. To show challenges like this. In future it will be important to provide generic and product-specific data required to apply the CFF.

6 PEF4Buildings project results

KU Leuven presented the results for Case study 1, Belgian case:

- Important to have two case studies to develop a modular, flexible approach applicable to multiple buildings;
- Overview of the two case studies and information materials used;
- Structuring of data collection: modular, hierarchical composition levels, ratios to dis/aggregate quantities on different levels;
- Data inventory workflow. Sources and steps in the assessment process (data gathering, quantity calculations and ratios in spreadsheet, LCIA in LCA software Simapro);
- Explanation of inventory levels, for amount of materials: Level 1 building element; Level 2: building sub-elements; Level 3: building materials;
- Explanation of scenarios in different life cycle stages. Scenarios for maintenance/replacement based on Belgian MMG (no scenarios described in current PEFCR/guidance 6.1); EoL scenarios from HISER (H2020 project which looked into detail of EoL scenarios);
- Parametrization of the model in Excel spreadsheet and LCA software SimaPro to identify elements and integrate parameters (1000+ parameters in the PEF4Buildings project);

- Modelling and coding conventions. Differences in SimaPro modeling of CS1 and CS2 (element/materials);
- Results case study 1, Belgian case.

TU Graz presented the results for Case study 2, Austrian case:

- Overview of the case study building "BE2226" in Lustenau, Austria;
- Hot spot analysis of results (impact categories, life cycle stages, processes).

Clarifications on midpoint and endpoint impact categories, which mustn't be mixed/aggregated.

C (Wienerberger): It would be expected that the energy has a lower contribution in the total for the Austrian case. Surprised to see Use Stage dominating Climate change indicator for such a material intensive building (A1-A3 expected to dominate)?
A (P4B team): Climate change is only 5% in impact categories. Maintenance replacement included in use stage. Results will be checked.

Q (Daxner & Merl): Future of EPDs. Could they be used for a PEF study on buildings? Do you think that any methodology to could be extracted to deal with the current EPDs or specific data? Which methodology should be used in the planning phase when you don't know the specific products yet, and so don't have specific data?
A (KU Leuven): If EPDs are compliant with the new EN15084 and provide the full range of indicators of PEF, then yes, EPDs can be used. For the early design stage, there is a need for more generic, average data.
Conclusion: Methodology required how to treat primary/secondary data on building level as "under operational control" is very vague. Also how to handle uncertainty in early stage (design) where no product-specific information can be used as decision is not made.

Q (BOKU Wien): Do you plan a project to compare LCAs of one and the same building and compare LCA using EN method or PEF method. To identify what is better? What is the added value of PEF?
A (P4B team): "Better" is not only in terms of absolute results but clarity and comparability of result. PEF addresses all relevant aspects and questions regarding data quality to assess the impact in a comparable way by using default values instead of some assumptions that again make results hard to compare. For data quality there is a quantitative data quality assessment, that will have to be fulfilled for future assessments (e.g. if product specific datasets will be used instead of default values, these have to meet data quality standards).

Q (Daxner & Merl): Recommendations have to be given how to revise EPDs to work with PEF method.
A (KU Leuven): For this reason, EN15804 is revised to better align both methods.

Q (Wienerberger): Request to include recommendation in the report regarding options how to use existing EPDs for PEF – and if not possible recommend how to update them in a way that is aligned with PEF. Requesting a guideline for manufacturers on what to report/ how to make their product data applicable in the context of the PEF methodology.
A (VITO): As EPDs have to be updated with a new CEN standard, they will then fit PEF standards anyway (if alignment within CEN is made as expected).
C (Wienerberger Belgium): Two reasons why recalculation of EPDs is required. Change in production process (new LCI, same methodology) or change in methodology (same LCI, new methodology, e.g. PEF). The first of which will have more cost than applying a new method to existing LCI, so providing PEF compliant EPDs in the future should not be a big or costly issue. If following CEN method in the future EPDs will be PEF compliant.

C (EAA): As there is more data required to apply CFF (e.g. Ev, R1, etc.) there won't just be a simple recalculation to obtain PEF compliant EPDs but additional data on input/output and process will be required.

Q (PORR): Back to building level. Hard to get good data about transportation of materials
A (VITO): In such a case, default data would be used (e.g. from a building PEFCR) if no specific data is available. If it is, with required quality, primary data can be used.

7 Conclusions and preliminary recommendations for steps forward

Presented by VITO:

- Methodological aspects:
  - Alignment of product level PEFCRs required. Recommendation to start with PEFCR on building level to take learnings from this for PEFCRs on construction product level
  - Recommendations to have different scenarios for assessing buildings built new or renovation scenarios (reuse scenarios)
- Data collection:
  - Challenges regarding data collection: Recommendation to have EF compliant datasets covering complex sub-systems.
- Modelling in Excel & SimaPro, including BIM models:
  - Application of BIM for LCI. Recommendations regarding BIM and LCA integration.
  - Highly complex LCA model in SimaPro, extra time invested for parametric model, benefits of using model for two case studies.
  - Disaggregation of generic datasets was required to apply CFF. Recommendation to develop a PEF compliant database for materials and production processes.
  - Adapting SimaPro model to another building (Case 2) was still very time consuming, while the Case 1 model was beneficial especially regarding the integration of CFF parameters for construction products.
- Interpretation of results:
  - Quality of LCIA relies on data quality, completeness and accuracy of LCI, etc. – as in conventional LCA.

Q (WKO): Where does information of reference service life come from?
A (P4B team): Values from national guidelines (e.g. MMG). Should be included e.g. in construction product PEFCRs in the future.

C (WKO): Supports the "top-down" approach of developing a PEFCR for buildings to then develop PEFCRs for construction products based on this.
C (Daxner & Merl): Important to align CEN to be able to provide PEF compliant EPDs in the future. Would be interesting to bring the PEF approach into building certification schemes (DGNB, BREEAM, etc.).
C (PORR): DGNB and Swiss system (?) have benchmarking system. In other schemes there are sometimes bonus points for calculating an LCA, but no benchmarking system.

VITO offers participants to prepare additional **written feedback/comments** via email **until 20th of October 2017**.

Closure of the meeting and summary of main actions

No	Action	Who	By when (ultimate deadline)
1.	Send minutes and accompanied slides to WKO	VITO	05/10/2017
2.	Written feedback from the stakeholders can be send to the project team	All	20/10/2017
3.	Additional sources and/or information on benchmarking buildings can be send to the project team	All	ASAP
4.	Invitation for the second stakeholder meeting in Brussels will be sent to WKO	VITO	As soon as date is definetively fixed

Presentations

See slides of the Brussels workshop.

ANNEX 1 – EXCEL FILE WITH LCI DATA, MODELLING DETAILS AND OVERALL BELORTA BUILDING STRUCTURE

The Excel file “Annex 1_D3_PEF4B_Structure office building data collection_BelOrta_20170821” includes all the information regarding the structure of the BelOrta building, as well as modelling details, such as datasets used for modelling, scenarios and parameters.

The Excel spreadsheet is organised in thematic worksheets as follows:

- General – presents the system boundaries and the considered life cycle stages;
- Worksheets per life cycle stage – give the information needed for the relevant life cycle stage or an overview of the life cycle stage.
- Element worksheets with in-depth data used in the modelling (amounts, datasets, specific calculations).
- Parameter worksheets – present the used parameters and generates a list with parameters for SimaPro
- Calculating tabs – present some final calculation about building amounts and disaggregation options for transport, cleaning and maintenance.

Colour codes were used in the Excel spreadsheet to allow the identification of information per category. Legends are added where needed.

ANNEX 2 – EXCEL FILE WITH LCI DATA, MODELLING DETAILS AND OVERALL BE2226 BUILDING STRUCTURE

The Excel file “Annex 2_D3_PEF4B_Structure office building data collection_BE2226_20170821” includes all the information regarding the structure of the BE2226 building, as well as modelling details, such as datasets used for modelling, scenarios and parameters.

The Excel spreadsheet is organised in thematic worksheets as follows:

- General – presents the system boundaries and the considered life cycle stages;
- Worksheets per life cycle stage, with overall information for the respective stage (such as the building structure, with all elements and layers for A1, details on scenarios for A2, A4, C2, and so on);
- Worksheets with in-depth data used in the modelling (amounts, datasets, specific calculations).

Colour codes were used in the Excel spreadsheet to allow the identification of information per category.

ANNEX 3 - DETAILED DATA COLLECTION BELORTA BUILDING

To develop a complete data collection for the BelOrta Building several sources were used. More specifically the following sources were used for this building: Building Information Model (BIM), building construction plans, technical information documents, building cost sheet, PEF guidance documents, national guidelines and data from the building owner. Even though plenty information was provided still some additional search was needed to complete this data collection. Nevertheless, some elements are not modelled due to several reasons. First, for some elements the available data was not detailed enough to model the element (e.g. electronic devices as sensors). Secondly, some elements are not part of a BAU office and therefore felt out of the scope of this project (e.g. garage door).
In the following sections the used data sources are discussed, followed by an overview of the modelled elements and their specific data sources and completed by a list of data gaps.

DATA SOURCES AVAILABLE

Building Information Model

The BIM model was the basis for the data collection for the BelOrta building. From this BIM model mainly element quantities (e.g. m² of a certain floor type) were extracted. Within the model some elements are modelled in 3D and others are 2D drawings. More specifically, the following building elements are modelled as 3D-elements: foundation, floors (ground & story floor), roof, external and internal walls, windows, doors, stairs, sun shading (partially), lighting fixtures and furniture. In addition smoke and heat evacuation and fire safety equipment are included in the 2D-drawings.

Although the model seems to be quiet complete at first sight, there are some remarks/ limitations about the BIM model.
First, some of the modelled 3D-elements give more information about the used materials. However, this is often limited information, e.g. an insulation layer is used without specifying the type of insulation. Besides, some materials, e.g. concrete, are used in different building elements even though the application of the material is different, e.g. in-situ or prefab concrete. In consequence, some adaptations had to be made to the model to split these materials to be able to extract correct quantities of materials.
Secondly, one of the limitations of the BIM model for the BelOrta building is the level of detail (LOD). Some of the nodes are modelled in detail, while others aren't (see Figure 45 and Figure 46). In consequence, quantities extracted could over- or underestimate the real quantities. However, as the results of the assessment are not the aim of this project, no further efforts are made to correct this limitation in the model.

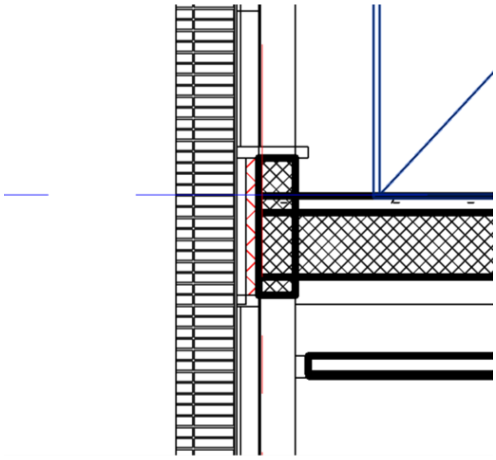

Figure 44: Badly modelled node

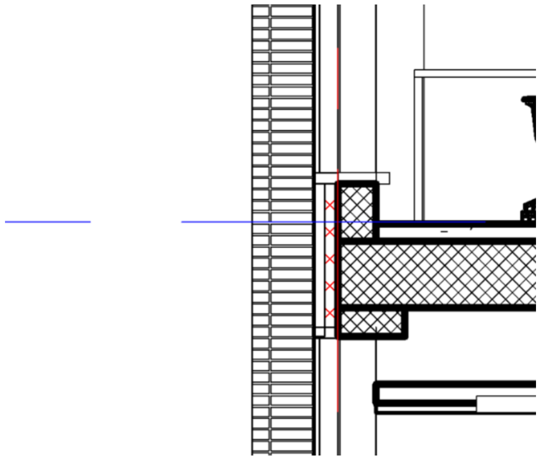

Figure 45: Good modelled node

Building construction plans

The building construction plans provided clarifications where necessary. Especially the elevations, detailed (node) drawings, and reinforcement plans were used in addition to the BIM model.
First, the elevations provided in addition to the BIM model give more information about the windows used. Even though these are modelled in the BIM model, they are modelled in a simplified way.
Secondly, the reinforcement plans were used to determine the amount of steel in the concrete used for floors and foundations. This was complemented with the detailed drawings of the prefab floor elements to determine all the steel amounts.
Last, more detailed drawings gave information about the smaller not modelled building elements. Moreover more detailed information about the building was extracted from these drawings. This was the case for the inner finishing layers of walls, type of window profiles, thickness of floor layers …

Technical information documents

The technical information documents were of great importance for material/product related information. Besides the fact which material is for example used as insulation in the wall, these documents also give a lot of information about the material/ product characteristics. In case these documents were still not detailed enough, these served as a basis to do some research.

Building cost sheet & Building specifications

The **building cost sheet** was of importance in two ways. First of all, this document was used to check the completeness level of the BIM model. So, not modelled elements were identified and added to the data collection. Secondly, the building cost sheet includes a quantity take-off and served as a source for element and subelement quantities as well as for material/product information. To obtain a building cost sheet, a **building specification document** was established for the contractors taking part in the tender. Nevertheless changes happened between the compiling of the building specification document and the execution of the building, this document serves a good sources for those elements were only few information is available about (e.g. doors).

PEF guidance documents

Besides the material information and quantities, PEF parameters such as A, B, R1, R2 and R3 were needed for each material. These were determined making use of the PEF guidance documents. Besides, these documents also served as a main source for transport linked scenarios.

National guidelines

As the available documents (PEF documents, technical information sheets …) do not cover all building products, national guidelines and documents were used to complement the data collection in several ways.
First, MMG was used as a reference to determine some material compositions, e.g. the amount of plaster coat and water used in a finishing wall layer. In addition, MMG served also as a source to determine some use phase related scenarios, such as cleaning, maintenance and replacement of elements and subelements.
Secondly, the BE PCR v4.1 was used to complement PEF parameters and transport scenarios. This document was also used for products covered by a certain PEFCR, but produced in Belgium. As the building is located in Belgium, this document is also used to determine the end-of-life scenario of the different building (sub)elements.

Building owner

As the BelOrta building was built in 2014, data about energy and water use is already available for this building. The BelOrta office building is an extension to the existing auction building. The energy consumption of the extension is calculated as the difference between the total consumption after building completion and the average consumption for the last three years for the auction building is made. For gasoil corrections were needed as this delivery is periodic instead of a continuous.
Furthermore data about the window cleaning was given.

Other

Besides the above mentioned data sources, additional research and were done to complete the data collection. This contains mainly further online research about material/product composition and related calculations.

OVERVIEW MODELLED ELEMENTS

In the following sections an overview of the modelled elements and their sources for quantities and material/ product information is given per building element type. Each time a table is added with this information. To reduce the size of the tables, the tables in the following sections are the summary the type of table shown in Figure 47. All tables give the information about the quantity source on element, subelement and material level, each time shown in the first column on the relevant level. The extended table in Figure 47 shows also these quantities which are left out in the other tables, similar for the quantities. On the subelement level the source also relies to the

information about the ratio of the subelement to the element level. For the material quantity this gives information about the ratio of material per unit of subelement. Besides the sources for quantities, these tables also give information about the source wherefrom material information is extracted.
Whenever subelements have a similar composition of an already mentioned subelement, the information about the material level is left out to reduce tables. Besides when a / is mentioned, this implies that no additional information was needed on this level (e.g. sanitary elements for which material quantities are already modelled on building level).

Data Source Quantities	Material Information	Element	Quantity	Unit	Subelement	Quantity	Unit	Ratio unit subelement/unit element	Material	Unit	Ratio material/sub element
BIM		Brick wall with insulation to existing building 26 cm	318.69	m²							
BIM					ConcreteBlocks	307	m²	1			
Technical Information Sheet	Technical Information Sheet								ConcreteBlock	kg	234.3
Own Calculation	Technical Information Sheet								CementMortar	kg	32.79685
BIM					MineralWool	318.69	m²	1			
Technical Information Sheet	Technical Information Sheet								GlassWoolRigidFoam	kg	3.36
Own Assumption	Technical Information Sheet								GlassFleece	kg	0.00
Own Calculation	Technical Information Sheet								ChromiumSTeel	kg	0.01

Figure 46: Extended overview modelled elements with data sources

Foundation

Figure 48 shows the modelled foundation elements with their respectively sources. All data about the foundation elements is retrieved from the foundation and reinforcement plans as these were better detailed than the BIM model.

Data Source Quantities	Material information	Element	Subelement	Material
Building Construction Plans		Foundation with pile head Type1		
Building Construction Plans			PileHead1	
Building Construction Plans	Building Construction Plans			ConcreteInSitu
Building Construction Plans	Building Construction Plans			ReinforcingSteel
Building Construction Plans			Pile	
Building Construction Plans	Building Construction Plans			ConcreteInSitu
Building Construction Plans	Building Construction Plans			ReinforcingSteel
Building Construction Plans		Foundation with pile head Type2		
Building Construction Plans		Foundation with pile head Type3		
Building Construction Plans		Foundation with pile head Type4		
Building Construction Plans		FoundationBeam1		
Building Construction Plans			Beam1	
Building Construction Plans	Building Construction Plans			ConcreteInSitu
Building Construction Plans	Building Construction Plans			ReinforcingSteel
Building Construction Plans	Building Construction Plans			XPS
Building Construction Plans		FoundationBeam2		
Building Construction Plans		FoundationBeam3		
Building Construction Plans		FoundationBeam4		
Building Construction Plans		FoundationBeam5		
Building Construction Plans		FoundationBeam6		
Building Construction Plans		FoundationBeam7		
Building Construction Plans		FoundationBeam8		
Building Construction Plans		FoundationBeam9		
Building Construction Plans		FoundationBeam10		
Building Construction Plans		FoundationWall		
Building Construction Plans			FoundationWall	
Building Construction Plans	Building Construction Plans			ConcreteInSitu
Building Construction Plans	Building Construction Plans			XPS
Building Construction Plans	Building Construction Plans			ReinforcingSteel

Figure 47: Overview modelled foundation elements with data sources

Floors

The quantities and material information for he floor elements were extracted from five sources: BIM model, building construction plans, building cost sheet, technical information documents and MMG. Figure 48 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
BIM		Concrete floor on earth		
BIM			VinylTiles	
/	Technical Information Sheet			VinylTiles
MMG	MMG			ButylAcrylate
BIM			ConcreetScreed	
Building Construction Plans	Building Construction Plans			ConcreteInSitu
BIM			PUR	
Building Construction Plans	Technical Information Sheet			PolyurethaneFlexibleFoam
BIM			ConcreteFloor	
Building Construction Plans	Building Construction Plans			ReinforcingSteel
Building Construction Plans	Building Construction Plans			ConcreteInSitu
BIM		Concrete storey floor 45 cm		
BIM			CeramicTiles	
Building Construction Plans	Technical Information Sheet			CeramicTiles
MMG	MMG			CementMortar
MMG	MMG			AcrylicBinder
MMG	MMG			Water
BIM			ConcreetScreed	
BIM			ConcretePrefabFloor	
Technical Information Sheet	Technical Information Sheet			ConcretePrefab
Technical Information Sheet	Technical Information Sheet			ReinforcingSteel
Building Cost Sheet	Technical Information Sheet			ConcreteInSitu
Technical Information Sheet	Technical Information Sheet			ReinforcingSteel
Building Cost Sheet	Technical Information Sheet			ConcreteInSitu
BIM		Concrete floor on earth with tile finishing		
BIM			CeramicTiles	
BIM			ConcreetScreed	
BIM			PUR	
BIM			ConcreteFloor	
BIM		Concrete floor on earth entrance		
BIM			FloorMat	
MMG	Technical Information Sheet			PolyamideTufted
MMG	MMG			AcrylicBinder
BIM			ConcreetScreed	
BIM			PUR	
BIM			ConcreteFloor	
BIM		Concrete floor on earth loods		
BIM			FloorMat	
BIM			ConcreetScreed	
BIM			PUR	
BIM			ConcreteFloor	
BIM		Concrete floor shaft		
BIM			ConcreteFloor	
BIM		Concrete floor elevator shaft		
BIM			ConcreteFloor	

Figure 48: Overview modelled floor elements with data sources

External Walls

The quantities and material information for the external wall elements were extracted from four sources: BIM model, building construction plans, technical information documents and MMG. Besides, own calculations for material quantities were made with the available data as well as some own assumptions about materials used. Figure 49 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
BIM		Cavity wall 65 cm		
BIM			Concrete	
Own Assumption	Own Assumption			ReinforcingSteel
Building Construction Plans	Building Construction Plans			ConcretePrefab
BIM			AirBarrier	
[redacted]				NoImpactMaterial
BIM			PUR	
Technical Information Sheet	Technical Information Sheet			PolyurethaneRigidFoam
BIM			Brickwall	
Technical Information Sheet	BIM			Brick
Own Calculation	BIM			CementMortar
MM BIM			Gypsum Plaster	
MMG	Technical Information Sheet			PlasterCoat
MMG	Technical Information Sheet			Water
MM BIM			Paint	
MMG	Technical Information Sheet			AcrylicPaint
BIM		Common wall with existing buildng		
BIM			Concrete	
BIM			PUR	
MM BIM			Gypsum Plaster	
MM BIM			Paint	
BIM		Brick wall with insulation to existing building 26 cm		
BIM			Concrete Blocks	
Technical Information Sheet	BIM			ConcreteBlock
Own Calculation	BIM			CementMortar
BIM			Mineral Wool	
Technical Information Sheet	Technical Information Sheet			GlassWoolRigidFoam
Own Assumption	Technical Information Sheet			GlassFleece
Own Calculation	Technical Information Sheet			ChromiumSTeel
BIM		Wall with Aluminium Finishing layer		
BIM			Concrete	
BIM			PUR	
BIM			Aluminium Finishing	
Technical Information Sheet	Technical Information Sheet			Aluminium
BIM		CurtainWall		
BIM			Aluminium Frame	
Own Assumption	Technical Information Sheet			WindowFrAl
Own Assumption	Technical Information Sheet			WindowPolyamide
BIM			Glazing	
/	/			GlazingDouble
BIM		Railing Plinth		
BIM			Plinth	
Own Calculation	Technical Information Sheet			Aluminium

Figure 49: Overview modelled external wall elements with data sources

Windows

The quantities for the windows were mainly extracted from the building elevations and sections. In combination with the technical information sheets available for the window elements, material information was added. More material information about the connections of the windows with the wall was retrieved from the building sections. Where needed additional calculations were made with the available material information to obtain material quantities used in frames and connection elements. Figure 50 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
Building Construction Plans		Composition Fixed, Openable window with panel between 1m		
Building Construction Plans			Glazing	
Technical Information Sheet	Technical Information Sheet			GlazingDouble
Building Construction Plans			Glazing2	
Technical Information Sheet	Technical Information Sheet			GlazingDouble2
Building Construction Plans			Frame A	
Technical Information Sheet	Technical Information Sheet			WindowFrAl
Technical Information Sheet	Technical Information Sheet			WindowPolyamide
Building Construction Plans			Frame B	
Building Construction Plans			Frame Ap	
Building Construction Plans			Frame Bp	
Building Construction Plans			Window Sill	
Building Construction Plans	Building Construction Plans			Aluminium
Building Construction Plans	Building Construction Plans			Plywood
Building Construction Plans			PUR	
Technical Information Sheet	Building Construction Plans			PolyurethaneFlexibleFoam
Building Construction Plans			EPDM	
Own Calculation	Building Construction Plans			EPDM
Building Construction Plans			Aluminium	
Own Calculation	Building Construction Plans			Aluminium
Building Construction Plans			PUR	
Building Construction Plans			EPDM	
Building Construction Plans			Aluminium	
Building Construction Plans			Panel	
Technical Information Sheet	Technical Information Sheet			GlazingSandblasted
Building Construction Plans			Lprofile	
Own Calculation	Own Assumption			AluminiumProfile
Building Construction Plans			Uprofile	
Own Calculation	Own Assumption			AluminiumProfile
Own Calculation	Own Assumption			ZincSteel
Building Construction Plans		Composition Fixed, Openable window with panel between 1.45m		
BIM		Roof window		
BIM			Glazing	
Technical Information Sheet	Technical Information Sheet			GlazingDouble2
Own Calculation	Building Construction Plans			Polycarbonate
Own Calculation	Building Construction Plans			PVC
BIM			Uprise	
Own Calculation	Building Construction Plans			Aluminium
Own Calculation	Building Construction Plans			PolyurethaneFlexibleFoam

Figure 50: Overview modelled window elements with data sources

Roof

Element quantities for the roof were obtained from the BIM model. Building construction plans (mainly sections) and technical information sheets provided most of the data needed about the subelement and material quantities and material information. Besides MMG was used and some calculations were made with the available data to complete all necessary information needed. Figure 51 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
BIM		Roof construction 76.5cm		
BIM			EPDM	
Own Calculation	Building Construction Plans			EPDM
MMG	MMG			ButylAcrylate
BIM			Screed	
Building Construction Plans	Building Construction Plans			PoorConcrete
BIM			RoofingFelt	
Technical Information Sheet	Technical Information Sheet			BitumenSealing
MMG	Technical Information Sheet			BitumenReinforcement
MMG	Technical Information Sheet			BitumenSealing
MMG	Technical Information Sheet			GlassFibre
BIM			PIR	
Building Construction Plans	Building Construction Plans			PolyurethaneRigidFoam
BIM			Concrete	
Technical Information Sheet	Technical Information Sheet			ConcretePrefab
Technical Information Sheet	Technical Information Sheet			ReinforcingSteel
Building Cost Sheet	Technical Information Sheet			ConcreteInSitu
Technical Information Sheet	Technical Information Sheet			ReinforcingSteel
Building Cost Sheet	Technical Information Sheet			ConcreteInSitu
BIM		Roof above stairs 76.5cm		
BIM			EPDM	
BIM			Screed	
BIM			RoofingFelt	
BIM			PIR	
BIM			Concrete	
BIM		Roofrailing		
Building Construction Plans			Multiplex	
Own Calculation	Building Construction Plans			Plywood
Building Construction Plans			PIR	
Own Calculation	Building Construction Plans			PolyisocyanurateRigidFoam
Building Construction Plans			EPDM	
Own Calculation	Building Construction Plans			EPDM
MMG	MMG			ButylAcrylate
Building Construction Plans			Aluminium	
Own Calculation	Building Construction Plans			Aluminium
BIM		RoofrailingWith Existing Building		
Building Construction Plans			Multiplex	
Building Construction Plans			PIR	
Building Construction Plans			EPDM	
Building Construction Plans			Aluminium	

Figure 51. Overview modelled roof elements with data sources

Internal walls

Besides the inner finishing wall layer, all the element and subelement quantities are retrieved from the BIM model. To determine the material quantities, mainly own assumptions and calculations were made, complemented with some MMG data. Most of the material information was obtained from the technical information sheets. Figure 52 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
BIM		Concrete wall 20cm		
BIM			concrete	
Own Assumption	Own Assumption			ReinforcingSteel
Building Construction Plans	Building Construction Plans			ConcretePrefab
BIM		Retention wall one side finished		
BIM			Metalstud	
Own Calculation	Technical Information Sheet			GalvanisedSteel
Own Calculation	Technical Information Sheet			Rockwool
BIM			Plasterboard	
MMG	Technical Information Sheet			ChromiumSTeel
MMG	Technical Information Sheet			PlasterBoards
Own Assumption			paint	
MMG	Technical Information Sheet			AcrylicPaintBoard
BIM		Retention wall two sides finished		
BIM			Metalstud	
BIM			Plasterboard	
Own Assumption			paint	
BIM		Wooden wall doors		
BIM			Wood	
Own Calculation	Own Assumption			WoodCherry
BIM		Wall concrete blocks		
BIM			ConcreteBlocks	
Technical Information Sheet	Technical Information Sheet			ConcreteBlock
Own Calculation	Own Assumption			CementMortar
Own Calculation		Internal glazed wall		
Own Calculation			Glazing	
Technical Information Sheet	Technical Information Sheet			GlazingLaminated
Own Calculation			AluminiumFrame	
Own Calculation	Technical Information Sheet			AluminiumFrame

Figure 52: Overview modelled internal wall elements with data sources

Doors

However doors are modelled in the BIM model, no further information about subelement and material quantities are available in the model. The material information is retrieved from the building specifications. This information made it also possible to calculate the amount of material per subelement for the door and so to calculate quantities on subelement level. The different MDF doors have the same composition but different quantities. As the information is about the sources is the same, the material level is left out here.

Table 53 gives a detailed overview of the element, subelements and materials used with their respectively data source for the modelled doors.

Data Source Quantities	Material information	Element	Subelement	Material
BIM		MDFDoorType1		
Own Calculation			MDF	
Own Calculation	Building Specifications			WoodChipBoard
Own Calculation			Hardboard	
Own Calculation	Building Specifications			HardBoard
Own Calculation	Building Specifications			AcrylicBinder
Own Calculation			LockHandleStop	
Own Calculation	Building Specifications			StainlessSteel
Own Calculation			Frame	
Own Calculation	Building Specifications			Plywood
BIM		MDFDoorType2		
Own Calculation			MDF	
Own Calculation			Hardboard	
Own Calculation			LockHandleStop	
Own Calculation			Frame	
BIM		MDFDoorType3		
Own Calculation			MDF	
Own Calculation			Hardboard	
Own Calculation			LockHandleStop	
Own Calculation			Frame	
BIM		GlazedDoorType1		
Own Calculation			Glazing	
Technical Information Sheet	Technical Information Sheet			GlazingLaminated
Own Calculation			AluminiumFrame	
	Building Specifications			AluminiumFrame
Own Calculation			LockHandleStop	
	Building Specifications			StainlessSteel
BIM		MDFDoorType4		
BIM		GlazedDoorType2		
			Glazing	
			AluminiumFrame	
			LockHandleStop	

Figure 53: Overview modelled door elements with data sources

HVAC

Figure 54 gives a detailed overview of the element, subelements and materials used with their respectively data source for the modelled HVAC elements.

Data Source Quantities	Material information	Element	Subelement	Material
Building cost sheet		GasBoiler		
/			GasBoiler	
/	Technical Information Sheet			CondensingGasBoiler
Building cost sheet		CoolingMachine		
/			CoolingMachine	
/	Technical Information Sheet			CoolingMachine
Building cost sheet		FloorHeating		
Building cost sheet			Piping	
Technical Information Sheet	Technical Information Sheet			PEXA
Own Calculation			PEFoil	
Technical Information Sheet	Technical Information Sheet			PE
Own Calculation			Insulation	
Technical Information Sheet	Technical Information Sheet			PEFoam
Own Assumption			Water	
Technical Information Sheet	Technical Information Sheet			Water
Building cost sheet		SteelPipes		
Building cost sheet			DoubleSteelPipe	
Technical Information Sheet	Technical Information Sheet			ZincSteelPipe
Building cost sheet		PipesClimaticCeiling		
Building cost sheet			LDPE	
Technical Information Sheet	Technical Information Sheet			LDPEPipes
Own Calculation			PEFoil	
Technical Information Sheet	Technical Information Sheet			PE
Own Assumption			water	
Technical Information Sheet	Technical Information Sheet			Water
Own Calculation			Insulation	
Technical Information Sheet	Technical Information Sheet			PEFoam
Own Calculation			Gypsumboard	
MMG	Technical Information Sheet			PlasterBoards
Own Calculation			Steelstructure	
Own Calculation	Technical Information Sheet			Steel
Building cost sheet		PipeGas		
Building cost sheet			PipeGas	
Technical Information Sheet	Technical Information Sheet			SteelPipe
Building cost sheet		ExpansionVessel110l		
/			ExpansionVessel110l	
/	Technical Information Sheet			ExpansionVessel110L
Building cost sheet		ExpansionVessel35l		
/			ExpansionVessel35l	
/	Technical Information Sheet			ExpansionVessel35L
Building cost sheet		ExpansionVessel80l		
/			ExpansionVessel80l	
/	Technical Information Sheet			ExpansionVessel80L
Building cost sheet		ExpansionVessel4l		
/			ExpansionVessel4l	
/	Technical Information Sheet			ExpansionVessel4L
Building cost sheet		PumpType1		
/			PumpType1	
Own Assumption	Technical Information Sheet			CastIron
Building cost sheet		PumpType2		
Building cost sheet		PumpType3		
Building cost sheet		PumpType4		
			PumpType4	
Own Assumption	Technical Information Sheet			CastIron
Own Assumption	Technical Information Sheet			StainlessSteel
Building cost sheet		PumpType5		
Building cost sheet		PumpType6		
Building cost sheet		BufferVessel1000L		
/			BufferVessel1000L	
Own Assumption	Technical Information Sheet			Steel
Building cost sheet		PlateHeatExchangerType1		
/			PlateHeatExchangerType1	
Own Assumption	Technical Information Sheet			StainlessSteel
Building cost sheet		PlateHeatExchangerType2		
Building cost sheet		PlateHeatExchangerType3		
Building cost sheet		PlateHeatExchangerType4		
Building cost sheet		AdditionalWater		
Building cost sheet			Water	
Building cost sheet	Building cost sheet			Water
Building cost sheet		PipesCentralHeating		
Building cost sheet			LDPEpipe	
Own Calculation	Technical Information Sheet			LDPEPipes
Building cost sheet		PipesAirDucts		
Building cost sheet			SteelPipe	
Own Calculation	Technical Information Sheet			SteelPipe
Own Calculation	Technical Information Sheet			Rockwool

Figure 54: Overview modelled HVAC elements with data sources

The HVAC elements are not modelled in the BIM model. In consequence element quantities had to be searched in the building cost sheet. Some of the subelement quantities could also be retrieved from this cost sheet (e.g. m of piping). Further quantities (material and some subelement ones) were calculated starting from the material information available which was mainly retrieved from technical information sheets and complemented with some additional online research. However it should be noticed that several elements were simplified for this element type. Some elements are presented as an amount of their main material, e.g. a pump which is simplified to an amount of cast iron. For some elements, e.g. expansion vessel 110l, the element is still the entry on the material level. In this case, either there is a generic dataset available in SimaPro or there is no information available about the exact materials used in the element. Figure 54 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Electricity

Similar as the HVAC elements, electrical elements are not modelled in the BIM model. The building cost sheet gave information about the element quantities. Some elements are only further specified on the level of material and do not require further information on the subelement level (e.g. sockets). Most of the information on material level is retrieved from the technical information sheets available. Figure 55 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
Building Cost Sheet		XVBCables		
Technical information sheet			Copper	
Own Calculation	Technical information sheet			Copper
Technical information sheet			PVC	
Own Calculation	Technical information sheet			PVC
Building Cost Sheet		PresenceSensorCeiling		
/			SensorCeiling	
Technical information sheet	Technical information sheet			Steel
Technical information sheet	Technical information sheet			StainlessSteel
Technical information sheet	Technical information sheet			Bronze
Technical information sheet	Technical information sheet			PP
Technical information sheet	Technical information sheet			PA
Technical information sheet	Technical information sheet			PE
Technical information sheet	Technical information sheet			Polycarbonate
Technical information sheet	Technical information sheet			Brass
Technical information sheet	Technical information sheet			ElectronicCircuit
Building Cost Sheet		Socket2P+A		
/			Socket	
Technical information sheet	Technical information sheet			Steel
Technical information sheet	Technical information sheet			PA
Technical information sheet	Technical information sheet			PE
Technical information sheet	Technical information sheet			Polycarbonate
Technical information sheet	Technical information sheet			Brass
Technical information sheet	Technical information sheet			PBT
Building Cost Sheet		CoverSocket		
/			SocketCover	
Technical information sheet	Technical information sheet			PMMA
Building Cost Sheet		CableHolder		
/			Cableholder	
Technical information sheet	Technical information sheet			Steel
Technical information sheet	Technical information sheet			StainlessSteel
Technical information sheet	Technical information sheet			Bronze
Technical information sheet	Technical information sheet			PP
Technical information sheet	Technical information sheet			PA
Technical information sheet	Technical information sheet			PE
Technical information sheet	Technical information sheet			Copper
Technical information sheet	Technical information sheet			Brass
Technical information sheet	Technical information sheet			Aluminium
Technical information sheet	Technical information sheet			PPE
Technical information sheet	Technical information sheet			PS
Technical information sheet	Technical information sheet			PolyurethaneRigidFoam
Building Cost Sheet		CableDucts		
Building Cost Sheet			GalvanisedSteelDucts	
Technical information sheet	Technical information sheet			GalvanisedSteel
Building Cost Sheet			WallDuctsZincCoated	
Technical information sheet	Technical information sheet			ZincSteel
Building Cost Sheet		OperationalPanels		
/			OperationalPanel	
Technical information sheet	Technical information sheet			Steel
Technical information sheet	Technical information sheet			Polycarbonate
Technical information sheet	Technical information sheet			Bronze
Technical information sheet	Technical information sheet			PA
Technical information sheet	Technical information sheet			PE
Technical information sheet	Technical information sheet			Polycarbonate
Technical information sheet	Technical information sheet			PVC
Technical information sheet	Technical information sheet			ElectronicCircuit

Figure 55: Overview modelled electrical elements with data sources

Sanitary

Information about the sanitary elements was extracted on from the building cost sheets in combination with the technical information sheets available and some additional online research. All the sanitary elements such as toilets, sinks … are modelled on material level. Each time the total amount of a certain material for a certain subelement is defined on the material level. The piping systems needed are modelled in a similar way as other elements in the building. Figure 56 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
/		Sanitary Elements		
/			Sanitary	
Building cost sheet & Technical information sheet	Technical information sheet			SanitaryCeramics
Building cost sheet & Technical information sheet	Technical information sheet			StainlessSteel
Building cost sheet & Technical information sheet	Technical information sheet			PVC
Building cost sheet & Technical information sheet	Technical information sheet			Messing
Building cost sheet & Technical information sheet	Technical information sheet			GlazedSteel
Building cost sheet		FirePipe		
/			FirePipe	
Own Calculation	Technical information sheet			LDPEPipes
Building cost sheet		RainWaterPipie		
/			RainwaterPipe	
Own Calculation	Technical information sheet			LDPEPipes
Building cost sheet		SteelPipes		
/			DoubleSteelPipe	
Own Calculation	Technical information sheet			ZincSteelPipe
Building cost sheet		WCDrainagePipes		
/			PEPipe	
Own Calculation	Technical information sheet			LDPEPipes
Building cost sheet		SupplyPipes		
/			PEPipe16mmm	
Own Calculation	Technical information sheet			LDPEPipes
				InsulationPipe
Building cost sheet		Boiler6L		
/			Boiler6l	
/	Technical information sheet			Boiler6l
Building cost sheet		Boiler50L		
/			Boiler50l	
/	Technical information sheet			ElectricBoiler

Figure 56: Overview modelled sanitary elements with data sources

Elevator

From the building cost sheet and BIM model it is known that only one elevator is present in this building. Further, in SimaPro the elevator is assumed as an amount of steel.

Data Source Quantities	Material information	Element	Subelement	Material
Building cost sheet		Elevator		
/			Elevator	
/	/			LowRiseElevator

Figure 57: Overview modelled elevator elements with data sources

Lighting

Besides the furniture for the lighting, no further elements were modelled in the BIM model. In addition, no distinction was made between different lighting types. More information about the different types of lighting was found in the building cost sheet. To simplify some lighting elements were simplified to another type when only a small difference was found between two elements. In general information could be find about the dimensions of the fixture and the fact that a ballast is present, but no further detailed information about the exact materials and their quantities was available. Therefore assumptions had to be made. Figure 58 gives a detailed overview of the element, subelements and materials used with their respectively data source.

Data Source Quantities	Material information	Element	Subelement	Material
Building Cost Sheet		ET1		
Technical information sheet			T5bulb	
Own Assumption	Technical information sheet			T5Bulb
Technical information sheet			Fixture	
Own Calculation	Technical information sheet			AluminiumSatinated
Technical information sheet			Ballasts	
Own Calculation	Technical information sheet			Ballast
Building Cost Sheet		PT1		
Technical information sheet			T5bulb	
Technical information sheet			Fixture	
Own Calculation	Technical information sheet			AluminiumSatinated
Own Calculation	Technical information sheet			Polycarbonate
Technical information sheet			Ballasts	
Building Cost Sheet		EF1		
Technical information sheet			TCTBulb	
Own Assumption	Technical information sheet			TCTLamp
Technical information sheet			Fixture	
Own Calculation	Technical information sheet			ZincSteel
Own Calculation	Technical information sheet			Polycarbonate
Technical information sheet			Ballasts	
Building Cost Sheet		EF2		
Technical information sheet			TCTBulb	
Own Assumption	Technical information sheet			TCTLamp
Technical information sheet			Fixture	
Technical information sheet			Ballasts	
Building Cost Sheet		MF1		
Technical information sheet			LED	
Own Assumption	Technical information sheet			LED
Technical information sheet			Fixture	
Own Calculation	Technical information sheet			AluminiumSatinated
Own Calculation	Technical information sheet			PMMA
Technical information sheet			Ballasts	
Building Cost Sheet		ET1 LED		
Technical information sheet			LED	
Technical information sheet			Fixture	
Technical information sheet			Ballasts	

Figure 58: Overview modelled lighting elements with data sources

Overview Data Gaps

In spite of the extensive data collection for the BelOrta building, still some elements are missing. Within this an attempt is made to give an overview of the different gaps.

First of all, there are some elements not modelled as they fall out of the scope of this project. Amongst others this includes furniture, kitchen equipment, external works …

Secondly, some of the elements are out of the scope of an BAU office and typical to the office in this context. An example is the garage door between the office part and the older auction part.

Besides, data gaps are mainly found in the more technical elements in the building. Due to a lack of data about the exact material composition of elements multiple smaller elements are not modelled. For example the XVB cables for electricity are modelled, but the switchboards aren't as no further information was provided. Another example are sensors, which are simplified to one type from which data was available. Similar only one control panel is modelled and for the different ones used in the building. In this way several assumptions were made. Considering fire safety elements and smoke and heat evacuation only the fire safety piping is modelled.

ANNEX 4 – DETAILED DATA COLLECTION BE2226 BUILDING

To develop a complete data collection for the BE2226 building several sources were used as mentioned before. More specifically for this building the following sources were used: Building Information Model, building construction plans, technical information documents, building cost sheet, PEF guidance documents, national guidelines and data from the building owner. Even though plenty information was provided still some additional search was needed to complete this data collection. Nevertheless, some elements are not modelled due to several reasons. First, for some elements the available data was not detailed enough to model the element (e.g. electronic devices as sensors). Secondly, some elements are not part of a BaU office and therefore fell out of the scope of this project (e.g. garage door). The following sections present the data sources used are discussed, followed by an overview of the modelled element, specific scenarios and their data sources completed by a list of data gaps.

DATA SOURCES AVAILABLE

BIM model

In the BIM model, the following building elements are modelled as individual 3D-elements: pile foundation and slab-on-grade as well as perimeter insulation, floor construction and flooring, roof construction and roofing, external and internal walls, windows, doors and stairs.
For a refined bill of quantities, the main building elements floor, roof and external walls are thus modelled as separately with their structural and non-structural components (both with multiple layers).

External walls for example are hence comprised of a structural inner element (brick, mortar, plaster) and an outer, mainly insulating, element with multiple layers, differing material specifications and slightly different geometry. To distinguish between all these differences in material specifications, depending on their application in building elements, several materials were defined and additional created when used in another element (e.g. distinction between the different insulation types in the roof and floors, different bricks in external and internal wall, for structural and non-structural purposes). In the following paragraphs the 3D modelled building elements are discussed in detail.

EXTRACTED DATA DETAILS PER BUILDING ELEMENT

Table 16: BE2226 - Overall building element structure

Overall building structure, elements with respective sub-elements and materials	
Foundation	FN01_Structural foundation, driven piles new, d42.0
	FN02_Structural foundation, slab-on-grade slab, reinf. Concrete, 25.0
	FN03_Structural foundation, special
	FC01_Perimeter insulation (slab-on-grade)
External walls	EW01_Exterior wall, outer brick + plaster, 40.5
	EW02_Exterior wall, brick attica, 38.0
Floor structure	FS01_Floor structure, upper floors, concrete slab+plaster, 24.5
Roof structure	RS01_Roof structure, concrete slab, 24.0
Stairs	ST01_Stair primary, concrete, w100.0
	ST02_Stair secondary, wood, w100.0
Internal walls	IW01_Interior wall, brick + plaster 27.0
	IW02_Interior wall, brick + plaster 17.0
	IW03_Interior wall, brick+plaster, 12.0
Flooring	FL01_Floor finish, ground floor, 29.5
	FL02_Floor finish, upper floors, 14.5
Roofing	RF01_Roofing, sealing+insulation+foil+gravel, 36.0
Windows	WE01_Windows exterior, ground floor, incl. side panel
	WE02_Windows exterior, upper floors, incl. side panel
Doors	DE01_Door exterior, ground floor, incl. side panel
	DI01_Door interior, wooden door + frame
	DI02_Door interior, glas door (modelled as wall), 5.5
	DI03_Door interior, wooden door + frame

Foundation

The foundation elements include concrete piles in the ground as well as the concrete slab beneath ground floor. Some of these piles are old piles from a previous building, which are thus considered outside the system boundaries for this assessment. **However, attention should be paid to the fact that increasingly reuse of building elements will become an issue and clear rules if and how to include those in the assessment need to be specified**. Furthermore, structural foundation includes a slab-on-grade below the ground floor. Perimeter insulation beneath this slab is modelled independently in the BIM model.

The assessment of the final quantities for concrete, steel and insulation in the foundation parts is based on a volumetric evaluation (BoQ from BIM). To specify the amount of concrete and steel in the piles and slabs a percentage value was used to calculate the amount of steel in reinforced concrete.

Floors

For the floor elements in the upper levels of the building, the structural part (reinforced concrete slab, ceiling putty) was modelled separately from the raised and non-structural flooring. These flooring elements can be found across all levels starting at the ground level up to the fifth level. For the raised floor system simplifications were made regarding the plastic supports used therein as now data could be obtained on the exact quantity and type of products. Thus only the wooden substructure in the raised floor system is assessed. All other layers of the flooring (sealing foil, sound insulation, screed) are modelled and evaluated based on the BIM models bill of quantity. Roof.

Similar to the modelling of floors also roof's structural and non-structural elements were modelled separately. While all relevant layers of these element's composition were modelled, simplifications were made for connections and geometry e.g. for the sloped insulation on the roof an average thickness was assumed and small pieces of insulation used to avoid thermal bridges at connection where not modelled. The inner finishing layer (ceiling putty) was modelled as part of the structural element (reinforced concrete slab).

External walls

External walls were modelled as structural inner element and outer, insulating, element. Both elements having multiple layers (brick, mortar, plaster), differing material specifications as well as differences in geometry e.g. due to corners and connections with other structural/non-structural elements. In the bill of quantities extracted from the BIM model, the material layers where thus individually evaluated to increase accuracy of material quantities.

Internal walls

Internal walls were modelled as one element with multiple layers. The type and thickness of brick and amount of mortar required were specified based on product information for each internal wall type while type of plaster used for the finishing is the same across all internal wall finishes.

Windows

The external windows in the ground and upper floors were assessed based on the number of windows and a simplified evaluation based on the type, area of glazing and frame. In addition, the ventilation panels accompanying the fixed glazing were assessed based on its size and material composition. Window sills were not included. No handles or mountings were modelled.

Doors

Doors were modelled as aggregated elements in BIM and SimaPro based on their type of door (wooden door, glass door) as well as size (height and width).

Stairs

The stairs in the BE2226 building were assessed based the BIM model geometry. Thus the volume of reinforced concrete for the main staircase, as well as wooden boards forming the steps of the secondary stair have been evaluated.

Lighting fixtures

Lighting fixtures are not included in the BIM model and not modelled in the assessment.

Furniture

Furniture is not modelled as it is outside of the system boundaries.

HVAC-system

No HVAC systems are installed in the BE2226 building.

Electrical service and distribution

The building automation system (sensors, tablets, motors in ventilation panels) as well as electrical wiring were not modelled. No freshwater or sewage piping was modelled for the building.Annex 5 - Building elements specified in GPP guideline, DGNB assessment, EN 15978 and proposal for elements included in the PEF4Buildings study.

ANNEX 5 – COMPARATIVE ANALYSIS OF SYSTEM BOUNDARIES FOR THE PEFCRS FOR CONSTRUCTION PRODUCTS

The Excel file “Annex 5_D3_PEF4B_Comparison_PEFCRs_20170821.xlsx” is provided as a separate annex to this report. The file contains the mapping of various aspects related to the system boundaries and scenarios as they are included in the 5 PEFCRs for construction products developed until the date of this study.

Client: European Commission
DG Environment
Dir B, Circular Economy and Green Growth
Unit B1, Sustainable Production, Products and Consumption

PEF4Buildings

Study on the Application of the PEF Method and related guidance documents to a newly office building (ENV.B.1/ETU/2016/0052LV)

Deliverable D4: Proposal for approach for benchmark and classes of performance for new office buildings

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LIST OF ACRONYMS

BIM	Building Information Model
EC	European Commission
EPD	Environmental Product Declaration
GPP	Green Public Procurement
LCA	Life Cycle Assessment
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules

INTRODUCTION

This report is focusing on a **possible approach for benchmark and classes of performance for new office buildings**. This report will be integrated as an Annex to the final study report for this project for the European Commission (DG ENV).

The report is focusing on the **task 2** (Deliverable D4) of the contract No 07.0201/2016/746615/ETU/ENV.B.1 “Study on the application of the PEF method and related guidance documents of a new office building”.

The key objective of task 2 is to develop a possible approach to benchmark office buildings and define classes of performance. In the report several important issues are covered: the definition of the reference building, how to define system boundaries, how many reference buildings should be defined to cover the building typology of office buildings, which construction techniques to be considered and how to handle this range of different option, etc.

This project report on Deliverable D4 consists of 4 main chapters and 2 annexes:

- Chapter 1 – Overview of publicly available literature and information sources;
- Chapter 2 – Activity 2.1 – Development of a possible approach to benchmark new office buildings;
- Chapter 3 – Activity 2.2 – Approach to define classes of performance for new office buildings;
- Chapter 4 – Final conclusions and recommendations;
- Annex 1 – Matrix with summary overview of literature sources consulted;
- Annex 2 – Minutes of second stakeholder workshop in Brussels on 29/01/2018 (including feedback of stakeholders).

CHAPTER 1 OVERVIEW OF PUBLICLY AVAILABLE LITERATURE AND INFORMATION SOURCES

The following documents and initiatives have been screened and assessed in order to give additional insights towards a possible approach for benchmarking and definition of classes of performance of newly built office buildings.

General methodological reports assessed in this desk research:

- VTT Report – Sustainability and Performance Assessment and Benchmarking of Buildings;
- BPIE report - EUROPE'S BUILDINGS UNDER THE MICROSCOPE, A country-by-country review of the energy performance of buildings;
- TABULA and EPISCOPE reports (Intelligent Energy Europe);
- BBP Sustainability Benchmarking Toolkit for Commercial Buildings;
- Building sustainability assessment and benchmarking – an introduction (UN-Habitat).

The following national sustainability certification schemes or LCA methods for buildings are assessed:

- LCA Benchmarks in Building's Environmental Certification Systems;
- German building certification system of DGNB;
- German assessment system for sustainable building (BNB) for public offices and administration buildings;
- MMG – Material based environmental profiles of building elements (Milieugerelateerde Materiaalprestatie van Gebouw(element)en);
- GRO – De nieuwe handleiding van het facilitair bedrijf, op weg naar toekomstgerichte bouwprojecten;

Besides these, existing national benchmarking approaches are studied:

- Legal requirements in the Netherlands;
- Green Public Procurement in the Netherlands;
- French initiative "Towards positive energy and low carbon buildings – The French experimentation for new buildings".

At the European level, the following sustainable building assessment or green public procurement methods are assessed:

- Level(s): Building Sustainability Performance;
- EN 15978;
- Green Public Procurement Criteria for Office Building Design, Construction and Management;
- Draft PCR 2.0 for buildings (for open consultation, International EPD® system);
- Existing benchmarks for energy performance of buildings.

Where relevant, the Product Environmental Footprint (PEF) Guide (Commission Recommendation 179/2013 on The use of common methods to measure and communicate the life cycle environmental performance of products and organisations) or the Product Environmental Footprint Category Rules (PEFCR) Guidance (European Commission (EC), 2017) are also reviewed, and interesting findings during the PEF study of two new office buildings of this project (VITO, KU Leuven, & TU Graz, 2018a) are also added.

1.1. VTT REPORT - SUSTAINABILITY AND PERFORMANCE ASSESSMENT AND BENCHMARKING OF BUILDINGS

This report presents and summarises the results of the European SuPerBuildings project, a comprehensive and accurate report that discusses the use of indicators and benchmarking process for buildings (VTT Technical Research Centre of Finland, 2012). The project was funded by the 7th Framework Programme, coordinated by Dr Tarja Häkkinen. The consortium included altogether 13 members from 9 countries. The report is structured as follows. Chapter 2 and 3 characterises and summarises the existing indicator systems and makes conclusions about the needs of development, as well as barriers and drivers for sustainable buildings. The project developed and selected sustainability indicators for buildings (chapter 4 and chapter 5), develop understanding about performance levels considering new and existing buildings (chapter 6), different building types and different national and local requirements, developed methods for the assessment and benchmarking of sustainable buildings (chapter 7) and made recommendations for the effective use of benchmarking systems as instruments of steering and in different stages of building projects (chapter 8). As the sustainability of buildings should always be assessed with the help of indicators, one of the key objectives of SuPerBuildings is to ensure "validity" for sustainability indicator systems. The report also discusses the problematics, the functional equivalent, and weighting and normalization criteria.
Finally, the report gives recommendations for the use of indicators in different stages of building processes, in connection with building information models and in connection with different steering instruments (chapter 9 and 10). The framework for the assessment of environmental, social and economic performance is being developed within CEN and ISO.

1.2. BPIE REPORT

According to a report from BPIE (BPIE, 2011) non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector. The retail and wholesale buildings comprise the largest portion of the non-residential stock while office buildings are the second biggest category with a floor space corresponding to one quarter of the total non-residential floor space. Variations in usage pattern (e.g. warehouse versus schools), energy intensity (e.g. surgery rooms in hospitals versus to storage rooms in retail), and construction techniques (e.g. supermarket versus office buildings) are some of the factors adding to the complexity of the sector.
To develop an approach for the definition of the representative product for office buildings we fully take advantage from the insights reported by BPIE.

1.3. TABULA AND EPISCOPE REPORTS (INTELLIGENT ENERGY EUROPE)

During the Intelligent Energy Europe (IEE) project TABULA (Typology Approach for Building Stock Energy Assessment) (Loga, Diefenbach, Dascalaki, & Balaras, 2010), residential building typologies have been developed for 13 European countries. Each national typology consists of a classification scheme grouping buildings according to their size, age and further parameters and a set of exemplary buildings representing the building types. TABULA tried also to develop some national approaches for non-residential building typologies (Stein et al., 2012). Because of the broad variety of uses and associated characteristics, setting up a typology for the non-residential sector was

rather complex. It was therefore important to consider both, practicability of and data availability for such a structure.
Following the TABULA project, residential building typologies for 10 European countries were further developed during the EPISCOPE project (Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks) and new typologies were developed for 6 additional countries (EPISCOPE, 2016).
To develop an approach for the definition of the representative product for office buildings we fully take advantage from the methodologies developed within two European IEE projects TABULA and EPISCOPE.

1.4. BBP Sustainability Benchmarking Toolkit for Commercial Buildings

This discussion paper by Better Buildings Partnership (BBP) (2010) aims at presenting an overview of current practices in sustainability benchmarking and identifying principles for best practice to support the development of this important process in the future, with a focus on measuring and benchmarking energy and carbon. BBP describes its learnings from its own benchmarking exercise in London, including the challenges accompanying that work, e.g. on the availability and capacity of data collection and the choice of metrics and indicators to quantify environmental performance.

1.5. Building sustainability assessment and benchmarking – An introduction (UN-Habitat)

As part of UN-Habitat’s mandate to promote sustainable urban development through knowledge-creation and management, this report (United Nations Settlements Programme (UN-Habitat), 2017) intends to address some of these concerns and contribute to four objectives: 1) establish the rationale for building sustainability assessment and benchmarking; 2) identify challenges and limitations that occupants, policy-makers and building practitioners face in applying or interpreting building sustainability assessment or benchmarking tools; 3) provide a sample overview of some environmental sustainability assessment and benchmarking tools for buildings and housing as well as those attempting to measure social and economic impacts; and 4) identify pathways for the wider uptake of assessment tools by industry, professional bodies, policymakers, vocational and higher education, and other actors working within the built environment.

1.6. LCA benchmarks in building’s environmental certification systems (2016)

The paper of Ganassali et al. deals with the definition of reference values (benchmarks) referred to the Life Cycle Assessment (LCA) indicators used in the environmental certification systems of buildings, highlighting their potentiality and criticality (Ganassali, Lavagna, & Campioli, 2016). In particular the analysis refers to the Green Building Rating Systems (GBRSs), such as DGNB, LEED, and BREEAM, and the energy-environmental certifications (Minergie-Eco). The paper moreover describes different benchmarks methodologies (related to LCA indicators). The paper demonstrates potentiality and criticality of the methodological approaches used, in order to understand the role of benchmark in the development of new policies and environmental strategies.

1.7. German building certification system of DGNB

The German Sustainable Building Council (DGNB) together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) developed a voluntary certification system for sustainable buildings in 2007. The building certification system of DGNB is based on the CEN/TC350 approach. During two years of co-operation between the Federal Ministry and the German Sustainable Building Council (DGNB), a first national catalogue of criteria was developed for an integrated analysis and assessment of sustainability aspects for buildings. The results were discussed with stakeholders from the construction sector by the “Round Table Sustainable Building” at the Federal Building Ministry and have been published since 2009 as the BNB (Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety (BMUB), 2014)

The DGNB certification system criteria-set includes five weighted topics (main criteria groups): ecological quality (22.5%), economic quality (22.5%), social quality (22.5%), technical quality (22.5%), quality of process (10%) and one additionally not weighted, separately evaluated topic (main criteria group) quality of the location (DGNB, 2017).

The assessment is based on a holistic life cycle approach considering the before-use phase, use phase and end-of-life phase with a reference study period of 50 years. DGNB implemented an explicit LCA method. The goal of the assessment is to quantify and document the environmental performance of the building under consideration (office building, retail, hospital, school, etc.) by means of applying LCA methodology and to compare the results with a defined benchmark (DGNB, 2014).

1.8. German assessment system for sustainable building (BNB) for public offices and administration buildings

In 2011 Federal Ministry of Transport, Building and Urban Affairs (BMVBS) introduced the Guideline for Sustainable Building as a set of binding rules for the use of the Assessment System for Sustainable Building (BNB) for public buildings. The BNB is mandatory for federal construction works with a dedicated budget threshold. In addition, the Federal Building Ministry of Germany promoted the Assessment System for Sustainable Building (BNB) for public offices and administration buildings.

In addition, the Federal Building Ministry of Germany promoted the Assessment System for Sustainable Building (BNB) for public offices and administration buildings. Within this assessment system the needs of public buildings and public authorities are reflected. BNB states, that it´s goal is to describe and evaluate the quality of the sustainability of buildings and annexes and their complexity. This is to obtain a higher quality of construction using the planning, beginning with the building construction, operation and maintenance, repair up to the demolition of buildings and annexes. The assessment is conducted using transparent and objectively comprehendible regulations.

1.9. MMG – Material based environmental profiles of building elements (Milieugerelateerde Materiaalprestatie van Gebouw(element)en)

Similar to the Dutch GWW assessment method, Belgium has also developed an assessment method for the environmental performance of building elements called MMG (Openbare Vlaamse Afvalstoffenmaatschappij (OVAM), 2013) This method was developed because the environmental performance of building elements becomes relatively more important for the total impact of buildings, since building’s energy efficiency is continuously improving. The MMG method forms the basis for a database of environmental profiles of 115 building elements, valid in Flanders, and is based on European norms EN 15804, EN 15978, EN 15643-2 and TR 15941.

1.10. GRO – De nieuwe handleiding van Het Facilitair Bedrijf. Op weg naar toekomstgerichte bouwprojecten

With the ambition to obtain an integrated design process to move towards future-oriented and liveable buildings, GRO is developed as a new sustainability meter by the Flemish Government (Agentschap Facilitair Bedrijf, 2017). The assessment method can be used independent on the function and scale of the building and is mandatory for public buildings in Flanders. The method can be used during all phases of the design process. The assessment method includes 25 criteria divided over three themes (people, profit and planet) as well as four criteria for climate responsive design and ten criteria to assess the quality of the site. The method strives for closed cycles and circular designs by spreading its criteria over the whole life cycle of the building. GRO uses a score system with defined performance levels (good, better, excellent) which is applied per criterion but can be up scaled to a building performance by equal weighting.

1.11. Legal requirements in the Netherlands

An Assessment Method for the Environmental Performance of Construction and Civil Engineering Works (GWW) over their entire service life has been developed by Stichting Bouwkwaliteit (Stichting Bouwkwaliteit, 2014). This guideline is based on EN 15804, and by extension on EN 15978, although this last one is not followed explicitly. The goal of the assessment method is to establish a clear way of calculating the environmental performance of both construction and civil engineering works within the Netherlands.

Legal requirements of buildings in the Netherlands are defined in the Bouwbesluit. As of January 1st 2013, an assessment according to the GWW method must be done for all newly built residential buildings and offices with a surface larger than 100 m^2. A study by W/E adviseurs (W/E advisors) researches possible performance levels of residential buildings (W/E adviseurs, 2014), of which the results are used to define the legal requirements in the Bouwbesluit.

1.12. Green Public Procurement in the Netherlands

On top of legal requirements in the Netherlands, also voluntary green public procurement (GPP) guidelines were created in the Netherlands. Also based on the GWW assessment method, PIANOo defined voluntary environmental criteria for socially responsible newly built office buildings (PIANOo, 2017). However, they define criteria for a wider range of topics: energy efficiency, used materials and health within the building. Benchmarking is set and different performance levels are defined compared to a baseline level.

1.13. French initiative - Towards positive energy and low carbon buildings - The French Experimentation for new buildings

In order to move from a thermal to an environmental regulation framework, the French law encourages new buildings to be low energy (positive energy buildings, E+) and low Carbon (C-). Low energy buildings are encouraged through focusing on the reduction of non-renewable energy consumption, the development of efficient solutions and the use of renewable energy, while low carbon buildings will be achieved through considering the whole life cycle of buildings and optimizing the balance between energy reductions and accompanying increased environmental burdens. A Methodology is developed to calculate the carbon footprint of buildings (République française, 2017) and to define performance classes (République française, 2016).

1.14. Level(s): building sustainability performance

Developed as a common EU framework of core indicators for the sustainability of office and residential buildings, Level(s) provides a set of indicators and common metrics for measuring the environmental performance of buildings along their life cycle (Dodd, Garbarino, & Gama Caldas, 2017). As well as environmental performance, which is the main focus, it also enables other important related aspects of the performance of buildings to be assessed using indicators for health and comfort, life cycle cost and potential future risks to performance. The scope of the Level(s) framework is office and residential buildings. This scope encompasses both new and existing buildings at the point of major renovation.

1.15. EN 15978

The document EN 15978 (Bureau for Standardisation (NBN), 2013) provides the calculation method for the environmental performance assessment of new and existing buildings, developed within the framework of CEN TC 350.

1.16. Green Public Procurement Criteria for Office Building Design, Construction and Management

To reduce the environmental impact of public purchasing, green public procurement (GPP) criteria for products, services and works have been identified and developed by European Commission. This Technical Report (Dodd, N., Garbarino, E., Gama Caldas, 2016) provides the technical background information and further details on the reasons for selecting the GPP criteria for office buildings. Together with this technical report, the GPP criteria for office buildings are also provided, supported by a guidance document that provides orientation on how to effectively integrate these GPP criteria into the procurement process.
The development of GPP criteria for office building design, construction and management aims at helping public authorities to ensure that office buildings projects are procured and implemented in order to deliver environmental improvements and with reference to the European policy framework for energy and resource efficiency.
GPP is a voluntary instrument. The criteria are divided into selection criteria, technical specifications, award criteria and contract performance clauses. These are further categorized in:

- The Core criteria, designed to allow for easy application of GPP, focusing on the key area(s) of environmental performance of a product and aimed at keeping administrative costs for companies to a minimum.
- The Comprehensive criteria, designed to take into account more aspects or higher levels of environmental performance

This GPP criteria set addresses the procurement process for office buildings, including their design, site preparation, construction, servicing and ongoing management, applicable both to renovation of existing buildings and construction of new buildings. The GPP includes minimum energy performance requirement, recognizing the significant variation in Member States' minimum energy performance. Performance requirements are also proposed for waste arising during construction and renovation (reference source BREEAM).

1.17. DRAFT PCR 2.0 FOR BUILDINGS (FOR OPEN CONSULTATION, INTERNATIONAL EPD® SYSTEM)

The draft Product Category Rules (PCR) for buildings provides rules for the assessment of the environmental performance of buildings within the International EPD® System (International EPD® System, 2017).

1.18. EXISTING BENCHMARKS FOR ENERGY PERFORMANCE OF BUILDINGS

The European Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), required new buildings to be nearly zero-energy. In this directive, a nearly-zero energy building is defined as a building that has a very high energy performance. In consequence of this directive, EU Member States have defined "nearly-zero energy buildings" in a more precise quantified value (max amount of kWh/m² floor area) taking into account their climatic context. These quantified values are hence benchmarks for the operational energy of buildings. Although the scope of the energy performance benchmark is more limited than the scope defined in environmental benchmarks of buildings, the approach followed to define the benchmarks could be a valid approach for environmental benchmarking of buildings too and is therefore included in this desk research.

CHAPTER 2 ACTIVITY 2.1: DEVELOPMENT OF A POSSIBLE APPROACH TO BENCHMARK NEW OFFICE BUILDINGS

In this chapter 2, each section starts with analysing what the PEF Guide and the PEF Guidance document defines on benchmarking. If relevant the findings of the PEF study of two office buildings are presented afterwards. After that, the findings of the desk research are described and conclusions and recommendations are formulated.

2.1. METHODOLOGICAL APPROACHES AND POTENTIAL MEANINGS OF BENCHMARKS OF BUILDINGS

2.1.1. PEF GUIDANCE

In this section it is described how the PEF Guide and PEF Guidance document define a benchmark. The contextualisation to the building case will be done in next chapters on the desk research, the conclusions and the recommendations.

According to the PEF guidance document (European Commission (EC), 2017) the *benchmark* is defined as a standard or point of reference against which any comparison can be made (reference value). In the context of PEF, the term 'benchmark' refers to the average environmental performance of the representative product sold in the EU market. For each product group the benchmark allows companies to see how well they are performing from an environmental point of view and identify ways they can become more competitive in that framework.

The benchmark calculation is only applicable for final products. It shall be provided for each representative product and shall correspond to the PEF profile of each representative product as modelled after the supporting studies results are taken into consideration.

The benchmark shall be provided in the PEFCR both as characterised results for each of the EF impact categories (not only the most relevant ones) and as single score, based on normalised and weighted results. In both cases the toxicity related impact categories shall not be considered.

As no benchmarking is allowed for intermediate products, reporting the characterised results calculated for each representative product is optional in the PEFCR (but mandatory in the EF study and report).

2.1.2. DESK RESEARCH

VTT report – Sustainability and performance assessment and benchmarking of buildings

According to the VTT report, **various definitions of benchmarks** exist and within the VTT report, the following potential benchmarking values are defined: **limit value, reference value, best**

practice value and target value. According to the VTT report, the following definitions are given to the four possible benchmark values (p. 172):

- The limit value is "*the lowest acceptable value of an evaluation scale representing generally the minimum acceptable performance*";
- The reference value represents "*the present state of the art (business as usual) and can be considered as an average or median value. For this reason, it should be noted that reference value is subject to temporal dynamics*";
- The best practice value represents "*values that have been reached (measured) in experimental or demonstration projects. This value is subject to technological advances and consequently it evolves with time*";
- The target value is "*a value that can only be reached in medium- or longterm perspective. It represents the upper limit of the scale and can be considered as the highest theoretically possible level (at least within a certain technology). Target values must adapt periodically to the scientific and technical progress*".

Various sources for benchmarks are furthermore reported by VTT. These can be **i) laws, prescriptions or standards; ii) statistical values; iii) existing economic or technical optimum; iv) political target values; v) labelling; vi) benchmarks based on reference buildings.** Depending on the type of value, an appropriate source needs to be chosen to define the benchmark value. Possible approaches for each of the benchmark value types is summarised in Figure 1.

Table 29. Nature of source adapted for specific type of benchmark.

Type benchmark	Possible sources for values
Target value	Political targets
	Technical optimum
	Economic optimum
Best practice value	Best practice
	Upper quartile
Reference value	Median value
Limit value	Legal minimum
	Prescriptive minimum

Figure 1: Overview of types and source of benchmarks (VTT report, p. 196)

In the VTT report hence no one single approach is proposed, but rather an overview is given of potential meanings of benchmarks (from limit to target values) and potential sources for values for each of these meanings (from legal minimum to political targets). For the PEF4Building benchmark the VTT report was an **important basic document providing a comprehensive overview of meanings and methods to define sustainability benchmarks of buildings** and was moreover helpful in analysing the benchmarks defined in existing sustainability schemes/national methods. It is furthermore **used in our study for comparing the various systems analysed** (see Table 1).

The VTT report furthermore describes **two potential approaches** for defining benchmarks. The first is a **bottom-up approach** and can for example consist of values derived from experiments or demonstration projects (i.e. "Best practice value") or can be derived from statistical analysis of the existing building stock (calculated values). The second approach is a **top-down approach** and defines the benchmark based on a political target set or based on a technical or economic optimum calculated. The VTT report highlights that these values are subject to technological advances and consequently evolve with time. No further recommendations are provided on the frequency of updates or how to decide when an update is needed.

A final important insight obtained from the VTT report were the steps to be taken in a benchmarking process. These consist of three main steps: definition of the assessment method of indicators, definition of functional unit and definition of benchmark values (see Figure 2).

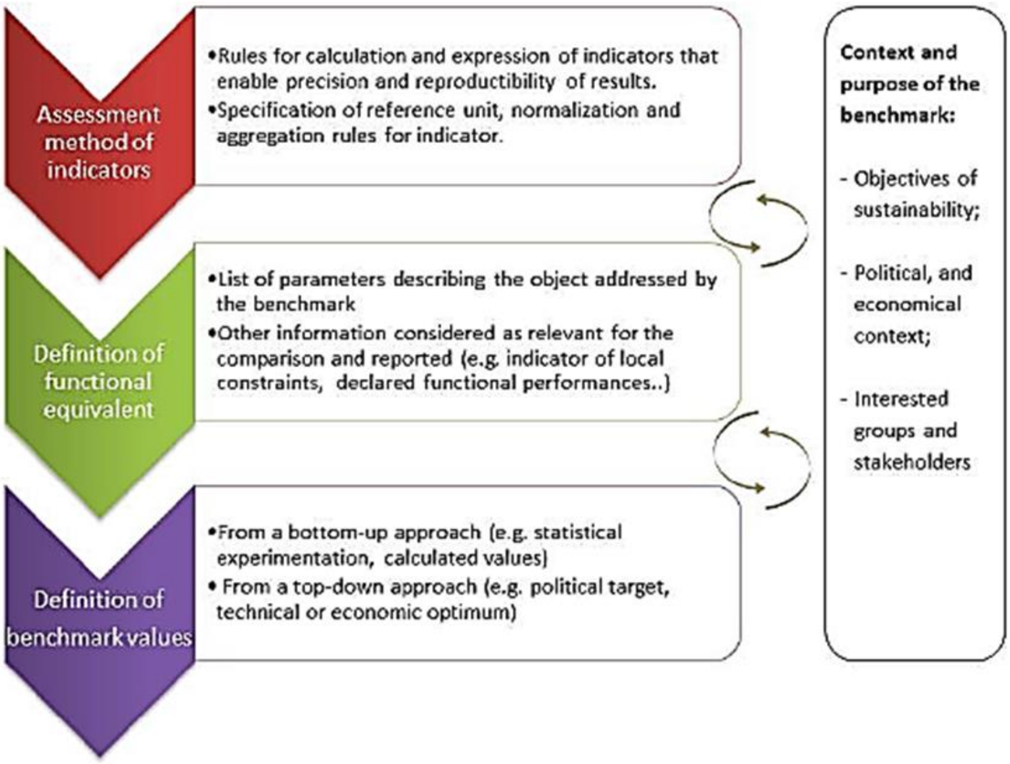

Figure 2: Description of benchmarking process (VTT Technical Research Centre of Finland, 2012)

In the first step, choice of assessment method of indicators, it is necessary to define the rules for the calculation of the impact categories and related indicators, the normalization and weighting or aggregation rules for the various indicators assessed. Translating this step to the PEF method, it is clear the impact categories and related indicators should be the ones of the PEF impact assessment method. Normalisation and weighting factors are moreover included in the PEF method. What still needs to be decided however when applying these for benchmarking purposes, is if benchmark values will be defined for each impact category separately (which are then aggregated in a second step) or if a single aggregated benchmark value will be defined, or a combination of both. The pros and cons of both options is further discussed after the analysis of all literature sources in section 2.1.3.

In the second step, the functional equivalent needs to be defined. This step requires a clear definition of the object addressed by the benchmark, e.g. office building in a certain climatic context with a certain size / typology and energy performance. This step requires to define the functional unit of the object that will be used for comparison with the benchmark. How this could be defined in the context of office buildings is further discussed after the analysis of all literatures sources in section 2.3.

Finally, in the third step the approach to define the benchmark values need to be defined. As described before, various methods are possible and include both bottom-up and top-down methods. Within both categories, various approaches are possible. The most appropriate method will depend on the benchmark definition. For example, if a limit value is chosen as benchmark, the benchmark could be defined based on buildings which fulfil legal requirements, while if a reference value is chosen as benchmark, the benchmark could be defined of a statistical analysis of business-as-usual buildings. If, for example, a target value is chosen as benchmark, then a top-down method is more appropriate and the benchmark value could then be defined based on a political target or economic or technical optimum. An analysis of the pros and cons of the various benchmark definitions and methods is provided in section 2.1.3 and is based on the analysis of the various literature sources.

BBP Sustainability Benchmarking Toolkit for Commercial Buildings

The discussion paper by Better Buildings Partnership (BBP) (2010) presents an overview of current practices in sustainability benchmarking and describes possible challenges of this process. Some relevant findings of the generic paper are presented in this section, but no explicit information on the benchmark in London is described in the paper.

Benchmarking is a method that assesses and compares sustainability performance of property assets against peers or against set targets and benchmarks. This process can incorporate a wide range of asset criteria and characteristics. Well-designed benchmarks should allow flexibility and adaptation to changes in the industry over time. The method distinguishes between applying the benchmarks in the design phase or the use phase of the building.

BBP refers to the ‘Graduated Approach’ developed by the Usable Buildings Trust, which encourages to start the benchmarking process in a simple manner and to add the necessary complexity over time (Better Buildings Partnership (BBP), 2010). This way, your sophistication and completeness will grow together with your understanding of the building stock.

Benchmark is a point of reference for measurement. The document defines potential benefits of benchmarking in the fact that it enables an organization to assess its environmental impact, develops greater understanding of how a portfolio is operating, identifies potential savings, enables to set and monitor the defined targets, enables comparison, assists legislative and regulatory compliance and helps to improve the asset value.

LCA benchmarks in building’s environmental certification systems (2016)

Ganassali *et al.* (2016) differentiate between benchmarks that are defined externally or internally. **External benchmarks** are obtained from the analysis of threshold values already used in construction field. These are typically established from values provided by national standards (such as primary energy consumption) or from studies of national building stocks. **Internal benchmarks** are set through the analysis of data obtained from the modelling of (a) building(s), in order to improve the performance. Internal benchmarks are derived from modelling a reference building with geometrical and context features equal to the project and conventional construction characteristics; this reference-model is the benchmark against to which the project must demonstrates the improvement to acquire scores. DGNB and BREEAM use the procedure of external benchmarks, through statistical analysis, while LEED uses the procedure of internal benchmarks.

According to Ganassali *et al.* (2016), an external benchmark is preferred in order to allow comparison between the environmental performance of a building compared to the building stock, while the internal benchmark verifies how the environmental impact of the building is compared to building standards (constantly update needed).

Based on their review study of benchmarks in **existing sustainability certification schemes**, Ganassali et al. (2016) furthermore identified different meanings of benchmarks of buildings: it can be a starting standard value (**reference value**) representing business-as-usual, or an improvement value (**target value**) or a minimum value to obtain the certification (**limit value**). This is in line with the various benchmark definitions mentioned in the VTT report. The VTT report however adds one more, i.e. the best practice value. It seems that the latter is hence not use in existing sustainability certification schemes. In the subsequent sections the various benchmark definitions used in various certifications systems / national benchmark systems are discussed in more detail and a summary overview is provided in section 2.1.3.

Based on their review study, Ganassali *et al.* (2016), moreover concluded that benchmarks are typically **developed through linear interpolation systems, statistical analysis and/or the modelling of (a) reference building(s)**.The various methods used by the various certification schemes are further described in section 0 an overview is provided in Table 3.

German building certification system of DGNB

The objective of the assessment is to quantify and document the environmental performance of the building and to compare the results against a defined benchmark. The scope of the LCA includes the environmental impacts of production, use and end-of life phases. External works are not included (DGNB CORE 2014).

In the DGNB system the benchmarks are defined according to the comparison with reference values that are obtained from reference buildings and split into a construction related (embodied) and operational part.

Based on these, reference values (Referenzwert), target values (Zielwert) and minimum values (Grenzwert) are established as explained in Figure 3 and Figure 4. The results of the LCA of the building are linearly interpolated, allowing customers to see how well they perform. The objective is to reduce the buildings' emission throughout the entire lifecycle for public buildings. Details for the calculation of the limit values and the calculation of targeted values are provided in the description of the assessment methods.

TABLE 2 Reference values for construction and operation of the reference building

	GWP	ODP	POCP	AP	EP
UNIT	[kg CO_2-equiv/(m^2_{NFAa}*a)]	[kg R11-equiv/(m^2_{NFAa}*a)]	[kg C_2H_4-equiv/(m^2_{NFAa}*a)]	[kg SO_2-equiv/(m^2_{NFAa}*a)]	[kg PO_4^{3-}-equiv/(m^2_{NFAa}*a)]
CONSTRUCTION	GWP_{Cref} = 9.4	ODP_{Cref} = $5.3 \cdot 10^{-7}$	$POCP_{Cref}$ = 0.0042	AP_{Cref} = 0.037	EP_{Cref} = 0.0047
OPERATION*	GWP_{Oref} = GWP_{OEIref} + GWP_{OHref} where GWP_{OEIref} = 0,62 * EI_{ref} GWP_{OHref} = 0,29 * H_{ref}	ODP_{Oref} = OD-P_{OEIref} + ODP_{OHref} where ODP_{OEIref} = 3,07 * 10^{-9} * EI_{ref} ODP_{OHref} = 3,8 * 10^{-11} * H_{ref}	$POCP_{Oref}$ = $POCP_{OEIref}$ + $POCP_{OHref}$ where $POCP_{OEIref}$ = 7,62 * 10^{-5} * EI_{ref} $POCP_{OHref}$ = 3,95 * 10^{-5} * H_{ref}	AP_{Oref} = AP_{OEIref} + AP_{OHref} where AP_{OEIref} = 1,03 * 10^{-3} * EI_{ref} AP_{OHref} = 3,92 * 10^{-4} · H_{ref}	EP_{Oref} = EP_{OEIref} + EP_{OHref} where EP_{OEIref} = 9,92 * 10^{-5} * EI_{ref} EP_{OHref} = 2,43 * 10^{-5} * H_{ref}

*NOTE: The environmental impact factors relate to the German reference building's **electricity demand** EI_{ref} and **annual heating demand** H_{ref}.

Figure 3: Reference values for construction and operation of the reference building (DGNB CORE 2014).

The limit (L) and target (T) values are calculated as follows:

$L_{EIP} = X_{EIP} * R_{EIP}$
$T_{EIP} = Y_{EIP} * R_{EIP}$

With the associated X and Y parameters defined as follows:

TABLE 3 Limit and target values

LIMIT AND TARGET VALUES	GWP	ODP	POCP	AP	EP
X	1.4	10.0	2.0	1.7	2.0
Y	0.7	0.7	0.7	0.7	0.7

Figure 4: Limit and target values (DGNB CORE 2014)[1]

At the indicator level, sub-points (SP) on a scale from 0 to 100 are allocated. These are then converted into checklist points (CLP) on a scale from 0 to 100 by means of the weighting key (GWP, etc.) listed in Figure 4. The maximum achievable number of checklist points is 100.

The weighting key of the indicators[2]: GWP (40%), ODP (15%), POCP (15%), AP (15%) and EP (15%).

[1] DGNB_CORE14_ENV1 1_Life Cycle Impact Assessment.pdf

The methodological procedure in DGNB 2018 and DGNB Core 2014 is the same apart from minor changes in weighting, which is now: GWP (40%), POCP (10%), AP (10%), EP (10%), PENE (15%), PEGES
(10 %) and GPENE/PEGES (5 %). The objective is to reduce the buildings' emission throughout the entire lifecycle for private buildings.

German assessment system for sustainable building (BNB) for public offices and administration buildings

The BNB system has a similar methodological approach and meaning to benchmarks as DGNB, but is applicable only to public buildings.

Legal requirements in the Netherlands

The Dutch legal requirements are based on the background study by W/E adviseurs (2014). In this report, five exemplary residential buildings are considered as representative buildings:

- Terraced house;
- Two under one roof house;
- Detached house;
- Apartment;
- Gallery.

The environmental impact of almost 1200 virtual variations of those buildings are calculated, by varying the building models. These variations differ in geometry, dimensions of building and the building elements, and used materials. The calculation of these variations provides useful examples and a realistic spread in the actual environmental impact of current practice residential buildings (see section 2.2.2). A sensitivity analysis is performed to investigate the influence of extreme choices of materials and increased energy performance. The national LCA method for buildings (Stichting Bouwkwaliteit, 2014) is used for the calculation of the environmental impacts. These are aggregated to a single score, expressed in external environmental cost. This is based on the shadow pricing method, as described in the national method by Stichting Bouwkwaliteit (2014).

As of January 1st 2018, MPG defines the legal requirements on the environmental impact of residential and office buildings larger than 100 m^2 to be no more than 1,00 euro per m^2 gross floor area per year (Rijksdienst voor Ondernemend Nederland (RVO), 2018). This number is based on the research by W/E adviseurs (2014) and this is a reference value that allows comparison of a building with the building stock in general.

Green Public Procurement in the Netherlands

The document on voluntary criteria for sustainable purchasing of newly built office buildings (PIANOo, 2017) uses legal requirements in order to define a benchmark. While they consider several aspects such as energy efficiency and used construction materials of the building as well as indoor health, we will focus on the first two for this literature study since they are most relevant.

[2] Climate change: Global Warming Potential (GWP), measured in kg CO2-equivalents
Depletion of the stratospheric ozone layer: Ozone Depletion Potential (ODP), measured in kg R11-equivalents
Summer smog: Photochemical Ozone Creation Potential (POCP), measured in kg C2H4-equivalents
Dying forests and fresh water fish: Acid Potential (AP), measured in kg SO2-equivalents
Eutrophication: Eutrophication Potential (EP), measured in kg PO4-equivalents

For voluntary GPP on energy performance of new office buildings, the baseline is defined as of a building that conforms to the legal requirements of the Netherlands (PIANOo, 2017) and is therefore a reference value, in line with the PEF guidance on the definition of a benchmark. This allows for comparison of a specific building with the building stock in general, and represents the level-playing-field with a lower limit as a starting point. The goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behaviour on the other hand. At the moment this document was published by PIANOo (2017), no legal requirements were defined in the Netherlands for the environmental performance of building materials. A monetised impact of 0,90 €/m^2 gross floor area is set as a benchmark, but no details on the calculations are provided.

Existing benchmarks for energy performance of buildings

In line with the European Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), EU Member States have defined benchmarks for the operational energy use of new buildings. How these benchmarks were established is not analysed in detail during the desk research as this is beyond the scope of this project. It is however noticed that a stepwise approach was taken in the Member States: first a method and tool were developed and provided to designers in order to calculate the operational energy use of buildings in a harmonized way. Secondly, benchmarks were defined, but these were defined as upper limit values, meaning that the energy use of the majority of the buildings being built was already lower than the benchmark set and so no important change in building practice was seen in the beginning. Year by year the benchmark values were defined more strictly, i.e. lower maximum values for the energy use of buildings were defined.

2.1.3. CONCLUSIONS

Departing from the definition of a benchmark in the PEFCR guidance document (European Commission (EC), 2017) as a standard or point of reference against which any comparison can be made, a literature study has been performed to gain insight in potential meanings and related methodologies to define environmental benchmarks of buildings. The literature study revealed that various reports describe benchmarks and related methods to define benchmarks, but remain rather vague and were not providing clear guidance or methodological recommendations. More insightful were the various approaches used in current sustainability certification schemes such as BREEAM, LEED and DGNB, which include environmental benchmarks of buildings. Furthermore, the study revealed that the Netherlands are advanced in terms of environmental benchmarking of buildings as since January 1st 2018, it is mandatory to calculate the life cycle environmental impact of new residential buildings to obtain a building permit and the impact shall be lower than the benchmark of 1,0 euro external environmental cost /m^2 floor area.

Several important differences were identified in the methods used for defining the environmental benchmarks of buildings. First of all, the meaning of the benchmark can differ: it can be a minimum value to obtain the certification (limit value) or to fulfill minimum legal requirements, or a starting standard value (reference value) which represents business-as-usual, or an improvement value (target value) reflecting policy goals or the economic or technical optimum.

Improvement values or target values in the systems analysed were either based on best-practice buildings (experimental or demonstration projects) or based on statistical analysis or political targets (e.g. 30% less impact than the reference value). Moreover, very often, certification schemes include more than one value to evaluate the score related to the environmental performance of buildings.

In the Netherlands, the current benchmark represents the level-playing-field with a lower limit as a starting point. The goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behavior on the other hand. Nevertheless, it is also important to mention that the literature review indicated that benchmarks should not be static values but should evolve in time as technology advances and knowledge of the building stock grows.

Furthermore, it can be concluded that most certification schemes use external benchmarks, but some use internal benchmarks. An overview of the encountered benchmarks is provided in Table 1. Table 2 lists the strengths and weaknesses of different benchmarking approaches. The various methods applied to define the benchmark are summarized in table xx.

Table 1: Benchmarking characteristics of analysed systems

Source	**Internal/external benchmark**	**Value**	**Target/aim**
Minergie-ECO	External	Limit value, target value	
BREEAM	External	5 classes of performance within the limit and target values	Minimum legal requirements to best-practice
LEED	Internal	Limit value	Legal requirements (in compliance with the American construction standards)
DGNB / BNB	Internal	Reference value, limit value, target value	
Legal requirements in the Netherlands	External	Limit value	Legal requirements / level-playing-field
GPP in the Netherlands	External	Limit value	Legal requirements / level-playing-field
French initiative E+C-	External	Limit value and best practice value	Level-playing-field + best practice
Existing benchmarks for energy performance of buildings	External	Target value	Policy target (nearly zero energy building)

Table 2: Strengths and weaknesses of different types of benchmarking

	Strengths	Weaknesses
Internal benchmark	• Allows to evaluate the material choices • If combined with external benchmark, could be insightful to understand the material impact separately	• Material amounts need to be calculated for the predefined baseline building (not for the real design) • Does not take into account building layout choices • Does not take into account energy performance
External benchmark	• Allows comparison with the impact of a representative building of the building stock; differentiating between various typologies if desired. • Allows to assess the full design in terms of material choice, building design and energy performance	• Overall assessment does not allow to see the influence of building design, material choice and energy performance separately
Standard value (reference value)	• Allows comparison to business-as-usual impact • Feasible in short term • Allows to get familiar with methodology • Will exclude buildings with high environmental burdens (i.e. free riders)	• Will not lead to major environmental improvement of the building stock • Requires update in terms of more severe benchmark values quite rapidly to allow for important reduction of the environmental impact of the building stock
Improvement value (target value	• Allows to steer to a policy target or economic or technical optimum • Especially useful for a longer term transition	• Might not be feasible for all buildings / countries due to high costs/lacking technology or knowledge • Not feasible in short term
Minimum value (limit value)	• Allows to address all stakeholders as it is already required • Feasible in short term • Allows to get familiar with methodology	• Will not lead to any environmental improvement of the buildings • Requires a very rapid (yearly) update in terms of more severe benchmark values if any change to be made regarding the environmental impact of the building stock

2.1.4. RECOMMENDATIONS

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF methodology, the desk research, the received feedback from the stakeholders and previous experiences of the project team.

The literature study revealed that a lot of systems and guidelines are based on national methods and norms, ensuring thereby the relevance of the environmental assessment for the considered buildings. Building typologies in European studies (see next section for the research projects TABULA and EPISCOPE) are generally defined at a national level. We therefore recommend to define **benchmarks** at a **national level** instead of at EU level. This ensures that external factors such as climate, construction practice and culture influencing the environmental impact of a building are taken into account.

Based on the learnings from the desk research, we recommend to define a **common EU method** to calculate the environmental impact of buildings and a common EU methodology on how to define environmental benchmarks. This is needed in order to reach a harmonized approach in Europe. This could be reflected in a PEFCR for buildings which is in line with the PEF method, but provides more specific guidelines for buildings. As sustainable building is more than environmental impact solely, such method could moreover be integrated in a broader assessment framework such as the LEVEL(s) framework. If this is aimed for, the Level 2 "Comparative performance assessment" could be considered as a starting basis to further develop a common EU methodology for environmental benchmarks for office buildings in order to make meaningful comparisons between functionally equivalent office buildings. The Level 2 framework lays down rules to support the comparability of results at national level (without flexibility to reflect in methods between Member States) or building portfolio level. The PEF method can be used in this framework to fix certain key parameters and input data and assumptions used for calculations. The experiences gained and the tools developed during the PEF assessment of the two office buildings can give input to the so-called "overarching assessment tool: Cradle to grave LCA" within the LEVEL(s) framework.

Finally, we recommend a **stepwise conservative approach**, meaning that initially benchmarks are defined representing lower limit values or reference values and which gradually become more severe in time, evolving to target values. In other words, when initiating environmental benchmarks in a legislative context, these are recommended to represent the level-playing-field with a lower limit or business-as-usual as a starting point.

In order to define an environmental benchmark for office buildings, insight is needed in the average environmental impact of office buildings in Europe and on the variation of it throughout the building stock. This insight can either be gained from **real cases** or **virtual cases**. This is further discussed in the subsequent sections 0 and 2.4 and recommendations are formulated in those sections. The first conservative benchmark should be set to allow all office buildings that **fulfill minimum legal requirements** on energy, water, fire safety, etc. To define the environmental impact fulfilling the improvement or target value, this can be based on best-practice buildings (experimental or demonstration projects) or based on virtual buildings with for example 30% less impact than the reference value (i.e. representing common practice to date). In the second approach, the percentage reduction could either be based on a statistical analysis of building practice in the specific member state or based on political targets set or economic or technical optima.

2.2. Definition of reference building

2.2.1. PEF Guidance

In this section it is described how the PEF Guide and PEF Guidance document define a benchmark. The contextualisation to the building case will be done in next chapters on the desk research, the conclusions and the recommendations.

According to the PEFCR guidance document (European Commission (EC), 2017) the representative product (model) may or may not be a real product that one can buy on the EU market. Especially when the market is made up of different technologies, the “representative product” can be a virtual (non-existing) product built, for example, from the average EU sales-weighted characteristics of all technologies around. A PEFCR may include more than one representative product if appropriate.

When using the benchmarking approach based on reference buildings, a first step in the development of a possible approach to benchmark office buildings is to define a representative product (office building) in Europe. Based on that definition the benchmark can be set. The range of environmental performance of the product category “office buildings” can then be determined by filling in realistic minimum and maximum values for the identified most relevant processes and elementary flows of the representative product.

2.2.2. Desk research

TABULA and EPISCOPE reports (Intelligent Energy Europe)

In both the TABULA and in the EPISCOPE project, building typologies are defined for several countries, mostly for residential buildings, but the same exercise is also done for non-residential buildings in Austria, Bulgaria, Germany, Greece and Poland. In the TABULA thematic report “Typology Approaches for Non-Residential Buildings in Five European Countries – Existing Information, Concepts and Outlook” the following parameters are determined for defining a typology for non-residential buildings:

- Function of the building (offices, schools, etc.);
- Year of construction, accounted for by construction year classes (no more than three or four classes should be defined);
- Size of the building (e.g. by the number of work places in an office building);
- The technical building equipment (energy systems, lighting, etc.);
- Climate, due to its influence on construction trends and energy demand of buildings.

Most of the studied countries lack a large database on non-residential buildings, and therefore the gathering of more data and the creation of databases are recommended.

German building certification system of DGNB

As explained in section 2.1.2, the reference values in the DGNB certification scheme are calculated as the sum of a fixed part for the construction related value (embodied) and a variable proportion (operational) for the use related value of the emission related environmental impacts.

The reference value is generally derived from:

- A fixed proportion for the construction related value of the emissions related to environmental impacts for manufacture, maintenance and removal/disposal (the data is gained from statistical inquiries from manufacture, end-of-life and maintenance). The construction related (embodied) values are obtained from an study (König, 2007).
- For the operational part DGNB reference buildings are defined by EnEV 2014 (Energy Saving Ordinance[3]), which is a regulation in Germany describing minimum requirements regarding energy use of new and renovated buildings. Non-domestic buildings shall be designed so that the annual primary energy requirements for heating, water heating, ventilation, cooling and built-in lighting are lower than the annual primary energy demand of a reference building of the same geometry, net floor area, orientation and use, including the layout of the functional units as specified in the technical reference design (see Appendix 2, Table 1). " The reference value for the environmental impact of the building in use is calculated and a sum of the environmental impact for the electricity demand of the reference building and the environmental impact of the fuel used to meet the reference building's annual heating demand.

Criteria for establishment of reference building:
For establishing a reference benchmark for office buildings different functional and technical criteria were defined in order to identify/create a representative building. The representative building was created on the basis of a real building which was evaluated and refined based on criteria of:

- Building typology; function; year of construction; shape; number of floors; gross internal volume; gross floor area; building footprint; ratio of volume to area; as well as the building's construction materials and technical systems.

German assessment system for sustainable building (BNB) for public offices and administration buildings

Uses the same approach as DGNB but applies it to public buildings.

LCA benchmarks in building's environmental certification systems (2016)

Instead of working with reference buildings, the **energy certification Minergie-ECO** use a different approach. In this scheme, the benchmarks are derived from a statistical analysis of a representative part of the national building stock, characterized by the choice of buildings with energy and environmental certifications. They are investigated according to typological, constructive and technological characteristics (Ganassali et al., 2016).

Swiss certification Minergie-ECO

To define their benchmark values, the building stock in Switzerland was studied. The building stock analysis differentiates various building types, materials and energy performances. It provides the definition of benchmarks related to grey energy consumption. The threshold values indicate the limit value (GW2) and the target value (GW1) in order to define an energy consumption interval in which the building must fall in order to obtain the certification (Figure 5). Benchmarks refer to the

[3] Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung - EnEV): *„§ 4 Anforderungen an Nichtwohngebäude: (1) Zu errichtende Nichtwohngebäude sind so auszuführen, dass der Jahres-Primärenergiebedarf für Heizung, Warmwasserbereitung, Lüftung, Kühlung und eingebaute Beleuchtung den Wert des Jahres-Primärenergiebedarfs eines Referenzgebäudes gleicher Geometrie, Nettogrundfläche, Ausrichtung und Nutzung einschließlich der Anordnung der Nutzungseinheiten mit der in Anlage 2 Tabelle 1 angegebenen technischen Referenzausführung nicht überschreitet.“*

new buildings with office, school and residential (single or multi-family) functions and they are different according to the building parts with heated surface or unheated surface.

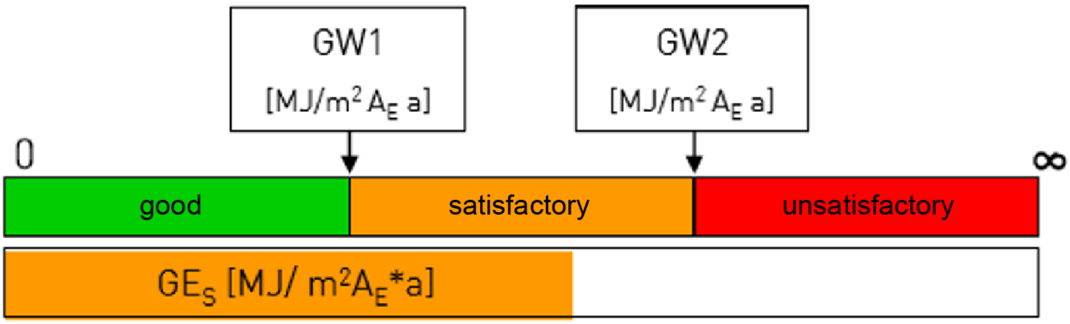

Figure 5: Threshold values to define an energy consumption interval in Minergie-ECO

Use	GW1 [MJ/m^2*a] Heated surface	GW2 [MJ/m^2*a] Heated surface	GW1 [MJ/m^2*a] Unheated surface	GW2 [MJ/m^2*a] Unheated surface
Office	110	150	30	50
School	90	130	30	50
Residential	90	130	30	50

Figure 6: Benchmark values defined in the Swiss Minergy-ECO with GW1 the limit value and GW2 the target value (Ganassali et al., 2016)

As indicated by Ganassali et al. (2016): "*If a new residential building has a grey energy consumption equal or lower than 50 MJ/m²*a (for "GW1 Heated Surface") is assigned to the building a best energy certification, the Minergie-A. In this case the reference value is mandatory, because the criteria have not a rewarding score, but they must be achieved in order to obtain the energy certification.*"

For the evaluation of the environmental impacts of materials within the **BREEAM certification scheme**, the impacts must be calculated with the BREEM International Calculator Mat01 software, which puts the sub-systems within a sustainable ranking from A+ (3 points) to E (0 points). These ratings have been determined based on the assessment of building sub-systems which are considered the most representative in UK and Wales (1200 technological sub-systems). Ten building elements and 16 relative sub-sections (within parenthesis): ground floor (solid; suspended), upper floors, separating floors (in situ concrete; precast concrete; timber; composite), roofs (flat; low pitched; pitched), external walls, windows and curtain walls, internal walls (framed; masonry; demountable and proprietary), separating walls (masonry; steel; timber), insulation and landscaping (pedestrian only; lightly trafficked areas; heavily trafficked areas) (Ganassali et al., 2016).

Ganassali et al. (2016) describe that, based on the LCA of these 1200 subsections, a maximum value (limit value) is defined for each environmental impact, indicated with the letter E; and a minimum value (target value) is defined for each environmental impact, indicated with the letter A+. The limit value equals the highest environmental impact of the 1200 subsections, while the target value equals the lowest environmental impact of the 1200 subsections. Then, the rating is divided into six equal parts and the sub-system's impacts are placed inside the sustainable rating sections.

LEED uses a different approach for the definition of its benchmark. Within LEED the reference values are obtained through the creation of a single model in accordance with the (American) construction standards (baseline building). To compare to the benchmark, the propose-building (project) must be similar and comparable in shape, size, function, site orientation and energy performance. The two buildings can have different characteristics, but they must be minimized. The baseline building becomes the internal benchmark. It will be evaluated if the project under certification is in compliance with the American construction standards. If so, the project will be compared with the baseline building in order to elaborate on potential improvements. The reference building hence allows a comparison to demonstrate the possible impact reduction of the building, expressed in terms of percentage impact reduction. The propose-building must demonstrates a minimum reduction of 10% at least of three environmental impact indicators to satisfy the criterion requests and to obtain the score. Furthermore, the propose-building environmental impact values must not exceed more than 5% if compared to baseline-building impacts (Ganassali et al., 2016).

Main differences in methodological approach

The DGNB certification allows to implement the overall environmental building performance (materials and energy consumption), while BREEAM only allows an improvement of materials choice. In Minergie-ECO the system boundaries are applied to materials, but it is an energy certification and the energy consumption theme is separately treated. In LEED, the LCA evaluation is used only for the material impact evaluation and is not applied to the energy consumption.

Legal requirements in the Netherlands

In the report by W/E adviseurs (2014), five exemplary residential buildings are considered as reference buildings, and the environmental impact of almost 1200 virtual variations of those buildings are calculated. These variations differ in dimensions and used materials and provide useful examples and a realistic spread in the actual environmental impact of current practice residential buildings (Figure 7). A sensitivity analysis is performed to investigate the influence of extreme choices of materials and increased energy performance. The national LCA method for buildings (Stichting Bouwkwaliteit, 2014) is used for the calculation of the environmental impacts. These are aggregated to a single score, expressed in external environmental cost.

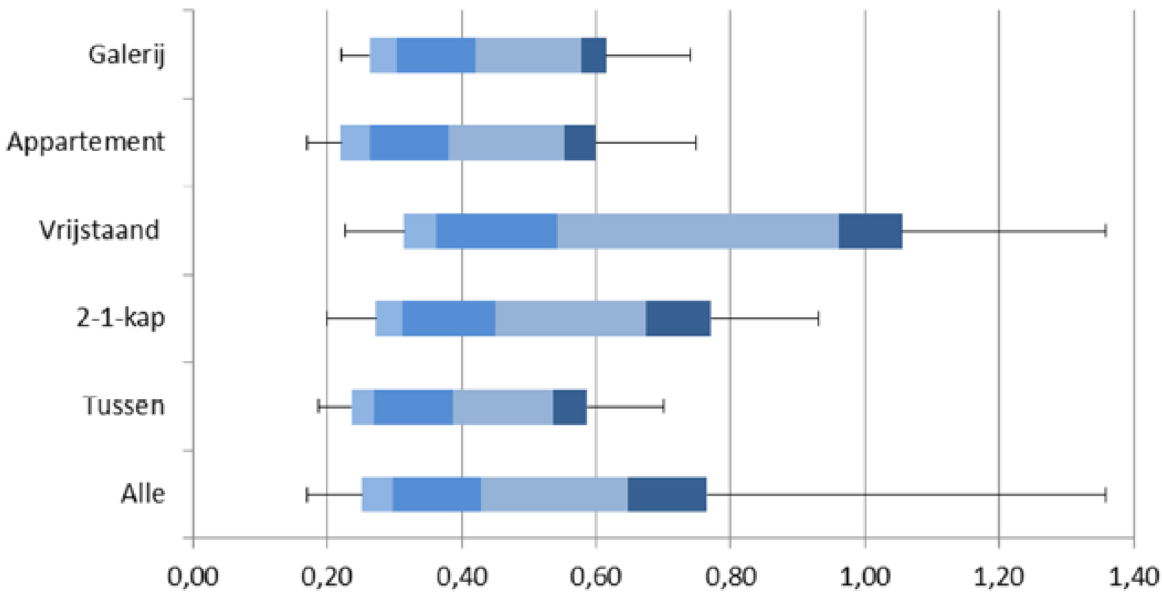

Figure 7: Environmental impacts per residential building type and for all types combined, calculated for 1200 variations of 5 reference buildings (W/E adviseurs, 2014)

French initiative – Towards positive energy and low carbon buildings – The French Experimentation for new buildings

While the E+C- initiative looks at both energy efficiency of buildings and at the greenhouse gas emissions of the building, we will focus our assessment on the latter.

Within E+C-, greenhouse gas emissions are calculated for four contributors: use phase, products and devices, water consumption and construction. One threshold was defined for all these contributors combined, to take the full life cycle into account. In order to ensure a minimum effort when it comes to the environmental performance of construction products and devices, a second threshold was defined for this contributor only. The thresholds were defined based on the HQE performance background study where environmental assessments were performed on 140 existing buildings between 2011 and 2012. Moreover, data was derived from virtual variations of 17 existing buildings.

2.2.3. CONCLUSIONS

Based on the input from the PEF Guide and the PEF Guidance documents, the representative product model could be based on the PEF assessments and the experiences gained during the PEF study of two new office buildings. The representative product "model" will need to represent a newly built office building, constructed and used in a specific country. There are two options for defining the representative office building:

1. It could be a virtual (non-existing) office building. This is probably the best option when the built environment for office buildings is made up of different technologies/materials and if there is sufficient market and technical information available.
2. It could be a real office building. This is probably the best option when the market is made up of different technologies, but incomplete market and/or technical information are

available. A real office building constructed in Europe may be chosen as representative product.

When the representative building is a virtual one, there is the risk that different technologies with very different market shares get mixed up and the ones with a relatively small market share might be overlooked. The same is valid for office buildings made up of very different materials. It needs to be avoided that relevant hotspots might not be retained.

When applying the PEF methodology to newly built office buildings, the reference building should represent average European newly built office buildings, constructed and used in Europe.

From the desk research it can be concluded that reference buildings are typically used to represent the national building stock. This can either be represented by real buildings or virtual buildings (i.e. based on statistical analysis of a representative part of the national building stock). Such statistical analysis differentiates various building types, sizes, materials and energy performances. For the reference buildings, various LCA calculations are made, representing the variety of building practices in a certain country. Based on these calculations, a mean value, and minimum and maximum value are typically defined. The latter are then used to define limit and target values and eventually classes of performance. In the Netherlands additional analyses are made by combining worst and best performing technologies in order to define extreme minima and extreme maxima.

The literature review on environmental benchmarks of buildings revealed large differences in scope:

- Some methods define a separate benchmark for operational energy and material impact (e.g. Minergie-ECO, the Dutch legal requirements for residential buildings, BREEAM and LEED only benchmark materials), while others define a benchmark for the combined impact of energy and materials (e.g. DGNB);
- Some methods define a separate benchmark per impact category, while others have one benchmark related to the aggregated environmental impact according to their national weighting scheme or a weighting defined in the sustainability certification scheme;
- Some methods define benchmarks at building level, while others define benchmarks at sub-system level (i.e. building element level).

Table 3 Overview of the scope and reference building definition within the various systems

Source	Scope	Separate impact categories or aggregated impact score	Type of reference building	Number of reference building	Number of variations per reference building
TABULA/ EPISCOPE					
DGNB	Materials and Energy, separately assessed, but summed	Seperate benchmark per impact category	Material variation for representative building	1 reference building. 7 buildings for comparison/ sensitivity analysis	9 variations of 56 construction elements, 18 HVAC elements
Minergie-ECO	Grey energy	Grey energy	Statistical		

			analysis of national building stock		
BREEAM	Only materials	Separate evaluation per impact category and then aggregated based on predefined weighting set in a summary rating	Statistical analysis of national building stock	10 building elements	120
LEED	Only materials	Separate benchmark per impact category	Baseline building	1 building	1 (in compliance with the American construction standards)
Legal requirements in the Netherlands	Only materials	Benchmark aggregated impact (external environmental cost)	Exemplary buildings representing the Dutch housing stock	5 residential buildings	1200
GPP in the Netherlands					
French initiative E+C-	Use phase, products and devices, water consumption and construction	Energy use and GHG emissions			

2.2.4. Recommendations

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF method, the desk research, the received feedback from the stakeholders and previous experiences of the project team. The recommendations are hence based on a limited number of studies and are not based on an extensive statistical analysis of the building stock or any calculations made. A more elaborated study is required to develop a building benchmark at EU level in an appropriate way.

The project team recommends to follow the approach that was used in the Netherlands, as this proved very successful. Translated to the office buildings, several steps are needed to define reference buildings. **Reference buildings** need to be defined in terms of building typologies representing the building practice in a specific member state. In D3 two types of buildings were analysed: courtyard building and compact cubic building. However other forms/typologies are seen on the market and should be covered when calculating the average environmental impact: e.g. high-rise buildings, less-compact buildings, etc. Representative typologies can differ per member state and are therefore recommended to be defined at the **national level**.

To calculate the environmental impact of each of the building types, the influence of the **market variations** on the impact of the building needs to be identified per building type in a dedicated **statistical study**. Market variation in terms of size, materials used and technical solutions are to be considered, so that the representative buildings can be defined so as to cover 51% of the market. Average data should be gathered related to average floor area, window-to-wall ratio, etc. Considering extreme values gives additional insight in the spread of environmental impacts of buildings. Based on the environmental impacts of the considered typologies and its variations, the lower values represent the level playing field.

The literature study revealed that benchmarks can be defined to cover both material and energy impact of the building, or a separate benchmark can be defined for each. Based on the PEF assessment of the two office buildings with a very different energy performance in Deliverable D3 (VITO et al., 2018a), the project team recommends to have one benchmark including both **material and energy impact**. However, taking practical implementations into account, it might be easier to separate both (in a first phase) because energy benchmarks are currently already established in the EU Member States. Although material and energy impact can be separated in a first implementation stage, it is recommended that the same environmental indicators are assessed in order to allow for a smooth aggregation in the second implementation stage.

This desk research provides an overview of insights gathered through a desk research of various studies, but it is clear that **additional data is needed** at the national level in order to define explicit recommendations on certain aspects that are relevant to defining reference buildings. E.g. which construction techniques and materials to consider, and how many reference buildings should be defined to cover all building typology of office buildings, are complicated questions that require specific knowledge on all the buildings you want to cover, which differ per country. The next sections provide additional information that can be used to answer these questions, but more in-depth research on the office building stock in different countries, climate zones, using different materials and construction techniques, among others, is required. Most countries lack a large database on non-residential buildings, and therefore the gathering of more data and the **creation of life cycle inventory databases** are recommended.

2.3. FUNCTIONAL UNIT , REFERENCE FLOW AND SYSTEM BOUNDARIES

2.3.1. PEF GUIDANCE

In this section it is described how the PEF Guide and PEF Guidance document define a functional unit, reference flow and system boundaries. The contextualisation to the building case will be done in next chapters on the desk research, the conclusions and the recommendations.

According to the PEF method, the functional unit describes the function(s) and duration of the project and is defined according to these aspects: what, how much, how well and how long.

According to the PEF method, the reference flow is defined as the amount of product needed to fulfil the defined function and shall be measured in m^2, m^3, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.

The PEF Guidance (European Commission (EC), 2017) indicates that the system boundary shall include a system diagram clearly indicating the processes and life cycle stages that are included in the product system. The diagram shall include an indication of the processes for which company-specific data are required.

The PEF assessment will be carried out according to the different life cycle stages of the building, where all life cycle stages, from cradle to gate will be considered.

As specified in the PEF Guidance (European Commission (EC), 2017), the criteria for the exclusion of inputs and outputs (cut-off rules) are intended to support an efficient calculation procedure. They shall not be applied in order to hide data.

2.3.2. LEARNINGS FROM THE PEF STUDY OF TWO NEW OFFICE BUILDINGS

The functional unit defined during the PEF study of two new office buildings is one office building with reference service period of 50 years, assessed from the bill of materials according to element method (VITO et al., 2018a).

The key aspects used to define the functional unit for the two new office buildings are presented below.

- **What?**
  - Office building excluding the surroundings.
- **How much?**
  - One office building.
- **How well?**
  - Energy performance and thermal comfort;
  - Relevant technical and functional requirements.
- **How long?**
  - 50 years of reference study period.

Providing a clear **reference flow** for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the **function of office buildings** into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m^2 floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends **m^2 floor area** per year as the most appropriate reference flow. When opting for m^2 floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

In task 1 a system diagram is presented that clearly indicates the processes and life cycle stages that were included in the building system boundaries for the PEF assessment (Figure 9). It is recommended to define the system boundaries from the perspective of the designer/architect. This means that everything that the designer/architect can influence shall be included in the system boundaries.

Life cycle stages have been defined for the assessment of the two office buildings (Table 4). This definition was based on a cross-analysis of the life cycle stages defined in the draft PEFCRs for the construction products already developed, but also in the EN norms related to construction products (EN 15978/EN15804). The details of this analysis can be found in Annex 5 of Deliverable D3 of this project (VITO et al., 2018a).

Based on this analysis the life cycle stages presented in Table 4 have been defined for the assessment of an office building. It is recommended to use these **life cycle stages for any other type of building. Besides using them for assessment at building level it is also recommended to use them as a reference for aligning the life cycle stages from various PEFCRs for construction products and when developing new PEFCRs for construction products.**

For the purpose of this study rules for allocation at building level and at product level have been identified as necessary.

At the building level, the allocation method of the impacts of re-used building elements can be discussed. While not applied in the presented study, **setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary** (such as the reuse of pile foundation of previous building). At product level the allocation follows the approach for the handling of multi-functional processes in the PEF Guidance 6.1 (European Commission (EC), 2017). In this direction the co-product allocation already existing in the datasets used was not altered, ensuring thus a consistent approach.

Currently the cut-off rules in the PEFCRs for construction products are not aligned with the one from the PEF Guidance 6.1 and 6.2. The PEF studies of two office buildings was set up similarly as a screening study. Therefore no cut-off were applied. It is recommended to define cut-offs on the screening of the representative office building.

2.3.3. Desk research

VTT report – Sustainability and performance assessment and benchmarking of buildings

The VTT proposes a general approach to select parameters that will be taken into account in the functional equivalent and parameters that shall be reported otherwise (i.e. developing indicator or other elements of communication to understand results of building sustainability assessment). According to the authors, comparisons between the results of assessments of buildings or assembled systems (part of works) shall only be made on the basis of their functional equivalency. This requires that the major functional requirements shall be described together with intended use and the relevant specific technical requirements. This description allows the functional equivalency of different options and building types to be determined and forms the basis for transparent and unbiased comparison. If assessment results based on different functional equivalents are used for comparisons, then the basis for comparison shall be made clear.

Reference unit suggested for office buildings are: i) number of workstations; ii) number of occupation days; iii) full-time equivalent; iv) Floor Area (GFA (gross floor area), NFA (net floor area), etc.).

According to the VTT report, the comparison between different buildings (benchmarking) *is possible only if the basis for comparison is made very clear, and to facilitate this clarity the contents of the functional equivalent should be defined carefully, and according to the purpose of the comparison.* It is therefore recommended that the functional equivalent shall *be adapted regarding the purpose of the benchmarking process in order to enlarge or reduce the scope of the comparison* (VTT Technical Research Centre of Finland, 2012).

According to the VTT report, numerous characteristics related to the intrinsic description of the project but also related to some external parameters can be considered as part of the functional equivalent. Among these, the following ones have been identified: i) Type of construction project (new building, refurbishment, extension…); ii) Parameters related to the location of the building site (Climate aspects, Geological aspects, Acoustic aspects, Urban context, national or local regulation and requirements); iii) Parameters related to the functionality and quality of use (Use-oriented typology (residential, offices, school, etc.), Number and type of users and scenario related to their occupation, Building service life, Size and space aspects, Comfort requirements, etc…) (VTT Technical Research Centre of Finland, 2012).

They furthermore highlight that the more parameters and level of detail is included into the functional equivalent, the more precise and relevant the benchmark would be.

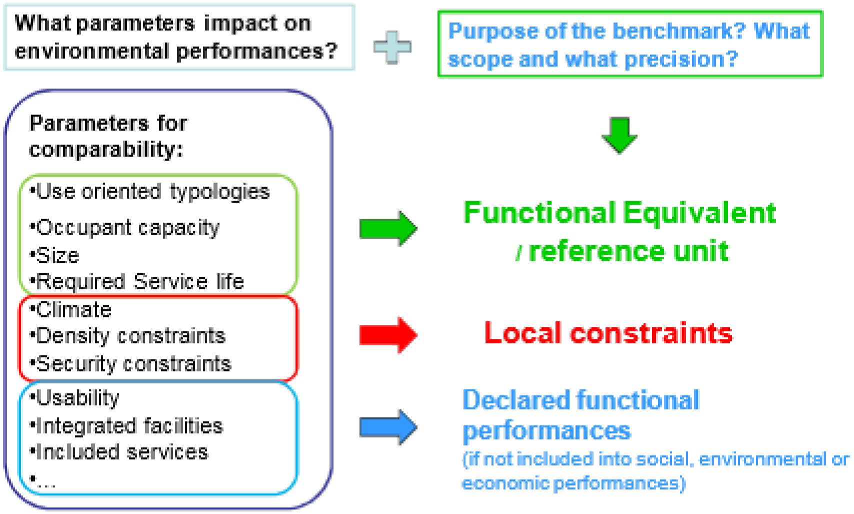

Figure 8: Example of methodology to define the functional equivalent regarding the purpose of the benchmark (VTT Technical Research Centre of Finland, 2012)

Based on these recommendations, it can be concluded that benchmarking at national level seems more appropriate than benchmarking at EU level as this is the only way to take into account local constraints.

BPIE report

The BPIE report comments on the different approaches to the measurement of floor area in different studies and countries, which can include external gross, internal gross, net, heated and treated parts of a building. For energy performance calculations of buildings, the report suggests using the concept of 'treated' floor area, referring to the portion of the building treated with some form of heating and/or cooling, but excluding areas such as plant rooms, car parks and other non-treated spaces.

BBP Sustainability Benchmarking Toolkit for Commercial Buildings

The document suggests that for the definition of the functional unit also other characteristics as m^2 of floor area is commonly used for benchmarking buildings. Benchmarking buildings using occupational density is another option, although there is currently no standard definition for the measurement. One possibility is to calculate based on some notion of a 'worker' (e.g. in terms of full time equivalents), or some description of workstation (e.g. the workplace density usually expressed as number of people per m^2 or also the effective workplace density expressed as NIA per person based on estimated effective density utilisation rates). This alternative functional unit is increasingly being discussed and researched. However, there are still challenges on how to define and measure occupancy, especially regarding the frequency of data availability (e.g. annual average, or based on monthly or quarterly assessments), and considering that increased occupational density does not endlessly improve sustainable performance, but rather a ceiling to sustainability gains exists.

LCA benchmarks in building's environmental certification systems (2016)

Minergie-ECO

The Swiss certification Minergie-ECO is an energy certification in which energy performance evaluation is not limited to the use phase, but includes the production phase (A1-3), the construction phase (A4-5), the use phase (B1-7) and the end-of-life phase (C1-4), during a life span of 60 years. The building system analysed includes building parts and technologies, according to the Swiss standard SIA 380/1: building envelope, unheated parts outside the building's perimeter, interior constructive parts, excavations and plants (electrical, heating, ventilation and plumbing systems). The environmental impact is expressed in MJ per m^2 heated floor area per year (MJ/m^2*a) (Ganassali et al., 2016). The energy use is calculated with software in compliance with the certification (Bauteilkatalog, Enerweb 380/1, Lesonsai, THERMO and GREG).

BREEAM

The different environmental impact indicators are calculated for a square meter of the construction subsystem. Various environmental impact categories are considered which are weighted to a single score for the benchmarking based on a weighting scheme defined in the BREEAM method. The building parts considered are the building envelop, the horizontal and the vertical internal partitions and the roof, with a lifespan of 60 years. The LCA system boundaries include the production phase (A1-3), the construction phase (A4-5) and the end-of-life phase (C1-4). The functional unit is not mentioned in the review study of Ganassali et al. (2016).

LEED

The system boundaries include the production phase of materials (A1-3), the transportation to the site (A4), the use phase for a life span of 60 years (B1-7) and the end-of-life phase (C1-4) (Ganassali et al., 2016).

German building certification system of DGNB

Within DGNB, the whole building and all life cycle stages are considered. The life cycle stages are in line with the standard EN 15978 (production phase A1-3, construction phase A4-5, use phase B1-7, end-of-life phase C1-4 and D). According to (Ganassali et al., 2016) national construction standards are considered for the construction characteristics of the building with a reference study period of 50 years. The impacts are expressed per m^2 net floor (NFA) area and per year. A specific software and database are defined, i.e. LEGEP and Ökobau.dat database. The method to calculate the electric energy and heating energy are specified (i.e. based on DIN V 18599 and on EnEV 2014 requirements).

The results are given for the Net Internal Floor Area. The cut off rules should be compliant with EN 15804. The cut-off should not exceed 5% of building mass or primary energy consumption or more of the impact of GWP, AP and EP impact categories. Also all materials that make up more than 1% of the total building mass or the primary energy or the GWP, AP and EP categories should be included.
If the quantity survey for the product stage follows the simplified approach, the results for replacement must be multiplied by the factor 1.1.

German assessment system for sustainable building (BNB) for public offices and administration buildings

Within **BNB** the whole building with its building components is assessed. The lifecycle production phase (A1- A3), use phase (B2, B4, B6) and end-of-life phase (C3, C4) and D are considered. For the calculation the tool eLCA was developed. The method used for the calculation of heating and cooling energy is based on DIN 18599. Cut off rules are the same as used for the DGNB.

MMG – Material based environmental profiles of building elements (Milieugerelateerde Materiaalprestatie van Gebouw(element)en)

In 2017 the MMG method was extended from building elements to the building level, defining the functional unit as a whole building of which the environmental impact of the sum of the amount of all elements is divided to the m^2 gross floor area of the building (OVAM, 2017).A lifespan of 60 years is considered, but the report notes that renovations will occur sooner in office buildings compared to other type of buildings. Production and construction phase (A1-5), use phase (B1-7) and end-of-life (C1-4) are included in the system boundaries.

Legal requirements & Green Public Procurement in the Netherlands

The assessment method GWW (Stichting Bouwkwaliteit, 2014) is used in the Netherlands for both the definition of legal requirements (Bouwbesluit) and the voluntary GPP guidelines for public office buildings (PIANOo, 2017). In this method, a lifespan of 50 years is considered for the building in which the assessed materials will be used for construction. The functional unit and reference flow are to be defined according to the norm EN 15804 and NEN 2580, in m^2 gross floor area per year, for which very strict rules are defined. In order to create an EPD of construction products, minimally the life cycle stages A1-3, C3-4 and D should be included. This can be expanded to the stages A1-5, B1-7, C1-4 and D in order to create a cradle-to-gate EPD or cradle-to-gate with options.

French initiative – Towards positive energy and low carbon buildings – The French Experimentation for new buildings

Greenhouse gas emissions are calculated for four contributors: use phase, products and devices, water consumption and construction. A building with a lifespan of 50 years is considered, including external works (parkings, roads, landscaping, etc.), structure and facilities. Its environmental impact is calculated per square meter of floor.

EN 15978

This norm defines the functional unit as the building, including its foundations and external works within the curtilage of the building's site, over its life cycle. Capital goods (e.g. truck) during stages A4-5 are excluded, while ground works and landscaping are included. As most of the studies we assessed in this desk research, the EN 15978 norm often refers to the EN 15804 norm for methodological choices such as system boundaries of production, module D calculations rules, data requirements, etc.

Green Public Procurement Criteria for Office Building Design, Construction and Management

The boundary for the analysis shall be cradle-to-grave (according to ISO 14040). Recycled or re-used materials either as inputs (product stage, ISO 14044, Section 4.3.4.3), or outputs (end of life stage, EN 15804 section 6.4.3). As a reference point for each design, the relevant technical and function requirements, the envisaged pattern of use and the requested service life should be the same for each LCA analysis and a common functional unit or reference unit shall be used to present the results (according to ISO 14040/14044).

Draft PCR 2.0 for buildings (for open consultation, International EPD® System)

The draft PCR 2.0 for buildings sets rules for the environmental assessment of buildings as follows: include the production and construction phase (A1-5), the use phase (B1-7) and the end-of-life (C1-4) of a building with a lifespan of 50 years and calculate the environmental impact per square meter gross internal area (GIA), which is defined as areas occupied by internal walls (whether structural or not) and partitions. Benefits and loads from reuse, recycling and energy recovery can optionally be included (D). The building structure and facilities are included, while furnishings such as kitchen fixtures, bathroom fittings, wallpapers, etc. are excluded.

2.3.4. CONCLUSIONS

50 years has been found as the most common reference service period of office buildings. A commonly used **reference flow** is per floor area, but a choice needs to be made: net or gross floor area. As the height of office buildings can be different, while it is more similar for various residential buildings, volume (m^3) could provide an alternative reference flow for offices. Some studies suggest to take the function of the building into account, e.g. the number of work stations in the office building or the amount of people in full time employee equivalent. More research on using this reference flow is needed, since it is not yet commonly used and has some practical challenges. Current studies and guidelines are not consistent, therefore providing a clear reference flow for the assessment of buildings will greatly improve comparability of future studies.

In order to avoid misalignment between assessment on construction products and building level, it is recommended to consider the same **life cycle stages** for the PEFCRs of both. Since most current LCAs of buildings are aligned with EN norms related to construction products (EN 15978/EN15804), we recommend to consider these life cycle stages, as show in Table 4.

No relevant assumptions on cut-off rules or scenarios were found in the desk research. At building level, the discussion can be opened related to the allocation of the impacts of re-used building elements. While not applied in the presented LCA study of two office buildings (VITO et al., 2018a), setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building).

2.3.5. RECOMMENDATIONS

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF methodology, the desk research, the received feedback from the stakeholders and previous experiences of the project team.

Based on the findings of the PEF study of two new office buildings and the desk research, the project team recommends to use the following functional unit for a new office building. *The **functional unit** is one office building with reference service period of 50 years, assessed from the bill of materials according to element method.*

The key aspects used to define the functional unit are presented below.

- **What?**
  - Office building excluding the surroundings.
- **How much?**
  - One office building.
- **How well?**
  - Energy performance and thermal comfort;
  - Relevant technical and functional requirements.
- **How long?**

- 50 years of reference study period.

Providing a clear **reference flow** for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the **function of office buildings** into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends **m² floor area** per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the complete building and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishing as well as technical equipment such as electricity, HVAC, sanitary equipment and elevators. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEF method for buildings on what shall and shall not be included when the PEF method is used for either benchmarking or comparative assertions. This is described in more detail in Deliverable D6 of this project (VITO, KU Leuven, & TU Graz, 2018b). PEF recommendations can be followed related to cut-off rules and scenarios.

Benchmarks are needed at different phases: during the **design phase** (for obtaining a building permit) and **post-construction** (e.g. when 2 years in use). For both benchmarks, a different approach is needed for the environmental impact of the operational phase:

- Design phase: impact of operational energy should be linked with the energy performance calculation methods already established in the member states.
- Post-construction: impact of operational energy should be based on primary data: measured data for at least two years (average yearly consumption)

To avoid burden shifting or trade-offs between impacts, the project team recommends to have a **benchmark for each impact category separately, as well as at the aggregated level**. Therefore several benchmarks need to be defined: one per impact category, one at the aggregated level. If in the long run the most relevant impact categories for buildings have been identified, the benchmarks could be limited to the relevant impact categories only. However, since these are not yet defined, at this moment the project team recommends to have a benchmark for each of the impact categories of the PEF method.

As **data quality requirements** are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

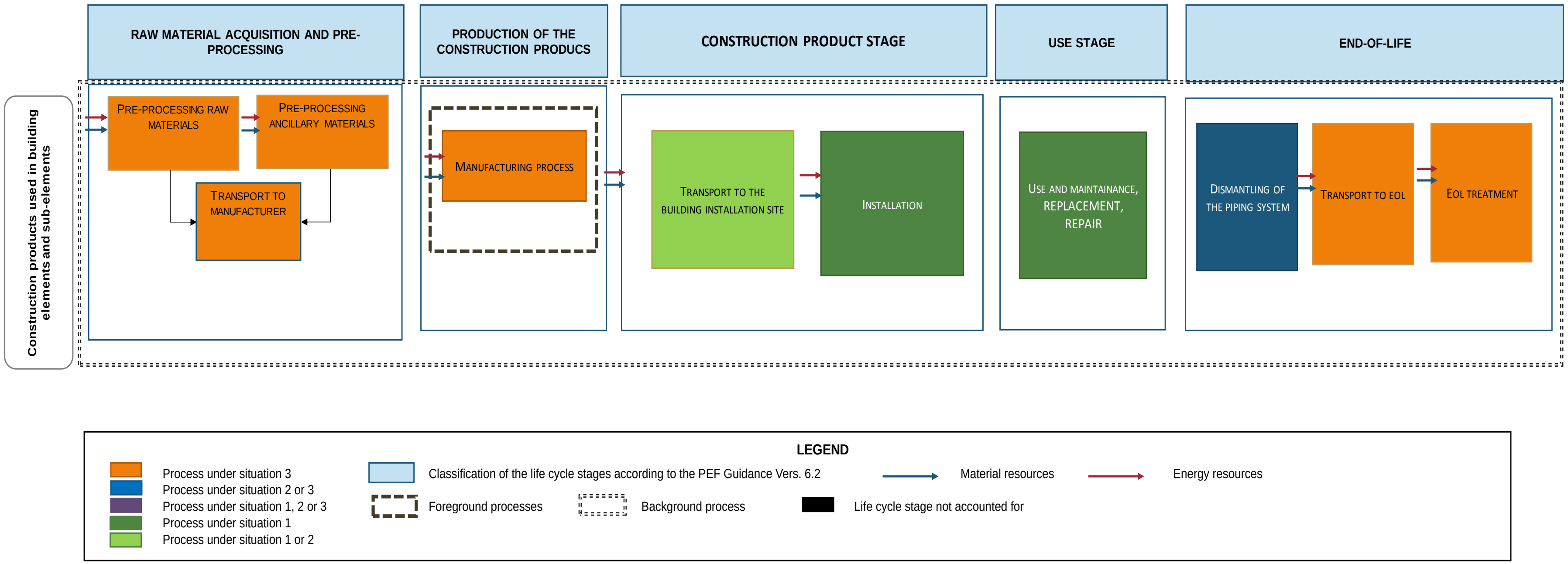

Figure 9: System boundary diagram for assessment at building level

Table 4: Life cycle stages for the assessment at building level

LCS name	The following shall be included
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment
PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL
PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

2.4. Conclusions and recommendations

The key objective of Activity 2.1 is to develop of a possible approach to benchmark office buildings. In the report several important issues are covered: the definition of the reference building, how to define system boundaries, how many reference buildings should be defined to cover the building typology of office buildings, which construction techniques to be considered and how to handle this range of different option, etc. Important findings from the PEF study of two new office buildings, of the PEF methodology and of the desk research described in this report, are combined.

2.4.1. Conclusions

Departing from the definition of a benchmark in the PEFCR guidance document (European Commission (EC), 2017) as a standard or point of reference against which any comparison can be made, a literature study has been performed to gain insight in potential meanings and related methodologies to define environmental benchmarks of buildings. The literature study revealed that various reports describe benchmarks and related methods to define benchmarks, but remain rather vague and were not providing clear guidance or methodological recommendations. More insightful were the various approaches used in current sustainability certification schemes such as BREEAM, LEED and DGNB, which include environmental benchmarks of buildings.

Several important differences were identified in the **methods** used for defining the environmental benchmarks of buildings. Most certification schemes use external benchmarks, but some use internal benchmarks. Furthermore, the national building stock is typically represented by reference buildings, which can either be represented by real buildings or virtual buildings. For the reference buildings, various LCA calculations are made, representing the variety of building practices in a certain country. Based on these calculations, a mean value, and minimum and maximum value are typically defined. The latter are then used to define limit and target values and eventually classes of performance. In the approaches analysed in this desk research, the benchmark typically represents/fulfills minimum legal requirements for new buildings.

Through the literature review various potential **meanings** of benchmarks of buildings were identified: it can be the starting standard value (reference value), or the improvement value (target value) or the minimum value to obtain the certification (limit value) or to fulfill minimum legal requirements. Improvement values or target values are either based on best-practice buildings (experimental or demonstration projects) or based on statistical analysis or political targets (e.g. 30% less impact than the reference value). Current benchmarks mostly represent the level-playing-field with a lower limit as a starting point. The goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behavior on the other hand. Nevertheless, it is also important to mention that the literature review indicated that benchmarks should not be static values but should evolve in time as technology advances and knowledge of the building stock grows.

The literature review on environmental benchmarks of buildings revealed large differences in **scope**. While some methods define a separate benchmark for operational energy and material impact, others define a benchmark for the combined impact of energy and materials. The benchmarks can be defined separately per impact category, or one benchmark related to the aggregated environmental impact, the benchmark can be defined at building level, or at sub-system level.

The **reference building** to determine the benchmark can either be a real building representing the reference building, or can be a virtual building (i.e. based on statistical analysis of a representative part of the national building stock). Such statistical analysis differentiates various building types, sizes, materials and energy performances. In many schemes, the spread of the environmental impact is calculated by analysing the environmental impact of a variety of building practice (i.e. technologies) used throughout the country. In the Netherlands additional analyses are made by combining worst and best performing technologies in order to define extreme minima and maxima.

50 years has been found as the most common reference service period of office buildings. A commonly used **reference flow** is per floor area, but a choice needs to be made: net or gross floor area. As the height of office buildings can be different, while it is more similar for various residential buildings, volume (m^3) could provide an alternative reference flow for offices. Some studies suggest to take the function of the building into account, e.g. the number of work stations in the office building or the amount of people in full time employee equivalent. More research on using this reference flow is needed, since it is not yet commonly used and has some practical challenges. Current studies and guidelines are not consistent, therefore providing a clear reference flow for the assessment of buildings will greatly improve comparability of future studies.

In order to avoid misalignment between assessment on construction products and building level, it is recommended to consider the same **life cycle stages** for the PEFCRs of both. Since most current LCAs of buildings are aligned with EN norms related to construction products (EN 15978/EN15804), we recommend to consider these life cycle stages, as show in Table 4.

No relevant assumptions on cut-off rules or scenarios were found in the desk research. At building level, the discussion can be opened related to the allocation of the impacts of re-used building elements. While not applied in the presented LCA study of two office buildings (VITO et al., 2018a), setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building).

2.4.2. RECOMMENDATIONS

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF methodology, the desk research, the received feedback from the stakeholders and previous experiences of the project team.

The literature study revealed that a lot of systems and guidelines are based on national methods and norms and building typologies in European studies are generally defined at a national level. We therefore recommend to define **benchmarks** at a **national level** instead of at EU level. To avoid an overwhelming and deconstructive workload, a gradual approach in the development of benchmarks is recommended. In the Netherlands this has worked very well, a lot of progress has been made in the last years and more progress can be expected in the coming years.

Based on the learnings from the desk research, we recommend to define a **common EU methodology** to calculate the environmental impact of buildings and a common EU methodology on how to define environmental benchmarks. This is needed in order to reach a harmonized approach in Europe. It is furthermore recommended to calculate the benchmark values at national level in order to take into account external factors such as climate, construction practice and culture influencing the environmental impact of a building. Finally, we recommend a **stepwise conservative approach**, meaning that initially benchmarks are defined representing lower limit values and which gradually become more severe in time, evolving to mean values and target values. In other words, when initiating environmental benchmarks in a legislative context, these are recommended to represent the level-playing-field with a lower limit as a starting point.

In order to define an environmental benchmark for office buildings, insight is needed in the average environmental impact of office buildings in Europe and on the variation of it throughout the building stock. This insight can either be gained from **real cases or virtual cases**. This is further discussed in the subsequent sections 0 and 2.4 and recommendations are formulated in those sections. The first conservative benchmark should be set to allow all office buildings that **fulfill minimum legal requirements** on energy, water, fire safety, etc. To define the environmental impact fulfilling the improvement or target value, this can be based on best-practice buildings (experimental or demonstration projects) or based on virtual buildings with for example 30% less impact than the reference value (i.e. representing common practice to date). In the second approach, the percentage reduction could either be based on a statistical analysis of building practice in the specific member state or based on political targets set.

For the definition of **reference buildings**, the project team recommends to follow the approach that was used in the Netherlands, as this proved very successful. Translated to the office buildings, several steps are needed to define reference buildings. Reference buildings need to be defined in terms of building typologies representing the building practice in a specific member state. In D3 two types of buildings were analysed: courtyard building and compact cubic building. However other forms/typologies are seen on the market and should be covered when calculating the average environmental impact: e.g. high-rise buildings, less-compact buildings, etc. Representative typologies can differ per member state and are therefore recommended to be defined at the **national level**.

To calculate the environmental impact of each of the building types, the influence of the **market variations** on the impact of the building needs to be identified per building type in a dedicated **statistical study**. Market variation in terms of size, materials used and technical solutions are to be considered, so that the representative buildings can be defined so as to cover 51% of the market. Average data should be gathered related to average floor area, window-to-wall ratio, etc. Considering extreme values gives additional insight in the spread of environmental impacts of buildings. Based on the environmental impacts of the considered typologies and its variations, the lower values represent the level playing field.

The literature study revealed that benchmarks can be defined to cover both material and energy impact of the building, or a separate benchmark can be defined for each. Based on the PEF assessment of the two office buildings with a very different energy performance in Deliverable D3 (VITO et al., 2018a), the project team recommends to have one benchmark including both **material and energy impact**. However, taking practical implementations into account, it might be easier to separate both (in a first phase) because energy benchmarks are currently already established in the EU Member States.

This desk research provides an overview of insights gathered through a desk research of various studies, but it is clear that **additional data is needed** at the national level in order to define explicit recommendations on certain aspects that are relevant to defining reference buildings. E.g. which construction techniques and materials to consider, and how many reference buildings should be defined to cover all building typology of office buildings, are complicated questions that require specific knowledge on all the buildings you want to cover, which differ per country. More in-depth research on the office building stock in different countries, climate zones, using different materials and construction techniques, among others, is required. Most countries lack a large database on non-residential buildings, and therefore the gathering of more data and the **creation of databases** are recommended.

Based on the findings of the PEF study of two new office buildings and the desk research, the project team recommends to use the following functional unit for a new office building. *The **functional unit** is one office building with reference service period of 50 years, assessed from the bill of materials according to element method.*

The key aspects used to define the functional unit are presented below.

- **What?**
  - Office building excluding the surroundings.
- **How much?**
  - One office building.
- **How well?**
  - Energy performance and thermal comfort;
  - Relevant technical and functional requirements.
- **How long?**
  - 50 years of reference study period.

Providing a clear **reference flow** for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the **function of office buildings** into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends **m² floor area** per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the complete building and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishings as well as technical equipment such as electricity, HVAC, sanitary equipment and elevators. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEF method for buildings on what shall and shall not be included when the PEF method is used for either benchmarking or comparative assertions. This is described in more detail in Deliverable D6 of this project (VITO et al., 2018b). PEF recommendations can be followed related to cut-off rules and scenarios.

Benchmarks are needed at different phases: during the **design phase** (for obtaining a building permit) and **post-construction** (e.g. when 2 years in use). For both benchmarks, a different approach is needed for the environmental impact of the operational phase:

- Design phase: impact of operational energy should be linked with the energy performance calculation methods already established in the member states.
- Post-construction: impact of operational energy should be based on primary data: measured data for at least two years (average yearly consumption)

To avoid burden shifting or trade-offs between impacts, the project team recommends to have a **benchmark for each impact category separately, as well as at the aggregated level**. Therefore several benchmarks need to be defined: one per impact category, one at the aggregated level. If in the long run the most relevant impact categories for buildings have been identified, the benchmarks could be limited to the relevant impact categories only. However, since these are not yet defined, at this moment the project team recommends to have a benchmark for each of the impact categories of the PEF method.

As **data quality requirements** are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

CHAPTER 3 ACTIVITY 2.2: APPROACH TO DEFINE CLASSES OF PERFORMANCE FOR NEW OFFICE BUILDINGS

In this chapter 3 we start with analysing what the PEF Guide and the PEF Guidance document defines on performance classes. After that, the findings of the desk research are described and conclusions and recommendations are formulated.

3.1. PEF GUIDANCE

The following requirements regarding the *definition of the performance classes* are specified in the Product Environmental Footprint Pilot Guidance document version 5.3 (European Commission (EC), 2016):

- There should be five classes of performance (from A to E, with A being the best performance class);
- The performance of the benchmark (the PEF profile of the representative product) always represents class C;
- The definition of the remaining performance classes should take into account the estimated spread around the benchmark. This might differ from impact category to impact category;
- In case the PEFCR includes sub-categories with appropriate functional units, then the benchmark (and classes of performance) shall be defined at the sub-category level.

In order to develop a possible approach to define classes of performance we started from the guidance described in the TAB issue paper “Determining the EF benchmark and performance classes” (Technical Helpdesk PEF, 2016). This paper describes the steps to take to arrive at the benchmark and performance classes.

The following steps need to be undertaken when defining classes of performance (Technical Helpdesk PEF, 2016):

- Determine market realistic minimum and maximum values for the most important parameters of the representative product and determine the best and worst performing product (class A and E);
- Divide the best and worst performing scores into even partitions (B and D);
- The use stage shall be dealt with consistently with what is foreseen in the use phase issue paper from the TAB.

3.2. INPUT FROM THE PEF STUDY OF TWO NEW OFFICE BUILDINGS

The range of environmental performance classes for office buildings could be determined by filling in realistic minimum and maximum values for the identified most relevant processes and elementary flows of the representative product. For this the results of the PEF study of two new office buildings can offer already good insights, although the building cases might not be considered yet as the representative office buildings. For example, applying the maximum energy use (in the use phase) in combination with the energy carrier with the highest emission factor, and at the same time using building materials with the highest emission intensity for constructing the building. We can use our experiences from the MMG project (Material-Based Environmental Profiles of different building elements[4]) in order to define for each building element the materials that causes most of the environmental impacts (during production, during use phase and during the EOL phase).

The same approach can be applied for the minimum values. However, the minimum and maximum values as well as the combination of them shall reflect realistic best and worst performing office buildings in Europe. In case of complex products, like office buildings, the minimum and maximum values can be based on the overall performance of the building. The best and worst performing products will represent class A and E, respectively (see Figure 10). When determining class A, we should also take into account expected product innovations in the near term future. Class C represents the benchmark. Once the benchmark (class C) and the best and worst performing products (class A and E) have been defined, the boundaries of the remaining performance classes can be determined by an even partitioning of the range between class A and C and between A and E.

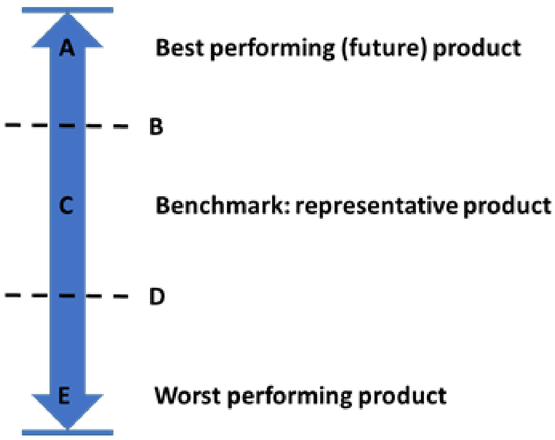

Figure 10: Determining the boundaries between performance classes (from TAB paper)

The results from The PEF study of two new office buildings (mainly the sensitivity analyses) can serve to determine class B and D:

[4] The Flemish Public Waste Agency (OVAM) granted in 2011 a research study to VITO, in association with the Catholic University of Leuven, Department of Architecture (KU Leuven - ASRO) and the Belgian Building Research Institute (BBRI), to develop an expert evaluation tool for the assessment of the environmental impacts caused by the choices of materials at the material element /building level and to set up a modest database of environmental profiles of 110 common building element options for the Belgian building context. (MMG: Material based environmental profiles of building elements). A further development of the tool and the MMG methods is needed. In this framework OVAM wish to have a long-term material performance methodology ("the M-level") to be developed and embedded in their policy. VITO will help OVAM to achieve this goal. Currently the methods are being aligned with the PEF methodology more specifically with regard to the different life cycle impact assessment methods.

- The boundaries between class A and B, and D and E can be tailored to adequately reflect the diversity of buildings in the group of office buildings. If there are clear differences in the environmental performance of buildings within the product group of office buildings, the boundaries could be chosen in between these groups of buildings.
- Another way would be to determine the boundaries in such a way that a predefined percentage will likely be in the best (A) or worst (E) performance class. This requires a good insight in the spread of environmental impacts with the product category of office buildings.

In our desk research we look at already existing approaches of benchmarking on building level, to see wether the approaches differ from each other.

3.3. Desk research

3.3.1. LCA benchmarks in building's environmental certification systems (2016)

The visualization and the understanding of benchmarks is fundamental for a correct evaluation of preliminary design choices. In DGNB and in Minergie-ECO the values are expressed through numbers, while in BREEAM the rating division is in six sections and each of them is signed by a letter. This does not allow to understand the LCA results in a transparent manner. Furthermore the allocation of a letter, and not of a number, does not allow to understand the exact result's location in the sustainable rating (near or far from the limit value and the target value), preventing the orientation of possible improvements (Ganassali et al., 2016).

3.3.2. GRO – De nieuwe handleiding van het facilitair bedrijf. Op weg naar toekomstgerichte bouwprojecten

GRO uses four performance levels based on a score on the building level (see Figure 11). For each criterion a score (0, 1, 2 or 3) is given which is in a next step up scaled to a building performance by equal weighting. The GRO tool shows per phase in the design process (tender, pre design, design, contracting, preliminary commissioning and final commissioning) the obtained performance level. However, this gives no indication where the project locates itself on the bar (close to a higher or lower performance level).

To get insight in the contribution of the different criteria to the global performance level, radar diagrams are provided per theme of criteria (see Figure 12).

Figure 11: Score & performance level system GRO (Agentschap Facilitair Bedrijf, 2017)

Figure 12: Radar diagram PEOPLE

In this phase of the application of GRO, in general the performance level 'better' is strived for as a target level. For some criteria the 'better' performance level is the minimum level that should be obtained.

3.3.3. LEGAL REQUIREMENTS IN THE NETHERLANDS

Dutch legal requirements are based on the report by W/E adviseurs (2014), in which 5 reference residential buildings and almost 1200 virtual variations in dimensions and used materials of these buildings are considered. W/E adviseurs define 5 performance classes (classes A-E) based on the statistical spread of the results of the environmental impacts of the variations of the different building types (Figure 13):

- Class E: transition to class D at the 95th percentile of the worst performing building type ("vrijstaand" is a detached building), which means that the 5% worst of the worst performing type are categorized in class E, having an environmental cost > 1,06 euro.
- Class D: transition to class C based on the 90th percentile of all building types (lowest boxplot in Figure 13), resulting in environmental costs between 0,65 and 1,06 euro.
- Class C: transition to class B based on the 50th percentile of all building types, resulting in environmental costs between 0,43 and 0,65 euro.
- Class B: transition to class A based on the 5th percentile of the best performing building type (apartment), which means that the 5% best of the best performing type are categorized in class A, having an environmental cost < 0,22 euro.

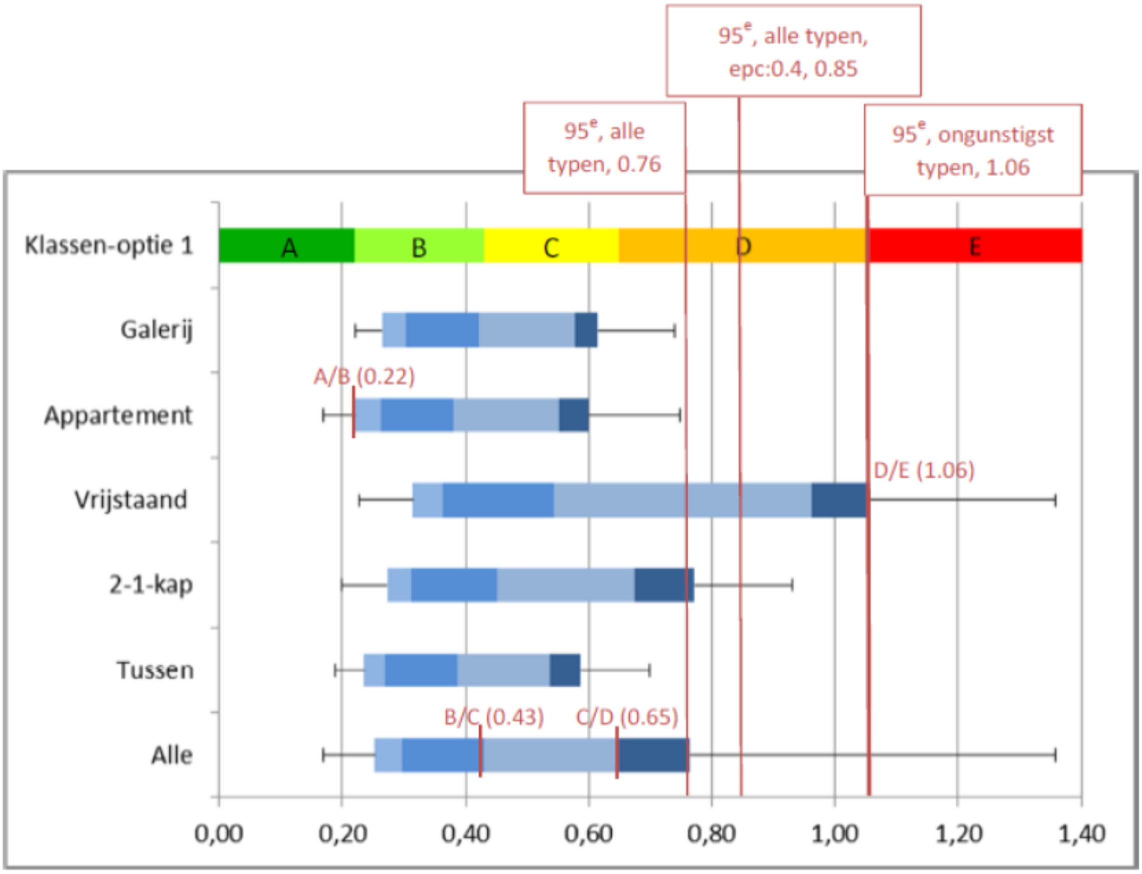

Figure 13: Performance classes A-E of residential buildings (W/E adviseurs, 2014)

3.3.4. Green Public Procurement in the Netherlands

The document on voluntary GPP guidelines for sustainable purchasing of newly built office buildings (PIANOo, 2017) uses legal requirements in order to define a benchmark, and defines classes of performance compared to this benchmark. While they consider several aspects such as energy efficiency and used construction materials of the building as well as indoor health, we will focus on the first two for this literature study since they are most relevant.

For energy performance, the baseline is defined as of a building that conforms to the legal requirements of the Netherlands. Performance levels A, B and C are defined as performing respectively 80%, 50% and 35% better than the baseline. For environmental performance, no baseline is provided, but level C buildings can have a monetized impact of no more than 0,90 €/m^2 gross floor area and must purchase 100% sustainable wood. Performance levels A and B are defined as performing respectively 25% and 15% better than the baseline.

3.3.5. French initiative – Towards positive energy and low carbon buildings – The French experimentation for new buildings

Two performance classes are defined. Performance class 1 (called “Carbone 1”) is accessible to all construction techniques, climate zones, etc., while performance class 2 (called “Carbone 2”) is only achieved by the buildings with the best environmental performance. Similarly, the performance classes Energie 1 and Energie 2 are defined for the energy performance of buildings.

These performance classes are based on statistical data of the environmental assessment of 140 existing buildings, as well as virtual variations on 17 existing buildings. In the environmental assessment, four contributors are considered: products and equipment, construction step, water use and energy use. For the first three contributors, performance class 1 is based on statistical data of the 140 assessed buildings, specifically the 9th decile and median. For energy use, Carbone 1 is defined based on data of the virtual variations of 17 buildings that reached the Energie 1 threshold. For the Carbone 2 class, a similar approach is followed, although some of the data for the contributor “products and equipment” is derived from the virtual variations, instead of the 140 existing buildings.

A formula is provided to calculate the maximal greenhouse gas emissions allowed for a building in order to comply with one of the performance classes, based on type of building and number of parking places, and correcting for climate zone, altitude and floor area.

3.4. CONCLUSIONS

The PEF guidance on how to calculate performance levels (based on most relevant parameters and by determining market realistic minimum and maximum values) is created for products. The desk research aims at exploring if other methods are used to define performance classes for buildings in existing approaches.

The **aim** of performance classes can be different:

- To categorize all existing buildings and to have a realistic idea of how a specific building compares to the total building stock;
- To enforce a “lower threshold” to encourage the use of materials/elements with lower environmental impacts;
- To also take future changes into account, e.g. more energy efficient materials that are not developed yet;
- To be able to differentiate the “best” buildings that have a distinctly lower environmental impact than the general building stock.

A lot of information is needed on the relevant buildings that you want to “represent” in the different classes to be able to set the desired thresholds between different performance classes. For that, as is also the case for defining a benchmark of buildings, you need to have an overview of the environmental impacts of the various buildings you want to cover, which can be either **real buildings or virtual buildings**. In the case of performance classes, as the amount of data needed is so large, generally virtual buildings are used. In the report by W/E adviseurs (2014), which forms the basis for the Dutch benchmark, virtual variations in dimensions and used materials are applied to several existing residential buildings, which represent certain subtypes of residential buildings. Sometimes **extreme** variations are also taken into account (both very positive and very negative), while some systems rely only on the most **realistic** variations.

To set the thresholds between different performance classes, some systems rely purely on the relative improvement compared to the benchmark (e.g. 5%, 10% or 15% better than the benchmark). Some other systems (such as in the report by W/E adviseurs) are based upon the statistical spread of the analysed building stock, which can be either virtual or real. In this last case, the designer of the performance classes has full control and designs the classes taking their specific aim into account.

In the previous chapter we described how BREEAM defines benchmarks at element level instead of at the building level. While none of the existing approaches on performance classes that were analysed in this desk research use the same level of analysis, but instead define performance classes on a building level, it could be considered to define performance classes at the element level instead.

3.5. Recommendations

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF methodology, the desk research, the received feedback from the stakeholders and previous experiences of the project team.

The approach recommended by the project team to define benchmarks for office buildings is described in the previous chapter. The project team recommends starting with conservative benchmarks at the level-playing-field and generally making the requirements stricter. Once national legal requirements are in place for the environmental performance of office buildings, these legal requirements can be used as the first performance class. This approach is followed in the green public procurement guideline for office buildings in the Netherlands for the energy performance of buildings.

Starting from the benchmarks defined at national level, performance classes can be defined. If environmental assessment data is available on a large amount of buildings representing the office building stock, data on existing building should be used. If such data is not available, few representative buildings should be chosen and virtual variations of these buildings can be analysed. **Market variation** in terms of size, materials used and technical solutions are to be considered. Considering extreme values gives additional insight in the spread of environmental impacts of buildings.

When the legal requirements define the lower limit of the first performance classes, and a statistical analysis defines the upper limit of the best performance classes, this range can be divided in 5 performance classes, as defined in the PEF Guidance.

CHAPTER 4 FINAL CONCLUSIONS AND RECOMMENDATIONS

4.1. CONCLUSIONS

Departing from the definition of a benchmark in the PEFCR guidance document (European Commission (EC), 2017) as a standard or point of reference against which any comparison can be made, a literature study has been performed to gain insight in potential meanings and related methodologies to define environmental benchmarks of buildings. The literature study revealed that various reports describe benchmarks and related methods to define benchmarks, but remain rather vague and were not providing clear guidance or methodological recommendations. More insightful were the various approaches used in current sustainability certification schemes such as BREEAM, LEED and DGNB, which include environmental benchmarks of buildings.

Several important differences were identified in the **methods** used for defining the environmental benchmarks of buildings. Most certification schemes use external benchmarks, but some use internal benchmarks. Furthermore, the national building stock is typically represented by reference buildings, which can either be represented by real buildings or virtual buildings. For the reference buildings, various LCA calculations are made, representing the variety of building practices in a certain country. Based on these calculations, a mean value, and minimum and maximum value are typically defined. The latter are then used to define limit and target values and eventually classes of performance. In the approaches analysed in this desk research, the benchmark typically represents/fulfills minimum legal requirements for new buildings.

Through the literature review various potential **meanings** of benchmarks of buildings were identified: it can be the starting standard value (reference value), or the improvement value (target value) or the minimum value to obtain the certification (limit value) or to fulfill minimum legal requirements. Improvement values or target values are either based on best-practice buildings (experimental or demonstration projects) or based on statistical analysis or political targets (e.g. 30% less impact than the reference value). Current benchmarks mostly represent the level-playing-field with a lower limit as a starting point. The goal is to allow buildings with a lower value on the one hand, but also to avoid free rider behavior on the other hand. Nevertheless, it is also important to mention that the literature review indicated that benchmarks should not be static values but should evolve in time as technology advances and knowledge of the building stock grows.

The literature review on environmental benchmarks of buildings revealed large differences in **scope**. While some methods define a separate benchmark for operational energy and material impact, others define a benchmark for the combined impact of energy and materials. The benchmarks can be defined separately per impact category, or one benchmark related to the aggregated environmental impact, the benchmark can be defined at building level, or at sub-system level.

The **reference building** to determine the benchmark can either be a real building representing the reference building, or can be a virtual building (i.e. based on statistical analysis of a representative part of the national building stock). Such statistical analysis differentiates various building types, sizes, materials and energy performances. In many schemes, the spread of the environmental impact is calculated by analysing the environmental impact of a variety of building practice (i.e. technologies) used throughout the country. In the Netherlands additional analyses are made by combining worst and best performing technologies in order to define extreme minima and maxima.

50 years has been found as the most common reference service period of office buildings. A commonly used **reference flow** is per floor area, but a choice needs to be made: net or gross floor area. As the height of office buildings can be different, while it is more similar for various residential buildings, volume (m^3) could provide an alternative reference flow for offices. Some studies suggest to take the function of the building into account, e.g. the number of work stations in the office building or the amount of people in full time employee equivalent. More research on using this reference flow is needed, since it is not yet commonly used and has some practical challenges. Current studies and guidelines are not consistent, therefore providing a clear reference flow for the assessment of buildings will greatly improve comparability of future studies.

In order to avoid misalignment between assessment on construction products and building level, it is recommended to consider the same **life cycle stages** for the PEFCRs of both. Since most current LCAs of buildings are aligned with EN norms related to construction products (EN 15978/EN15804), we recommend to consider these life cycle stages, as show in Table 4.

No relevant assumptions on cut-off rules or scenarios were found in the desk research. At building level, the discussion can be opened related to the allocation of the impacts of re-used building elements. While not applied in the presented LCA study of two office buildings (VITO et al., 2018a), setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building).

The PEF guidance on how to calculate **performance levels** (based on most relevant parameters and by determining market realistic minimum and maximum values) is created for products. The desk research aims at exploring if other methods are used to define performance classes for buildings in existing approaches. The **aim** of performance classes can be different and should be defined clearly. For the definition of performance classes, a lot of information is needed on the relevant buildings that you want to “represent” in different classes, to be able to set the desired thresholds. For that, as is also the case for defining a benchmark of buildings, you need to have an overview of the environmental impacts of the various buildings you want to cover, which can be either **real buildings or virtual buildings**. In the case of performance classes, as the amount of data needed is so large, generally virtual buildings are used. Sometimes **extreme** variations are also taken into account (both very positive and very negative), while some systems rely only on the most **realistic** variations. To set the thresholds between different performance classes, some systems rely purely on the relative improvement compared to the benchmark (e.g. 5%, 10% or 15% better than the benchmark). Some other systems (such as in the report by W/E adviseurs) are based upon the statistical spread of the analysed building stock, which can be either virtual or real. In this last case, the designer of the performance classes has full control and designs the classes taking their specific aim into account. It could also be considered to define performance classes at the element level instead of at the building level, as is done in BREEAM for the definition of benchmarks.

4.2. RECOMMENDATIONS

Some recommendations are made by the project team based on the findings of the PEF study of two new office buildings, the PEF methodology, the desk research, the received feedback from the stakeholders and previous experiences of the project team.

The literature study revealed that a lot of systems and guidelines are based on national methods and norms and building typologies in European studies are generally defined at a national level. We therefore recommend to define **benchmarks** at a **national level** instead of at EU level. To avoid an overwhelming and deconstructive workload, a gradual approach in the development of benchmarks is recommended. In the Netherlands this has worked very well, a lot of progress has been made in the last years and more progress can be expected in the coming years.

Based on the learnings from the desk research, we recommend to define a **common EU methodology** to calculate the environmental impact of buildings and a common EU methodology on how to define environmental benchmarks. This is needed in order to reach a harmonized approach in Europe. It is furthermore recommended to calculate the benchmark values at national level in order to take into account external factors such as climate, construction practice and culture influencing the environmental impact of a building. Finally, we recommend a **stepwise conservative approach**, meaning that initially benchmarks are defined representing lower limit values and which gradually become more severe in time, evolving to mean values and target values. In other words, when initiating environmental benchmarks in a legislative context, these are recommended to represent the level-playing-field with a lower limit as a starting point.

In order to define an environmental benchmark for office buildings, insight is needed in the average environmental impact of office buildings in Europe and on the variation of it throughout the building stock. This insight can either be gained from **real cases or virtual cases**. This is further discussed in the subsequent sections 0 and 2.4 and recommendations are formulated in those sections. The first conservative benchmark should be set to allow all office buildings that **fulfill minimum legal requirements** on energy, water, fire safety, etc. To define the environmental impact fulfilling the improvement or target value, this can be based on best-practice buildings (experimental or demonstration projects) or based on virtual buildings with for example 30% less impact than the reference value (i.e. representing common practice to date). In the second approach, the percentage reduction could either be based on a statistical analysis of building practice in the specific member state or based on political targets set.

For the definition of **reference buildings**, the project team recommends to follow the approach that was used in the Netherlands, as this proved very successful. Translated to the office buildings, several steps are needed to define reference buildings. Reference buildings need to be defined in terms of building typologies representing the building practice in a specific member state. In D3 two types of buildings were analysed: courtyard building and compact cubic building. However other forms/typologies are seen on the market and should be covered when calculating the average environmental impact: e.g. high-rise buildings, less-compact buildings, etc. Representative typologies can differ per member state and are therefore recommended to be defined at the **national level**.

To calculate the environmental impact of each of the building types, the influence of the **market variations** on the impact of the building needs to be identified per building type in a dedicated **statistical study**. Market variation in terms of size, materials used and technical solutions are to be considered, so that the representative buildings can be defined so as to cover 51% of the market. Considering extreme values gives additional insight in the spread of environmental impacts of buildings. Based on the environmental impacts of the considered typologies and its variations, the lower values represent the level playing field.

The literature study revealed that benchmarks can be defined to cover both material and energy impact of the building, or a separate benchmark can be defined for each. Based on the PEF assessment of the two office buildings with a very different energy performance in Deliverable D3 (VITO et al., 2018a), the project team recommends to have one benchmark including both **material and energy impact**. However, taking practical implementations into account, it might be easier to separate both (in a first phase) because energy benchmarks are currently already established in the EU Member States.

This desk research provides an overview of insights gathered through a desk research of various studies, but it is clear that **additional data is needed** at the national level in order to define explicit recommendations on certain aspects that are relevant to defining reference buildings. E.g. which construction techniques and materials to consider, and how many reference buildings should be defined to cover all building typology of office buildings, are complicated questions that require specific knowledge on all the buildings you want to cover, which differ per country. More in-depth research on the office building stock in different countries, climate zones, using different materials and construction techniques, among others, is required. Most countries lack a large database on non-residential buildings, and therefore the gathering of more data and the **creation of databases** are recommended.

Based on the findings of the PEF study of two new office buildings and the desk research, the project team recommends to use the following functional unit for a new office building. *The **functional unit** is one office building with reference service period of 50 years, assessed from the bill of materials according to element method.*

The key aspects used to define the functional unit are presented below.

- **What?**
    - Office building excluding the surroundings.
- **How much?**
    - One office building.
- **How well?**
    - Energy performance and thermal comfort;
    - Relevant technical and functional requirements.
- **How long?**
    - 50 years of reference study period.

Providing a clear **reference flow** for the assessment of buildings will greatly improve comparability of future studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit for benchmarking that takes the **function of office buildings** into account, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all member states use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends **m² floor area** per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the complete building and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishings as well as technical equipment such as electricity, HVAC, sanitary equipment and elevators. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEF method for buildings on what shall and shall not be included when the PEF method is used for either benchmarking or comparative assertions. This is described in more detail in Deliverable D6 of this project (VITO et al., 2018b). PEF recommendations can be followed related to cut-off rules and scenarios.

Benchmarks are needed at different phases: during the **design phase** (for obtaining a building permit) and **post-construction** (e.g. when 2 years in use). For both benchmarks, a different approach is needed for the environmental impact of the operational phase:

- Design phase: impact of operational energy should be linked with the energy performance calculation methods already established in the member states.
- Post-construction: impact of operational energy should be based on primary data: measured data for at least two years (average yearly consumption)

To avoid burden shifting or trade-offs between impacts, the project team recommends to have a **benchmark for each impact category separately, as well as at the aggregated level**. Therefore several benchmarks need to be defined: one per impact category, one at the aggregated level. If in the long run the most relevant impact categories for buildings have been identified, the benchmarks could be limited to the relevant impact categories only. However, since these are not yet defined, at this moment the project team recommends to have a benchmark for each of the impact categories of the PEF method.

As **data quality requirements** are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

Starting from the benchmarks defined at national level, **performance classes** can be defined. If environmental assessment data is available on a large amount of buildings representing the office building stock, data on existing building should be used. If such data is not available, few representative buildings should be chosen and virtual variations of these buildings can be analysed. **Market variations** in terms of size, materials used and technical solutions are to be considered. Considering extreme values gives additional insight in the spread of environmental impacts of buildings.

When the legal requirements define the lower limit of the first performance classes, and a statistical analysis defines the upper limit of the best performance classes, this range can be divided in 5 performance classes, as defined in the PEF Guidance.

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ANNEXES

ANNEX 1 – MATRIX WITH SUMMARY OVERVIEW OF LITERATURE SOURCES CONSULTED

The separate excel file “Matrix_20171220.xls” includes a detailed analysis of the documents that were analysed during the desk research that is described in this report. The matrix gives a systematic overview of certain aspects related to goal and scope definition, standards or norms applied, etc.

ANNEX 2 – MINUTES OF 2ND STAKEHOLDER WORKSHOP IN BRUSSELS, INCLUDING FEEDBACK OF STAKEHOLDERS

Date and location

PEF4Buildings – 2nd Stakeholder Workshop at EC
Date: Monday 29th of January 2018
Time: 10 am to 4 pm
Venue: Premises of European Commission (Brussels)

Agenda

1. **10:00 – 10:30:** Registration and welcome coffee
2. **10:30 – 10:40:** Introduction by EC
3. **10:40 – 10:50:** PEF4Buildings project in a nutshell
4. **10:50 – 11:15:** Brief summary of the results of the PEF assessment of two office buildings
5. **11:15 – 12:15:** Possible approaches for benchmark and classes of performance for office buildings
6. **12:15 – 13:00:** Interactive discussion with stakeholders
7. **13:00 – 14:00:** Lunch break / networking
8. **14:00 – 14:45:** Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
9. **14:45 – 15:30:** Interactive discussion with stakeholders
10. **15:30 – 16:30:** Closing of the meeting – Coffee – Networking

Representatives from the following organisations participated

Aetic Architectes
Afnor
AGV Glass Europe
Aliaxis/ PEF pipes pilot
ArcelorMittal
Archipelago ar'te
Austrian Chamber of Commerce
BASF
Belgian Brick Association
Belgian Building Research Institute
BIBM
BRE
BRE and CEN TC 350 WG1
CEMBUREAU, the European Cement Association
CEN/ TC 350
CEN/ TC 350 / DIN
Cerame-Unie
Colruyt Group
Construction Products Europe
DGNB (German Sustainable Building Council)
DHUP
EPPA
EUMEPS
Eurima
Eurogypsum
European Aluminium
European Calcium Silicate Producers' Association
European Parliament
European Partnership for Energy and the Environment (EPEE)
European Steel Association (EUROFER)
Fachverband Steine-Keramik
Federal Public Service of Health and Environment, Belgium
French Federation Tiles & Bricks (FFTB)
Gesamtverband der Aluminiumindustrie e.V.
Glass for Europe
GFE / AGC
IBO GmbH
Knauf Insulation
KU Leuven
Ministry for and Ecological and Solidarity Transition – Ministry of Territorial Cohesion, France
NIBE
PEP Ecopassport
PlasticsEurope
PU Europe

Rockwool
Saint Gobain
Solinnen
Thinkstep
Treeze Ltd
TU Graz
UECBV
VELUX Group
VITO/ EnergyVille
VITO
WeLoop
Wienerberger

Minutes

1. Registration and welcome coffee

2. M. Galatola, EC: Introduction to PEF, PEF4Buildings and the relation to other approaches (e.g. Level(s)). Comment from J. Lindblom (DG ENV): End of Level(s) phase by end of 2019.

3. C. Spirinckx, VITO: (see slides) Introduction of PEF4Buildings team; Agenda overview; PEF4Buildings in a nutshell: Overview and introduction to project tasks 1 to 4. (see slides) Project planning and important dates: **Deadline for written feedback** by stakeholders is **09/02/2018**.

4. K. Allacker, KU Leuven: (see slides) Results of the PEF assessment of the case study buildings (see slides). However, it is important to keep in mind that the results of the two studies, in terms of numerical values for each impact category, are not the main objective of this project. The focus is on the assessment methodology and challenges and learnings from application on building level. Presentation of functional unit, system boundaries, definition of life cycle stages, case studies, element method used to structure inventory, data used to compile life cycle inventory.

Q= Questions; A=Answer; S=Statement

Q1 (*unknown*): How can we have negative impacts in PEF_A1 if we don't have module D?
A1 (P4B project team): Because you can have recycled content for the new product, which allows to have negative impact, depending on (recycled) materials used.

Q2 (WeLOOP): At which level EoL scenarios are defined? Is there any recycling scenario considered in the modelling?
A1 (KU Leuven): Recycling scenarios per material. For scenarios, we followed PEFCRs where available, else we used Belgian/Austrian PCRs. Considering data, the datasets that were available are used, with proxies added where needed.

Q3 (BRE and CEN TC350 WG1): 1) How did you use EN 15978? As it is being revised at the moment. Purpose to align indicators within EN 15978, 15804 and PEF – which is okay. 2) Did you change definition of Life Cycle Stages and excluded module D? What are implications of defining the LCS as done in the PEF4Buildings study? 3) Did you attempt to analyse one building in two different ways?

A3.1 (DG ENV): No link/immediate connection to mandate and work done in Cen TC 350. No need to align with what is done in the PEF4Buildings project at this point.
A3.2. (VITO): Not excluded module D, but modelled in a way to include information usually contained in module D and allocate these to PEF_A1 acc. to the Circular Footprint Formula (CFF). Thus partly included in the beginning (PEF_A1) and in the end (PEF_C3/C4).
A3.3. (KU Leuven): Not so much difference in modelling of buildings, but big difference in how results are aggregated and presented (interpretation phase). In the design phase, it is easier to have a smaller list of elements/materials for interpretation reasons.

Q4 (CEN TC 350/DIN): How was assessment done for total use of energy, which would have been excluded in EN 15978 assessments.
A4 (KU Leuven): Discussion referring to assessment during design vs. ex-post assessment. Data that was available for energy use was aggregated and it was not possible to split. Moreover, lighting in the Austrian case is also used for heating of the building.

Q5 (VELUX): These studies intended to be used to improve building impact, however trade-off between construction and use stage. Have you done analysis between implications of comparing construction and use phase? Tendency to compare them 1:1, independent of uncertainty contained in these results (especially for use phase related results)
A5 (KU Leuven): was not part of this study. This issue also arises in the benchmarking discussion.

Q6 (CEN TC 350/DIN): Which five PEFCRs were used for the assessments? What other (generic) data was used? (from databases, e.g. the German database, or Life cycle databases (GaBi, Ecoinvent) Did you find differences in applicability of this data?
A6.1 (VITO): Hot and cold water supply piping, thermal insulation, decorative paints, metal sheets, and photovoltaics. For other not covered by PEFCRs we used European PCRs where available, national PCRs and scenarios indicated there. Generic data was mainly taken from EcoInvent but had to be customised, some ELCD data (as PEF compliant datasets were only published at a time when they could no longer be implemented in the study).
A6.2 (DG ENV): Data learnings: proof that harmonization of secondary datasets is important but difficult as wide margins for improvements of quality of data, quality of documentation. If you don't harmonize backbones of databases, it won't be possible to achieve comparable results.

Q7 (Treeze): Question to clarify the CFF and assignment of footprints to LCS (always 50/50)? Asks for clarification on water consumption indicators.
A7.1 (DG ENV): Footprint formula not always 50/50, now closer to market conditions (20/80, depending on material). Problem with water is about implementation of water method in software.

5. K. Allacker, KU Leuven and A. Passer, TU Graz: (See slides) Presentation of desk study/literature review. Overview of potential meaning and approach for benchmarking at building level. Details on definition of reference building (acc. approach of DGNB 2015, Minergie-ECO, BREEAM, LEED, Dutch legal requirements). Conclusions regarding differences in approach/scope. Functional unit, reference flow, system boundaries (VTT report, BBP report, DGNB 2015).
   L. Damen, VITO: Classes of performance (PEF guidance, French initiative E+/C-, Dutch legal requirements, GRO)

6. Interactive discussion with stakeholders (moderated by C. Spirinckx, VITO):
   Question 1: Reference building/benchmark. How to define reference buildings?

S1 (DGNB): Most important to know purpose of benchmark later on. Different possibilities what you use benchmark for (minimal requirements vs. future goals), different ways of developing the benchmark possible. Important to talk about function of building – energy performance and comfort (important to specify what comfort? Thermal, visual, acoustic comfort? All have influence on how building is designed. Other design criteria (accessibility, etc.) – without definition of "function" it is hard to take next step and define benchmarks. Experience from DGNB suggests it is better to have different assessments for different criteria which are then combined in the final score (not all of which may be related to LCA criteria).
Do you have a recommendation for the commission already?
S1 (VITO): Based on desk review and feedback from stakeholders the recommendations for the commission will be drafted.

Q (EURIMA): Have you assessed learnings/conclusions regarding benchmarks from Level(s) regarding benchmarks? As there it is stated to have different levels to assess and compare. Differences in benchmarks for e.g. portfolio management versus benchmarks used to implement policy.
A (DG ENV): Goal is to look at an LCA/PEF specific benchmark (while aware this only covers a part of the important aspects).

S (CEN TC350): Performance criteria of different countries, setting benchmarks against these criteria is important. BREEAM has benchmarks for different parameters.

S (Thinkstep/CEN TC 350): Decision important whether benchmark is based on e.g. energy consumption of existing buildings. Better to look forward at new buildings. Not focus too much on old buildings.
Besides, on European level things like electricity mix will influence benchmark/performance when comparing buildings – e.g. due to energy mix Scandinavian buildings could perform very well.

Q (Treeze): in Switzerland, starting point to establish benchmarks was "what goal do we need to achieve"? Based on 1Gt CO_2, or these days more likely the 2°C goals, they calculated the budget for buildings, per m² of buildings, per person. Recommendation to establish benchmarks starting from the requirements which goal/reduction is to be achieved.

S (DG ENV): When developing weighting system for PEF, they looked also at distance to target approach. However, we have not looked into the issue of benchmarking from the perspective of the political targets. That is an interesting concept.

S (European Environmental Bureau): Distance to target approach very attractive from environmental point of view. Regarding ways to define benchmarks, important not to go for one aggregated benchmark but be clear about purpose (e.g. architect who needs information to improve building design) and distinguish. Important to include adaptability, flexibility, replicability of elements in buildings and incorporate this in benchmark discussion – building "fit for purpose" over its life span. Sees limitations in that regard in LCA and PEF approach.

Q (EUMEPS) Important to look at long term targets (longterm roadmaps). How design decisions connect to high level targets, thus need to break them down to national targets.

Diversity in classification methods is confusing for participants in the process. Important to harmonize in order to know what we are talking about.

S: (ECI) Buildings in future will have to be more productive. Buildings that pass on benefits. If only done on inventory base, we might miss opportunity to bring buildings forward in the future.

S (DGNB): E.g. if we use electricity mix of now to calculate operational phase we miscalculate (as this will change a lot). Sam issue in reference building used for benchmarking. Indicating "potential" to do something, a specific measure, to assess future scenarios. Indicate e.g. potential to recycle an element/material.
Question is, how much investment in materials makes sense to have a well operating building over time. As ways of operating will change it is important to anticipate this. Just looking at material will not lead to best life cycle performance.

S (DG ENV): Energy mix will be different, recycling is unknown. How to combine the high uncertainty with the cradle to grave?

S (Velux): Could set limits for extreme situations an know that it will be between those limits (zero carbon versus no requirements). Now only looking at optimisation of the use phase.

S (Treeze): Looking at measures, dynamic systems to establish benchmarks for e.g. 2030 and then analyse buildings and check them against set benchmarks.

S (PU Europe): Benchmarks, complicated political environment. We can draw pathways for the European Union, having an agreement amongst 28 member states might be difficult. Suggests to fit benchmarks according to national context.

S (ECI): Only focusing on benchmarks that drive down resource use, we might miss opportunity to have buildings, which are productive but use more resources.

S (CEN TC350): Is there a benefit to having a standardized approach to determine your benchmark, as opposed to what the actual value of benchmark is.

S (DGNB): for use stage, they use dynamic benchmark based on type of use (of office. E.g. for office with a lot of meeting rooms is different than office with a lot of workplaces and hardly meeting rooms). This approach tries to incorporate the "occupational density", which is especially hard to specify during design stage otherwise. DGNB experience show this approach works well.
Importance to look at flexibility of building, especially regarding the service life of buildings. Current problem of market is that we have good quality buildings which are not flexible to adapt to market demands, thus are torn down after e.g. 20 years and replaced. This shows importance of flexibility, even though this is hard to standardize.

S (PU Europe): Development of "smartness" indicator within CEN?

Q (WeLOOP): In French approach there is experimentation phase, where people apply approach and from the sample results (e.g. two-year phase) are collected and grouped to establish an empirical benchmark. Experimentation phase where people can look on method and provide results to base benchmark based on this.

7. Lunch break

8. C. Spirinckx, VITO: (See slides) Link between the assessment of environmental performance of construction products and the assessment of the environmental performance on buildings by using the PEF method.
   Existing methods and tools; check of draft PEFCRs; preparation of recommendation and guidance on how to link assessment on product level with building level; relevant existing approaches e.g. EN 15978 (Europe), MMG (Belgium), Elodie (France), eLCA (Germany), GPR Gebouw (Netherlands)
   L. Damen, VITO: (See slides) Analysis and comparison of existing PEFCRs for construction products.
   C. Spirinckx, VITO: (See slides) Conclusions and preliminary recommendations regarding provision of data (PEFCRs) on different levels, differences in application (assessment during design vs. post-construction/during use), software solutions (Note: No specific LCA software is endorsed for use), requirements towards LCA/PEF for buildings applicability, BIM for LCA/PEF.

9. Discussion with stakeholders: Do we need a PEFCR for buildings?

Q1 (CEN TC 350/DIN): We have to deal with the question of databases. Harmonization of calculation is necessary, maybe separate from the discussion on harmonized benchmarks. Maybe a harmonized approach towards benchmarking is more feasible, rather than fixed values for benchmarks. This should be up to market and good ideas from construction world.
Common calculation rules are important. Part of difficulties with PEF are scalability to certain types of buildings. Exercise should give light on applicability of PEF towards building assessment. Wondering whether data used from PEF pilots were useful to assess buildings. What was useful, what needs to be changed? If next to the CEN amendment, with the goal to harmonize. Common calculation rules which have to be same for EPD and PEF. If a PEFCR for buildings, tailored for PEF, is developed, this would move away from a harmonized approach, also in the context of the amendment of EN 15804/15978.

S (DG ENV): Some things will not be aligned. We are not going to develop PEFCRs for buildings. Under assumption, that mandate will be delivered as expected, the EC will follow and refer to CEN standards.
Back to calculation rules: still situation is that data quality, secondary datasets, etc. will not be used in EPDs. Thus there is a value in maintaining PEFCRs already developed for construction products, to get more information/guidance on modelling/scenarios. Wish is that next evolution of PCRs will move closer to PEF.

S (BRE and CEN TC350 WG1): Thanks for reassuring answer (tw. MG). Invites project team to share lessons learned from practicality of PEF application within CEN WG1. Emphasizes the direction to use building assessment as the driver for requirements towards building products (EPDs/PEFCRs), rather than other way around.

S (Thinkstep): sometimes manufacturer deliver system (full window: frame, glazing, etc.), sometimes only parts of system (e.g. window frame only).

S (EUMEPS): Difficulty with additional requirements at national level which need attention. Roadmap for stakeholders regarding strategic decisions would help. Also it would be valuable to get deeper insight into learnings from BIM application within PEF4Buildings project. What information was available – what did work, what did not?

S (European Steel Association): Benefits from PEF due to more clear specification of certain aspects still vague in EN 15804. Maybe too early for benchmarks as methodology is not fixed (for EN 15804/15978)

S (*unknown*): Regarding renovation scenarios, PEFCRs could help in decisions due to stricter guidelines on end of life scenarios.

S (AGC Glass Europe): If you want reproducibility you have to ensure databases are the same. One European database would be nice.

S (*unknown*): Group Indata, led by BBSR, to define digital format for EPD (ILCD+EPD). Target is to create European network where you can find all EPDs on one platform in digital format.

Q to stakeholders (DG ENV): Is there any movement to tackle issues of quality of data? In PEF tried to establish an approach to assess data quality. Main interest is to actually look at the data and see how data quality can be assessed and quantified. Is there a timeframe in 3,5,10 years where quality of data used will become part of EPD schemes?

S (Federal Public Service of Health and Environment Belgium): In Belgium 2-3 years ago studies on data quality were done. Not only interesting but necessary to dig into data quality. Most important burden is time, hence added cost, that comes with using high quality data. Difficult to implement as this would require additional time (cost) for establishing EPD in the first place, would hinder the market.

S (CEN TC 350/DIN): We have data on what drives the results and some data is not so relevant, for this data quality can differ and won't matter too much. New standard on data quality will be launched in CEN TC 350 – regarding generic data and product specific data. Complications on who will do the quality assessment for LCA data? Not manageable for LCA practitioner, required to have extra data verifier (related to data provider).

Q (DG ENV): Data provider responsible for data quality. Data peer-reviewed, should be quality assurance. Findings of major errors raise questions on current quality of peer review.

S (Thinkstep): Data quality depends on requirements and intended application of data. Commission need to "shout" more about data quality issues it identifies.

S (DGNB): Bigger influence is not coming from individual datasets in the model, more from the way modelling has been done for the building (e.g. completeness of model, way how datasets were linked, how aggregation was done, etc.). Does not mean that data quality does not matter, but influence is lower than stated in discussion now. Ensuring data quality won't solve the problem. People are using data in inappropriate way, for many reasons. People might need information in the moment they do assessment, at moment they can influence design/decision. If you have all information on building level it is too late to take decision as building is built already. More important to have good quality of assessment rather than of dataset.

S (Treeze): Thus, no need for one single European database.

S (DGNB): Depends on what you want to do. For e.g. early design stage scenarios you don't need single data source, as its different than for detailed assessment of full building.

S (DG ENV): No intentions to have single European database. Competition of data providers is good to ensure quality. Idea is to have list of database providers who provide the required quality of data (following certain calculation method, etc.).

S (EUMEPS): Better to start working on basis of existing approaches than aim at starting it from beginning. If looking one step further, e.g. declarations at product level.

S (*unknown*) About databases, distinction between background data and EPD data needs to be made. E.g. for Netherlands background data is fixed. Definitely advantage to have one database for background data.

S (ROCKWOOL): Otherwise agreement, no one European database for EPDs required. However, would be beneficial to have common standard for background data quality.

10. C. Spirinckx, VITO: Closing of meeting.

Additional feedback from stakeholders after stakeholder meeting

In Italic grey: comments from respective stakeholders.
After each comment: feedback from project team.

Velux
Thank you for a very interesting report, I am looking forward to the additional material that will be added in the final report.

- *I would suggest to rescope the conclusion a bit according to the development of TC350 PEF alignment and focus on how we can further strengthen that work to achieve a good platform for building assessment. As mentioned, EN 15978 is up for revision and any concrete inputs would probably be very useful.*
- *Making two LCAs on buildings, one traditional and one NZEB building is interesting – it would be further interesting if the buildings also had been assessed in the same geographical location thus to see positive and negative impacts of the NZEB concept compared to traditional constructions. As the energy systems are different for Austria and Belgium the results are not really comparable as it is.*
- *I would very much like some considerations on how to deal with the great uncertainties of future energy systems and future waste management systems and how to include this in the building assessment. Right now, the use phase will always be more important than materials and EoL due to the present highly polluting energy systems, but they are simultaneously under a great technological and political pressure to change within a short time frame (some targets are setting*

2030 as a point of CO2 neutrality). Then the building's use phase of 50 years suddenly becomes rather different than expected today – and all our legislative requirements for the energy efficient use phase will be a gross overshoot and not give us real environmental benefits due to the high material investments in the construction phase.

Again thank you for the report and the presentation.

<u>Feedback from project team:</u>
Thank you for your valuable feedback. Although you raised three important issues, none of these can be addressed within the PEF4Buildings project.
<u>Comment 1:</u> Although the project team understands the request to provide further input to the revision of EN 15978, that was not the goal of this project and hence was not studied as such. More specifically, this study did not check the outcomes of this project with EN 15978. Nevertheless, we think that the results of this project can be used for this purpose and hence can be considered as input for the revision of EN 15978.
<u>Comment 2:</u> the project team agrees that the analysis of both buildings in the same climatic context would be interesting to further derive learnings from that, but that is not feasible within the scope of this project. This would require quite a lot of additional work in order to accurately estimate the operational energy use of the buildings in a different climate than their actual climate. Dynamic energy simulations would be needed to estimate the operational energy use, while current assessment is based on real consumption.
<u>Comment 3</u>: The influence of the changing energy systems and waste management systems in future on the life cycle environmental impact of the building has not been assessed. The PEF method requires to assume current common practice for both energy and end-of-life processes. This project followed the PEF method as that was the goal and did not question this issue. We do recognise that changing energy mix might influence the life cycle impacts to an important extent and is in general an interesting issue to be investigated. However, this is beyond the scope of the PEF4Building project.

Rockwool

Further to your question to check the statements about the Dutch system:

First of all thanks for taking the Dutch approach explicitly into account. Most of the info is fine, except for two slides where I believe you mixed up the legal requirements (in the Bouwbesluit) for buildings and related to a building permit, with the voluntary Green Public procurement system for office buildings. Both make use of the same Bepalingsmethode, but use another system of benchmarking:

The Bouwbesluit applies to all buildings (dwellings, offices, hospitals etc), both new-built and renovations for which you need a permit. The Bouwbesluit requires a minimum value for the single-score indicator of the building LCA. The W/E report "Bepaling kwaliteitsniveaus milieuprestatie van woonfuncties" referred to on slide 94, 89 and 80, 81 are related to this and well-quoted.

GPP (Duurzaam Inkopen) applies to public office buildings and is strictly spoken not a legal requirement. Public buying is a private activity in NL. They don't use the A-E classes investigated for the Bouwbesluit, but quality classes A-C relative to the Bouwbesluit level. See annex in

https://www.rijksoverheid.nl/documenten/rapporten/2016/07/01/bepaling-kwaliteitsniveaus-milieuprestatie-van-woonfuncties
This is mixed up in slide 65 and 95, see comments below.

Anyways, it will not change the conclusions and your PEFCR work.
Good luck with the finalisation.

Feedback from project team:
Thank you for clarifying this. We will make this clear in the final report and clearly distinguish between the legal requirements in the Netherlands, and voluntary GPP. The powerpoint presentation used during the second stakeholder workshop will however not be updated.

VITO

First of all let me congratulate you with the nice workshop you've organised. I was very glad to be able to participate at it.

I would like to take the opportunity to share some thoughts with you…
I leave it up to you whether you want to add this in the final report or not.

- ***Regarding the use of BIM:***
  - *BIM is – and will certainly be in the future – an important way of exchanging data. If a BIM model is available, it can facilitate data inventory considerately*
  - *As you've mentioned, it is not possible to cover all LCI data and parameters through BIM. It would be very instructive to have an overview of LCI data and parameters that is generally available through BIM and which data should be retrieved through other means.*
  - *The use of BIM is increasing through Europe, but at an uneven pace. Countries such as the UK, Finland and Norway are quite ahead over the rest of Europe, mainly because the use of BIM has been made mandatory for public and/or new buildings. Hence, an aligned policy to adopt BIM will play an important role in the near future (at least for new and public buildings; existing building will be far more difficult to inventory)*
  - *Nevertheless, don't forget that the construction sector is mainly made by SMEs, for which adopting BIM software (from a financial, logistics and learning point of views) is really not easy. It will take time!*
  - *This brings me to the following concluding question/remark: For which type of buildings (public/private; new/existing) and EU regions (in all EU or parts of it) will a PEF study be actually affordable/applicable, knowing that time = money and the investment of (often commercial) BIM software is often too high for SMEs within the building value chain?*
- ***Regarding PEF and Circular Economy:***
  - *A participant of the workshop (sorry, I don't know his name) argued that PEF4Buildings could play an important role to assess 'circularity' within the built environment. (note: I didn't answer at that moment, because the answer is quite technical, as you will see below)*
  - *I think it does (the circular footprint formula is after all an important component within the PEF methodology)…but only partly. The following methodological*

aspects are currently missing in the PEF (and also CEN) methodology (or at least unclear). Most of them have been discussed within the OVAM study "Design for Change", performed by VITO, KU Leuven and VUB in 2014-2015

i. *to take into account the unpredictability of the use and EoL phases, we suggest to take into account different (realistic and extreme) scenarios, instead of one fixed scenario. This may involve e.g. different transformation scenarios, involving a minimum, median or maximum number of replacements of building parts, but also different EoL practices differentiating current practices (often incineration, landfill and down-cycling) from (near future) circular practices (reuse, recycling/upcycling and composting/biodegrading). This scenario analysis will support decision-makers in the design stage to take sound decisions for the future.*

ii. *Related to this, not all 'circularity/circular economy' aspects can be covered by an LCA, ergo a PEF study. 'the easiness to deconstruct a building (part)', 'the potential of a building layout/composition to be transformed', 'the capacity of a building element to be reused', etc. should be addressed in a quality assessment, prior or in parallel with the LCA study. Also, the financial benefits/constraints of designing and buildings for 'circularity' is not addressed in an LCA. Life cycle costing should be used to assess this. However, also here, some methodological choices within the existing standards should be questioned: such as the linear (financial) depreciation of the building (parts) along their life span and the real value of materials and building components after their use period. How to determine the latter is still under debate, primarily because of the fluctuation of materials/commodities. (in the H2020 BAMB project, these aspects are all integrated in a 'Circular Building Assessment' – to be presented on the Ecobuild fare in London, in April 2018)*

Feedback from project team:

Thank you for your valuable comments. We herewith want to provide some insights/feedback based on the learnings from this project.

Use of BIM - data inventory:

- We agree that BIM is indeed an important source of information for the life cycle inventory of the building. However, based on the learnings from the two BIM models in this project, BIM models can be build up in various ways. In order to make these useful for LCA studies, rules should be developed to guide the practitioner in how to build its BIM model if to be used for LCA studies. As this was not the aim of this project, such rules were not derived yet, but is seen as an important next step if the aim is to mainstream LCA in building practice.
- Regarding the data available in BIM and the additional information needed from other sources: this is reported in the report D3 where the modelling of and data sources for both buildings are explained in detail.
- Feasibility of PEF studies of Buildings throughout Europe and for all types of buildings: we understand your concern and indeed BIM models of small-scale buildings might not be the most time efficient. We think that LCA tools for buildings (see for example the Netherlands, France or Belgium) will be needed in future in all Member States. The way how buildings are modelled in these software might be different depending on the complexity of the building. More specifically, for large scale or complex buildings, this software might be

coupled with BIM models, while for smaller or more simple buildings, the necessary data can be manually input in the software (or by using other CAD models)

PEF and circular economy:

- The issues raised relate to the PEF method and PEF Guidance document. As this project aimed at testing the PEF method and the PEF Guidance document at building level, the issues raised were not analysed. However, this input is valuable for further developments of the PEF method.
- Various aspects raised are however covered in LEVELs in which environmental impact (LCA) is coupled with other sustainability criteria.

French government - Ministry for the Ecological and Inclusive Transition

Thank you again for the organisation of this very interesting workshop on PEF4Buildings.As discussed, we would like to share some thoughts with you.

First of all, some comments on the presentation *- We would like to clarify information on EPDs in France (slide 110): Elodie is not the only tool for LCA at building level. Today, there are 6 software available to carry out a building LCA in accordance with the E+C- framework. So we would prefer not to quote Elodie alone.*

Some comments/answers to the questions *you raised in your document or during the meeting:*

- The goal of the method to be implemented should be clearly define. In France, the goal of the E+C- framework and the next national building regulation is to steer the building designer's choices (choice of energy, of material, shape of the building...) and to encourage the industrials to improve their processes.

- As regard the reference building: t would be logical to build the threshold with the overall goal of GHG reduction of each country. However to link the overall goals and the goals for the buildings with a LCA point of view is not that simple (we are facing some difficulties to do that for France); what is more, from a building regulation point of view, the reference should take into account the designer constraints, what he cannot change (climate, foundations, obligation of a car park...)

- As regards the link between EPDs and LCA at the building level. We have encountered difficulties with some EPDs that were not adapted for LCA at the building levels (inappropriate functional unit); besides, to ensure EPDs are homogeneous the 15804 norm should be clarified for each category of product in PCRs and those PCRs should be given a status, and their process of development scrutinized.

Feedback from project team:

Thank you for your appreciation of the workshop and sharing your thoughts.

- Elodie: Thank you for clarifying that Elodie is not the only tool for LCA at building level in France. We corrected this in the report and mention all six software tools available in France to date. The powerpoint presentation used during the second stakeholder workshop will however not be updated.
- Thank you for your inputs for the questions raised based on your expertise in France. These will be considered for the recommendations regarding benchmarking in our report.

Politecnico di Milano

I tried to answer the questions, in my opinion

1. How to define reference buildings?

Reference building(s)/benchmark per climate zone (for variation in the energy efficiency requirement) and per country (for variation in legislation requirement)
Probably it is not possible to define one reference building, but it is necessary to define different reference buildings related to different typology (geometry) and then define an average impact value among them
The reference building should be based on statistical data. It is not possible to select a real building. It is necessary to define a synthetical average building: so average sqm, average WWR, average S/V, and so on.
If the representative building is representative of the actual building stock, also for the energy consumption it is necessary to use average data, because a single building cannot be representative. But if the representative building has to define a target (related to actual legislation), legal requirement limits should be used (but for energy carriers, statistical data are good), so the reference building is a baseline building (as in energy directive)
Statistical data on construction materials are not available. Maybe some reference related to research report

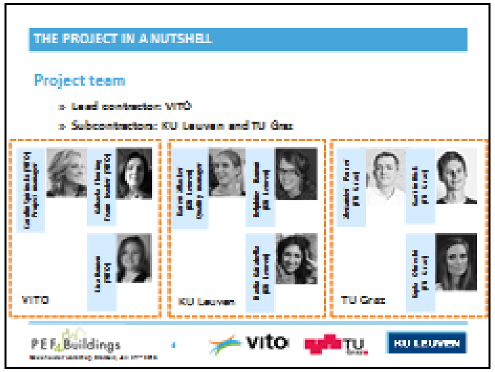
2. How to define the functional unit for office buildings?
In the energy certification, the reference unit is m^3
Square meter is a good reference for housing, because there is a standard height, but for office is not good because of different heights. Using the same reference of energy certification could be useful to allow comparison. Reading a value related to number of office is not simple for a designer. Instead read a value express in m2 or m3 is more simple for architect and construction engineers.
3. Which approach for defining benchmark and performance classes should be applied?
If the representative product is representative of actual building stock, it could be based on statistical data, buti if it is representative of new buidlings and is define for a limit value, the benchmark should be based on legal requirement as baseline (like in all Green Buildings Rating Systems, as LEED) and statistical data for characteristics not regulated.

1. Do we need a PEFCR for buildings?
More defined rules for LCA of buildings probably are necessary, but it is a very hard work.
Rules have to be defined based on experience of experts and on a huge number of studies. Not just assessing a representative building.
Probably are necessary general rules, and then specific rules related to the different functions (housing, office, etc)

2. Do we need one database?
A database can guarantee more comparable results.

<u>Feedback from project team:</u>
The project team thanks for the valuable feedback on the questions raised. These will be considered for the recommendations regarding benchmarking and PEF method for buildings in our report.

Slides used during workshop



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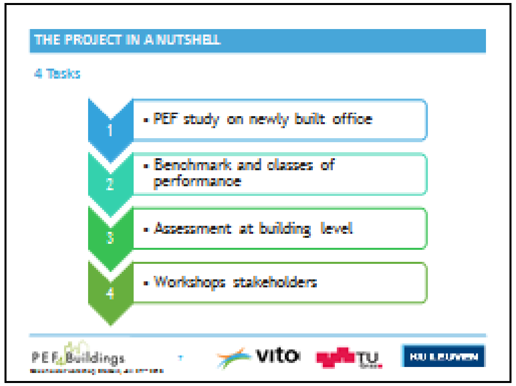
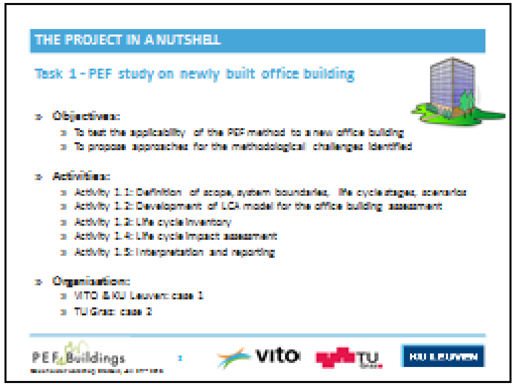
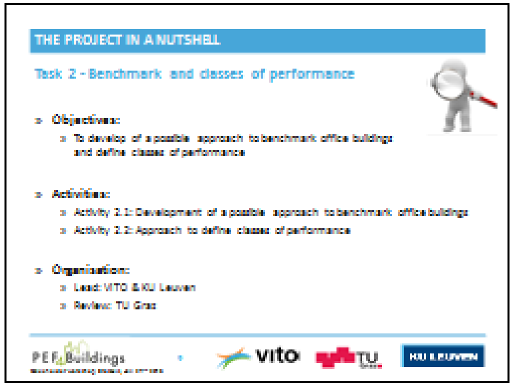
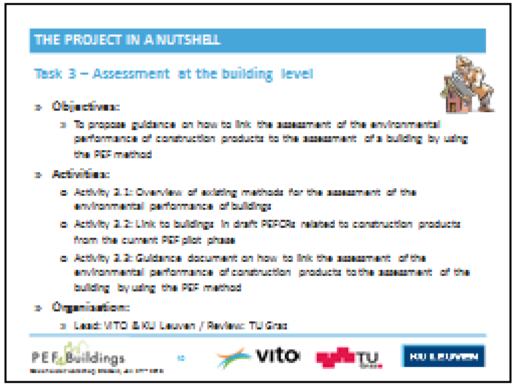
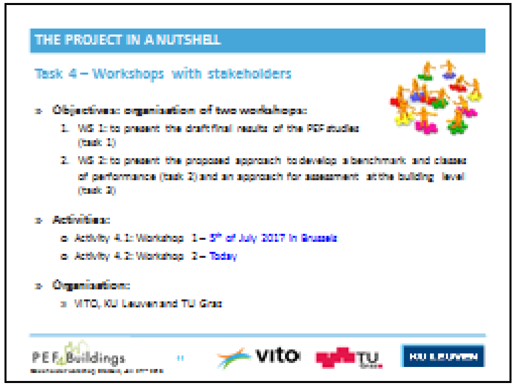

THE PROJECT IN A NUTSHELL
4 Tasks
1 • PEF study on newly built office
2 • Benchmark and classes of performance
3 • Assessment at building level
4 • Workshops stakeholders
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 1 - PEF study on newly built office building
Objectives:
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
Activities:
Activity 1.1: Definition of scope, system boundaries, life cycle stages, scenarios
Activity 1.2: Development of LCA model for the office building assessment
Activity 1.3: Life cycle inventory
Activity 1.4: Life cycle impact assessment
Activity 1.5: Interpretation and reporting
Organisation:
VITO & KU Leuven: case 1
TU Graz: case 2
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 2 - Benchmark and classes of performance
Objectives:
To develop of a possible approach to benchmark office buildings and define classes of performance
Activities:
Activity 2.1: Development of a possible approach to benchmark office buildings
Activity 2.2: Approach to define classes of performance
Organisation:
Lead: VITO & KU Leuven
Review: TU Graz
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 3 – Assessment at the building level
Objectives:
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method
Activities:
Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings
Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Organisation:
Lead: VITO & KU Leuven / Review: TU Graz
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 4 – Workshops with stakeholders
Objectives: organisation of two workshops:
1. WS 1: to present the draft final results of the PEF studies (task 1)
2. WS 2: to present the proposed approach to develop a benchmark and classes of performance (task 2) and an approach for assessment at the building level (task 3)
Activities:
Activity 4.1: Workshop 1 – 5th of July 2017 in Brussels
Activity 4.2: Workshop 2 – Today
Organisation:
VITO, KU Leuven and TU Graz
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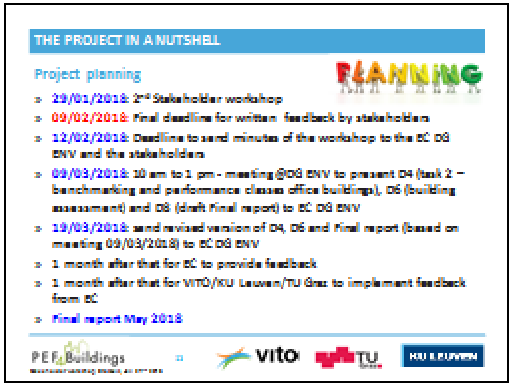
THE PROJECT IN A NUTSHELL
Project planning
PLANNING
29/01/2018: 2nd Stakeholder workshop
09/02/2018: Final deadline for written feedback by stakeholders
12/02/2018: Deadline to send minutes of the workshop to the EC DG ENV and the stakeholders
09/03/2018: 10 am to 1 pm - meeting @DG ENV to present D4 (task 2 – benchmarking and performance classes office buildings), D5 (building assessment) and D8 (draft Final report) to EC DG ENV
19/03/2018: send revised version of D4, D5 and Final report (based on meeting 09/03/2018) to EC DG ENV
1 month after that for EC to provide feedback
1 month after that for VITO/KU Leuven/TU Graz to implement feedback from EC
Final report May 2018
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AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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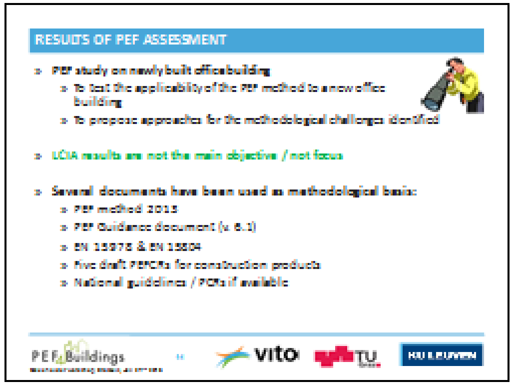
RESULTS OF PEF ASSESSMENT
PEF study on newly built office building
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
LCIA results are not the main objective / not focus
Several documents have been used as methodological basis:
PEF method 2013
PEF Guidance document (v. 6.1)
EN 15978 & EN 15804
Five draft PEFCRs for construction products
National guidelines / PCRs if available
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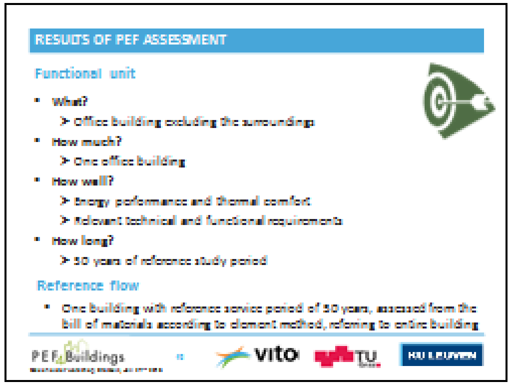
RESULTS OF PEF ASSESSMENT
Functional unit
What?
Office building excluding the surroundings
How much?
One office building
How well?
Energy performance and thermal comfort
Relevant technical and functional requirements
How long?
50 years of reference study period
Reference flow
One building with reference service period of 50 years, assessed from the bill of materials according to element method, referring to entire building
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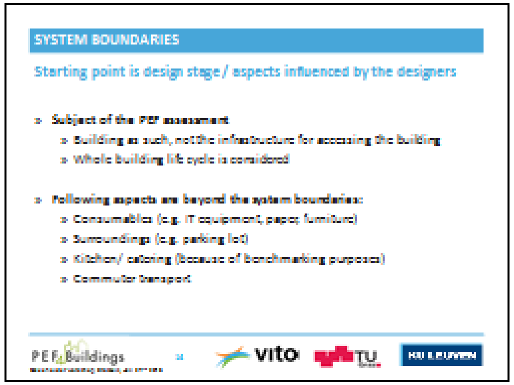
SYSTEM BOUNDARIES
Starting point is design stage / aspects influenced by the designers
Subject of the PEF assessment
Building as such, not the infrastructure for accessing the building
Whole building life cycle is considered
Following aspects are beyond the system boundaries:
Consumables (e.g. IT equipment, paper, furniture)
Surroundings (e.g. parking lot)
Kitchen/ catering (because of benchmarking purposes)
Commuter transport
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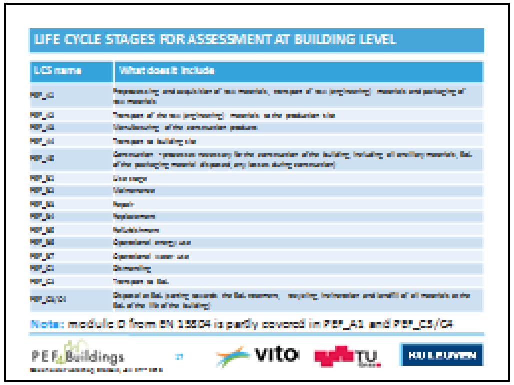
LIFE CYCLE STAGES FOR ASSESSMENT AT BUILDING LEVEL
LCS name
What does it include
Note: module D from EN 15804 is partly covered in PEF_A1 and PEF_C3/C4
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CASE STUDIES
Case study 1 – Belgium: BelOrta
Architect: A9-TE
Client: BelOrta scrl
Construction year: 2014
Context: suburban (St-Katelijne-Waver)
Net floor surface: 2000 m²
Energy performance: E69
Represents: BAU office, in use
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CASE STUDIES
Case study 2 – Austria: be 2226
Architect: Baumschlager & Eberle
Client: AD Vermietung OG
Construction year: 2013
Context: suburban (Millennium Park, Lustenau)
Net floor area: 2700 m²
Heating demand: 8 W/m² (covered by waste heat from users and appliances)
Represents: advanced building concept (passive, no heating/cooling)
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DATA INVENTORY – WORK FLOW
Structuring of the data collection
Main challenge: develop an approach to assess the building from PEFs/LCAs of construction products (available at different levels)
Hierarchical decomposition of the building
Building
Level 0
Building - Elements
Level 1
Building - sub-elements
Level 2
Building materials
Level 3
PEF4Buildings
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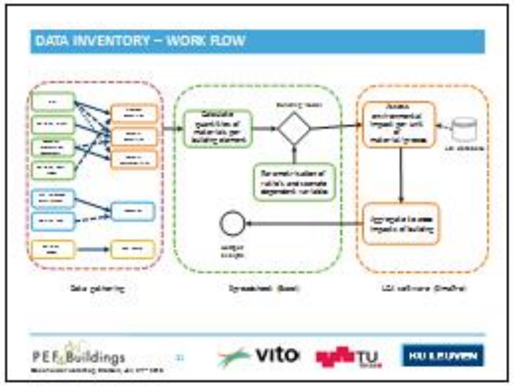
DATA INVENTORY – WORK FLOW
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LCIA RESULTS / HOTSPOTS
Characterised results
Results for both case studies
Highlight the effect of differences in modelling
Normalised and weighted results
Results for both case studies
Highlight the differences in hotspots
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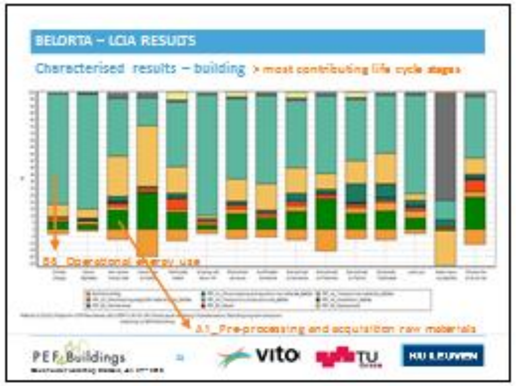
BELORTA – LCIA RESULTS
Characterised results – building > most contributing life cycle stages
B6_Operational energy use
A1_Pre-processing and acquisition raw materials
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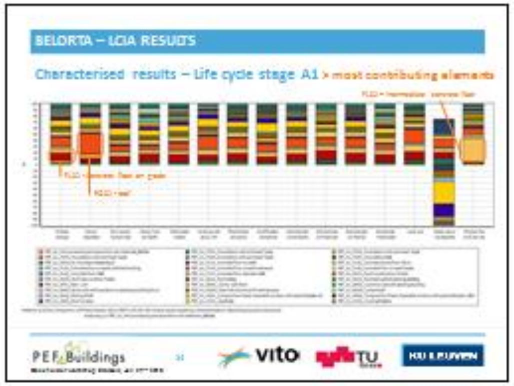
BELORTA – LCIA RESULTS
Characterised results – Life cycle stage A1 > most contributing elements
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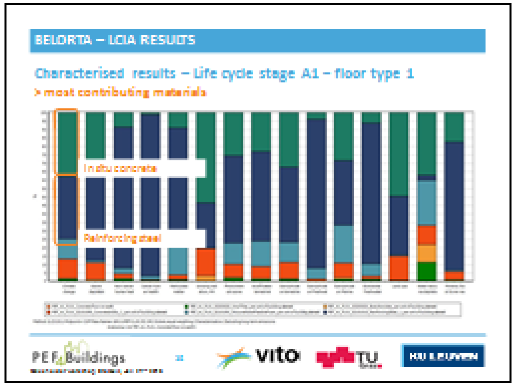
BELORTA – LCIA RESULTS
Characterised results – Life cycle stage A1 – floor type 1
> most contributing materials
In situ concrete
Reinforcing steel
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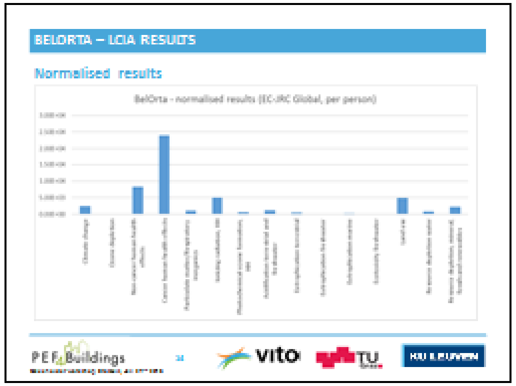
BELORTA – LCIA RESULTS
Normalised results
BelOrta - normalised results (EC-JRC Global, per person)
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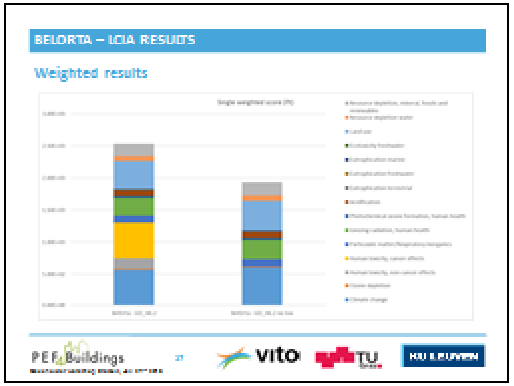
BELORTA – LCIA RESULTS
Weighted results
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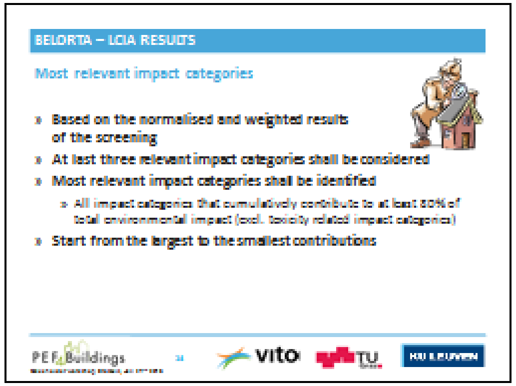
BELORTA – LCIA RESULTS
Most relevant impact categories
» Based on the normalised and weighted results of the screening
» At last three relevant impact categories shall be considered
» Most relevant impact categories shall be identified
» All impact categories that cumulatively contribute to at least 80% of total environmental impact (excl. toxicity related impact categories)
» Start from the largest to the smallest contributions
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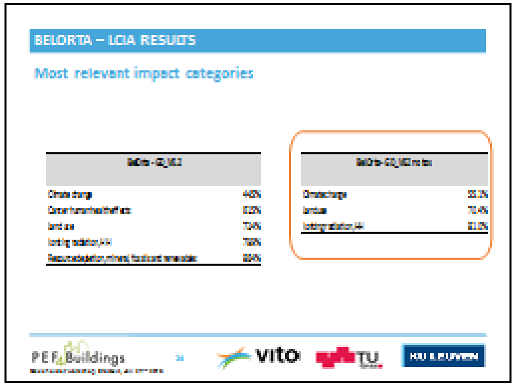
BELORTA – LCIA RESULTS
Most relevant impact categories
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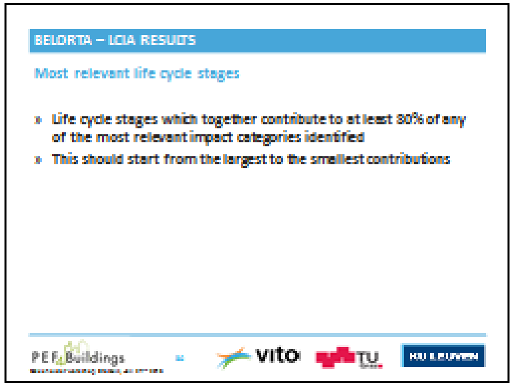
BELORTA – LCIA RESULTS
Most relevant life cycle stages
» Life cycle stages which together contribute to at least 80% of any of the most relevant impact categories identified
» This should start from the largest to the smallest contributions
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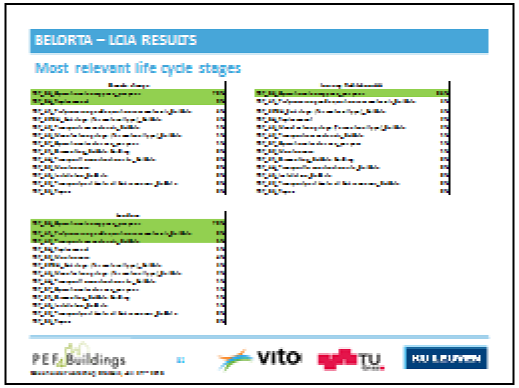
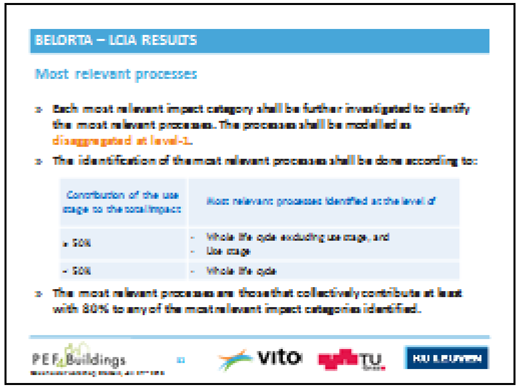
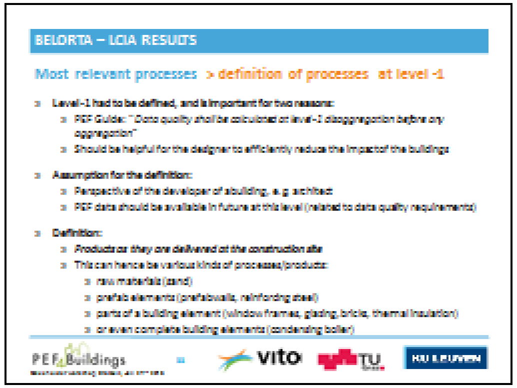
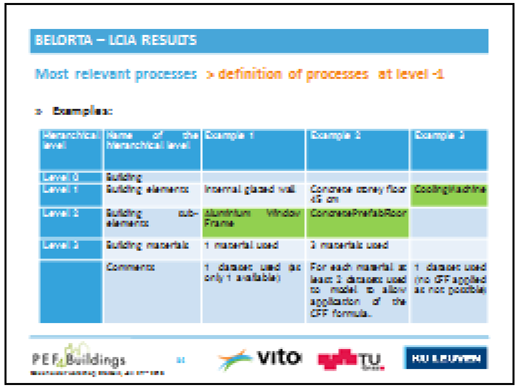
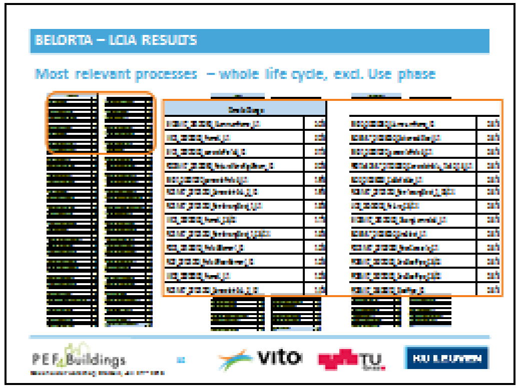
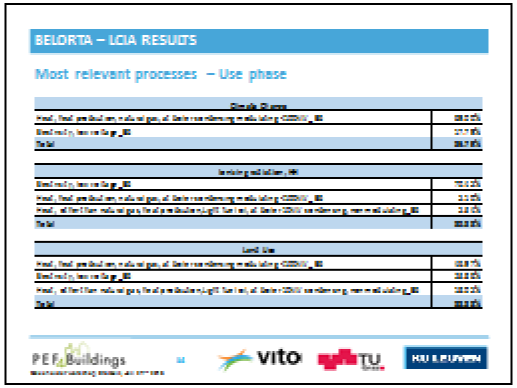

BELORTA – LCIA RESULTS
Most relevant life cycle stages

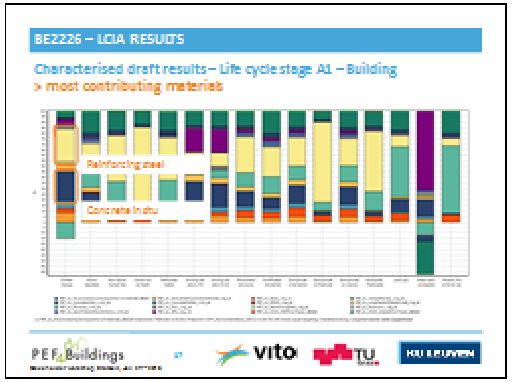

BELORTA – LCIA RESULTS
Most relevant processes
Each most relevant impact category shall be further investigated to identify the most relevant processes. The processes shall be modelled as disaggregated at level-1.
The identification of the most relevant processes shall be done according to:
Contribution of the use stage to the total impact
Most relevant processes identified at the level of
≥ 50%
Whole life cycle excluding use stage, and
Use stage
< 50%
Whole life cycle
The most relevant processes are those that collectively contribute at least with 80% to any of the most relevant impact categories identified.


BELORTA – LCIA RESULTS
Most relevant processes > definition of processes at level -1
Level-1 had to be defined, and is important for two reasons:
PEF Guide: "Data quality shall be calculated at level-1 disaggregation before any aggregation"
Should be helpful for the designer to efficiently reduce the impact of the buildings
Assumption for the definition:
Perspective of the developer of a building, e.g. architect
PEF data should be available in future at this level (related to data quality requirements)
Definition:
Products as they are delivered at the construction site
This can hence be various kinds of processes/products:
raw materials (sand)
prefab elements (prefab walls, reinforcing steel)
parts of a building element (window frames, glazing, bricks, thermal insulation)
or even complete building elements (condensing boiler)


BELORTA – LCIA RESULTS
Most relevant processes > definition of processes at level -1
Examples:
Hierarchical level
Name of the hierarchical level
Example 1
Example 2
Example 3
Level 0
Building
Level 1
Building elements
Internal glazed wall
Concrete storey floor 45 cm
CoolingMachine
Level 2
Building sub-elements
Aluminium Window Frame
ConcretePrefabFloor
Level 3
Building materials
1 material used
3 materials used
Comments
1 dataset used (as only 1 available)
For each material at least 2 datasets used to model to allow application of the CFF formula.
1 dataset used (no CFF applied as not possible)


BELORTA – LCIA RESULTS
Most relevant processes – whole life cycle, excl. Use phase


BELORTA – LCIA RESULTS
Most relevant processes – Use phase


BE2226 – LCIA RESULTS
Characterised draft results – Life cycle stage A1 – Building
> most contributing materials
Reinforcing steel
Concrete in situ
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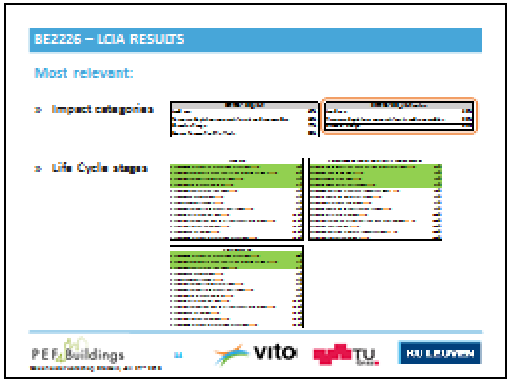
BE2226 – LCIA RESULTS
Most relevant:
Impact categories
Life Cycle stages
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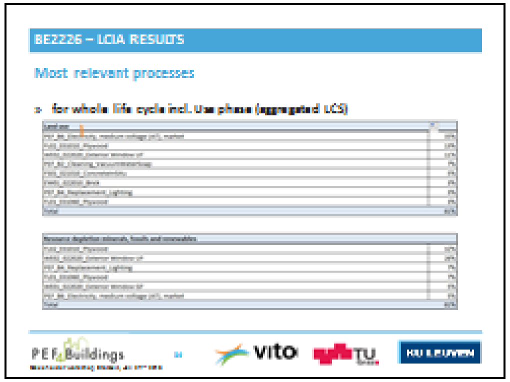
BE2226 – LCIA RESULTS
Most relevant processes
for whole life cycle incl. Use phase (aggregated LCS)
PEF4Buildings
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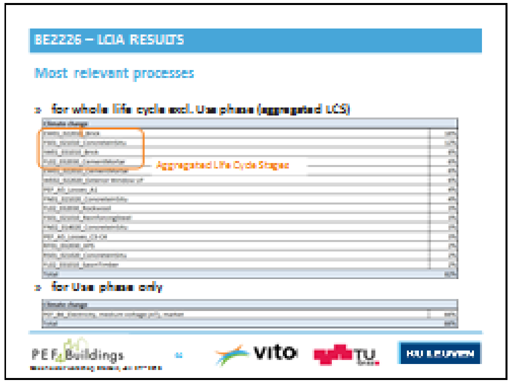
BE2226 – LCIA RESULTS
Most relevant processes
for whole life cycle excl. Use phase (aggregated LCS)
Aggregated Life Cycle Stages
for Use phase only
PEF4Buildings
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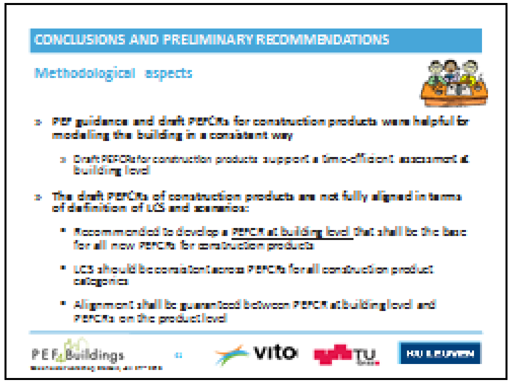
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
PEF guidance and draft PEFCRs for construction products were helpful for modeling the building in a consistent way
Draft PEFCRs for construction products support a time-efficient assessment at building level
The draft PEFCRs of construction products are not fully aligned in terms of definition of LCS and scenarios:
Recommended to develop a PEFCR at building level that shall be the base for all new PEFCRs for construction products
LCS should be consistent across PEFCRs for all construction product categories
Alignment shall be guaranteed between PEFCR at building level and PEFCRs on the product level
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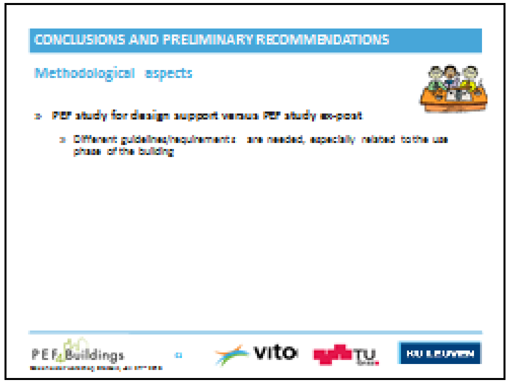
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
PEF study for design support versus PEF study ex-post
Different guidelines/requirements are needed, especially related to the use phase of the building
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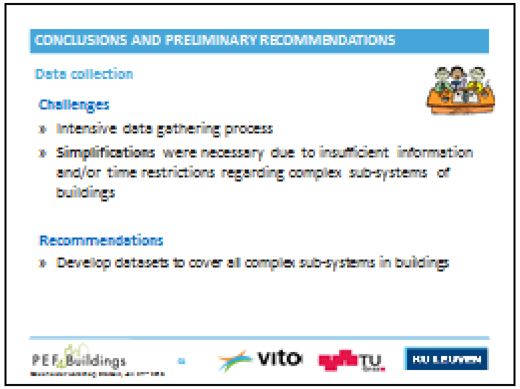
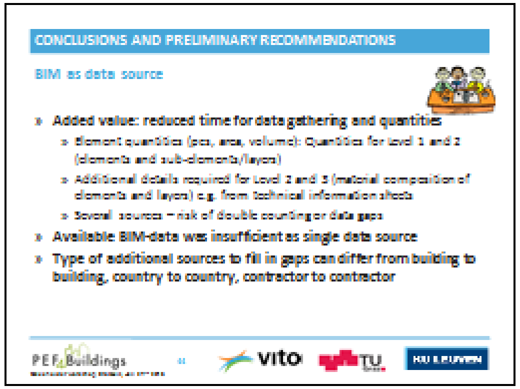
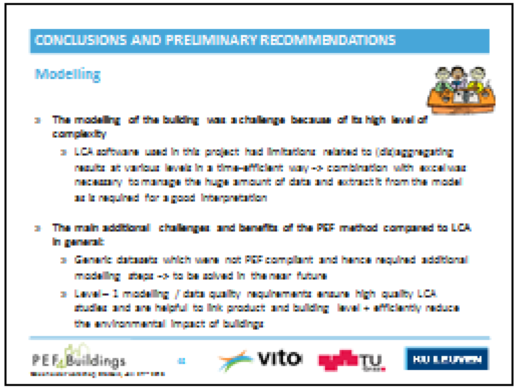

CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Data collection
Challenges
Intensive data gathering process
Simplifications were necessary due to insufficient information and/or time restrictions regarding complex sub-systems of buildings
Recommendations
Develop datasets to cover all complex sub-systems in buildings


CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
BIM as data source
Added value: reduced time for data gathering and quantities
Element quantities (pcs, area, volume): Quantities for Level 1 and 2 (elements and sub-elements/layers)
Additional details required for Level 2 and 3 (material composition of elements and layers) e.g. from technical information sheets
Several sources – risk of double counting or data gaps
Available BIM-data was insufficient as single data source
Type of additional sources to fill in gaps can differ from building to building, country to country, contractor to contractor


CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Modelling
The modelling of the building was a challenge because of its high level of complexity
LCA software used in this project had limitations related to (dis)aggregating results at various levels in a time-efficient way -> combination with excel was necessary to manage the huge amount of data and extract it from the model as is required for a good interpretation
The main additional challenges and benefits of the PEF method compared to LCA in general:
Generic datasets which were not PEF compliant and hence required additional modelling steps -> to be solved in the near future
Level – 1 modelling / data quality requirements ensure high quality LCA studies and are helpful to link product and building level + efficiently reduce the environmental impact of buildings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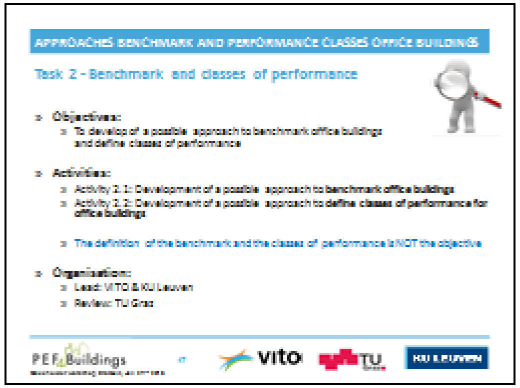
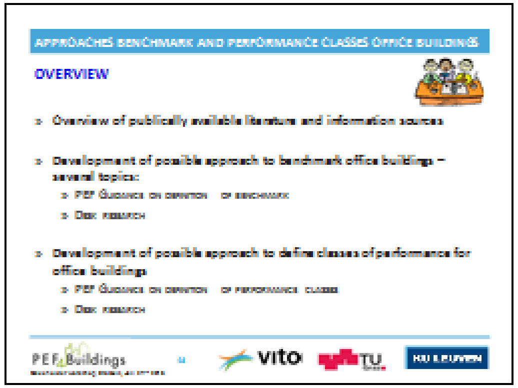
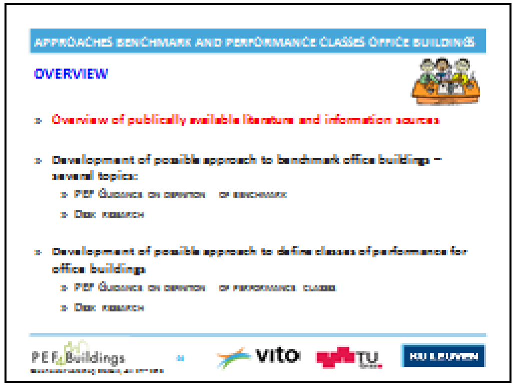

APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Task 2 - Benchmark and classes of performance
Objectives:
To develop of a possible approach to benchmark office buildings and define classes of performance
Activities:
Activity 2.1: Development of a possible approach to benchmark office buildings
Activity 2.2: Development of a possible approach to define classes of performance for office buildings
The definition of the benchmark and the classes of performance is NOT the objective
Organisation:
Lead: VITO & KU Leuven
Review: TU Graz


APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
PEF Guidance on definition of benchmark
Desk research
Development of possible approach to define classes of performance for office buildings
PEF Guidance on definition of performance classes
Desk research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Development of possible approach to define classes of performance for office buildings
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
General methodological reports
1. VTT report - Sustainability and performance assessment and benchmarking of buildings
2. BPIE report - EUROPE'S BUILDINGS UNDER THE MICROSCOPE, A country-by-country review of the energy performance of buildings
3. Intelligent Energy Europe: TABULA and EPISCOPE reports
4. SBP - Sustainability Benchmarking Toolkit for Commercial Buildings
5. UN-Habitat - Building sustainability assessment and benchmarking – an Introduction
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
National Sustainability Certification Schemes / LCA methods for Buildings
1. Ganassali et al. (2016) - LCA benchmarks in building's environmental certification systems
2. German building certification system of DGNB
3. German assessment system for sustainable building (BNB) for public offices and administration buildings
4. Belgian MMG – Material based environmental profiles of building elements
5. Belgian GRO
National Benchmarking Approaches
1. Dutch legal requirements GPR
2. French Initiative - Towards positive energy and low carbon buildings - The French Experimentation for new buildings
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
European Sustainable Building Assessment Methods / Green Public Procurement
1. Level(s): building sustainability performance
2. EN 15978
3. EC - Green Public Procurement Criteria for Office Building Design, Construction and Management
4. Draft PCR 2.0 for open consultation (from Int. EPD programme)
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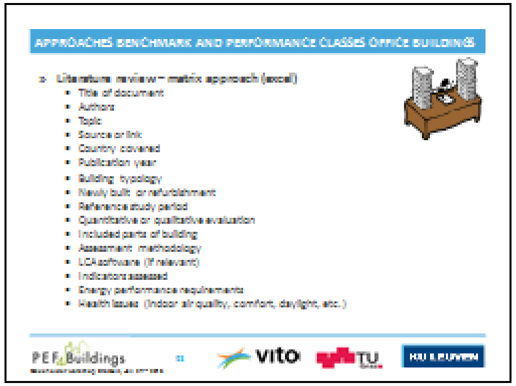
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Literature review – matrix approach (excel)
Title of document
Authors
Topic
Source or link
Country covered
Publication year
Building typology
Newly built or refurbishment
Reference study period
Quantitative or qualitative evaluation
Included parts of building
Assessment methodology
LCA software (if relevant)
Indicators assessed
Energy performance requirements
Health issues (indoor air quality, comfort, daylight, etc.)
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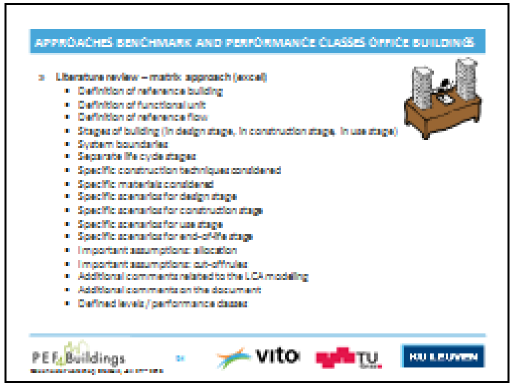
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Literature review – matrix approach (excel)
Definition of reference building
Definition of functional unit
Definition of reference flow
Stages of building (in design stage, in construction stage, in use stage)
System boundaries
Separate life cycle stages
Specific construction techniques considered
Specific materials considered
Specific scenarios for design stage
Specific scenarios for construction stage
Specific scenarios for use stage
Specific scenarios for end-of-life stage
Important assumptions: allocation
Important assumptions: cut-off rules
Additional comments related to the LCA modelling
Additional comments on the document
Defined levels / performance classes
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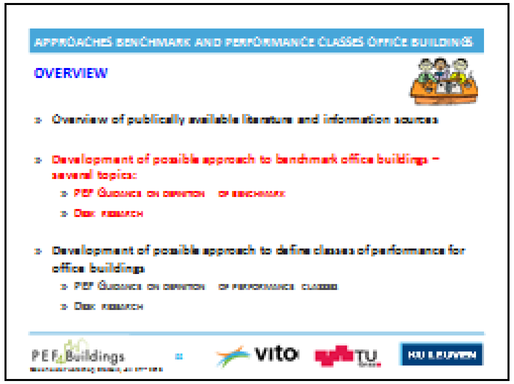
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PEF Guidance on definition of benchmark
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PEF Guidance on definition of performance classes
Desk research
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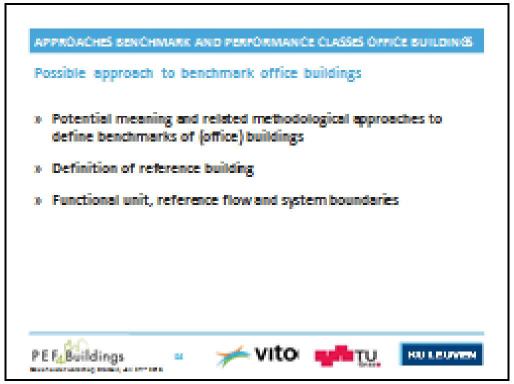
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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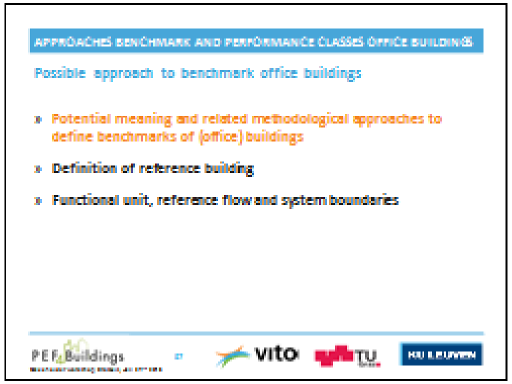
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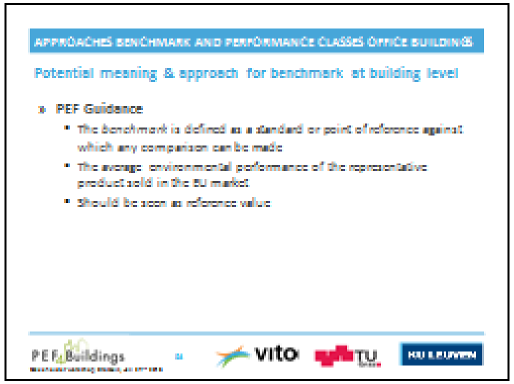
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
PEF Guidance
The benchmark is defined as a standard or point of reference against which any comparison can be made
The average environmental performance of the representative product sold in the EU market
Should be seen as reference value
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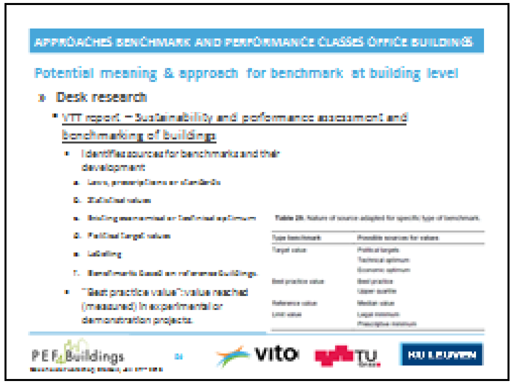
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
VTT report – Sustainability and performance assessment and benchmarking of buildings
Identifies sources for benchmarks and their development
"Best practice value": value reached (measured) in experimental or demonstration projects
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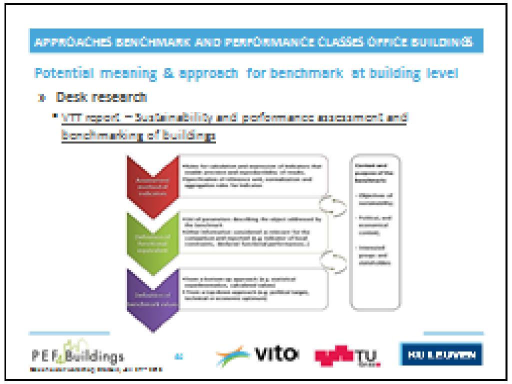
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VTT report – Sustainability and performance assessment and benchmarking of buildings
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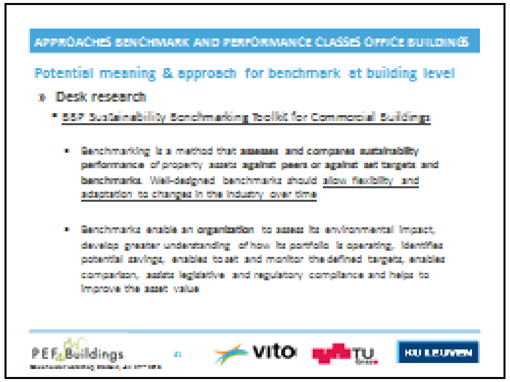
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
BBP Sustainability Benchmarking Toolkit for Commercial Buildings
Benchmarking is a method that assesses and compares sustainability performance of property assets against peers or against set targets and benchmarks. Well-designed benchmarks should allow flexibility and adaptation to changes in the industry over time
Benchmarks enable an organization to assess its environmental impact, develop greater understanding of how its portfolio is operating, identifies potential savings, enables to set and monitor the defined targets, enables comparison, assists legislative and regulatory compliance and helps to improve the asset value
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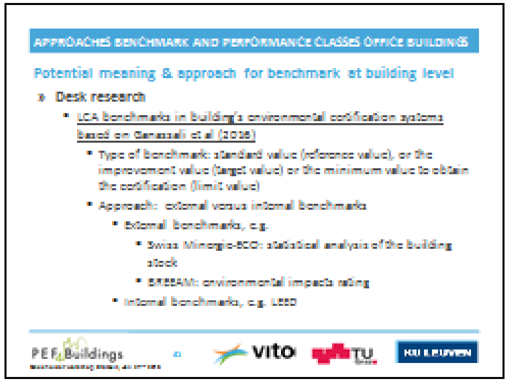
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
LCA Benchmarks in building's environmental certification systems based on Ganassali et al (2016)
Type of benchmark: standard value (reference value), or the improvement value (target value) or the minimum value to obtain the certification (limit value)
Approach: external versus internal benchmarks
External benchmarks, e.g.
Swiss Minergie-ECO: statistical analysis of the building stock
BREEAM: environmental impacts rating
Internal benchmarks, e.g. LEED
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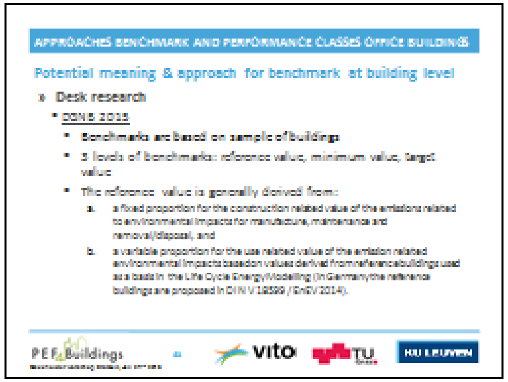
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
DGNB 2015
Benchmarks are based on sample of buildings
3 levels of benchmarks: reference value, minimum value, target value
The reference value is generally derived from:
a. a fixed proportion for the construction related value of the emissions related to environmental impacts for manufacture, maintenance and removal/disposal, and
b. a variable proportion for the use related value of the emission related environmental impacts based on values derived from reference buildings used as a basis in the Life Cycle Energy Modelling (In Germany the reference buildings are proposed in DIN V 18599 / EnEV 2014).
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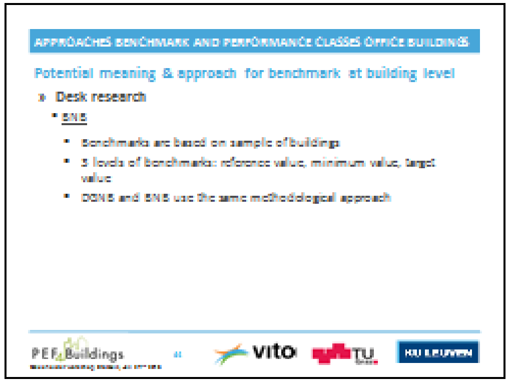
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
BNB
Benchmarks are based on sample of buildings
3 levels of benchmarks: reference value, minimum value, target value
DGNB and BNB use the same methodological approach
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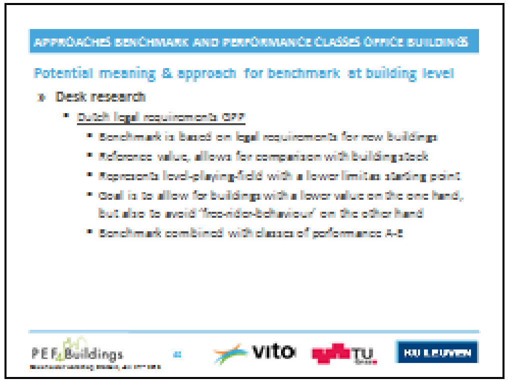
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
Dutch legal requirements GPP
Benchmark is based on legal requirements for new buildings
Reference value, allows for comparison with building stock
Represents level-playing-field with a lower limit as starting point
Goal is to allow for buildings with a lower value on the one hand, but also to avoid 'free-rider-behaviour' on the other hand
Benchmark combined with classes of performance A-E
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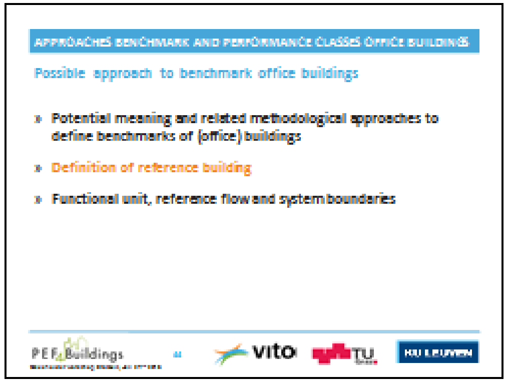
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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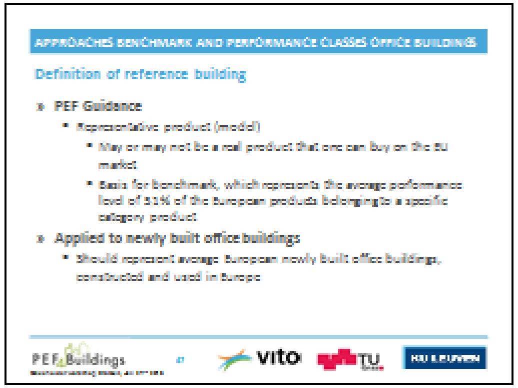
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
PEF Guidance
Representative product (model)
May or may not be a real product that one can buy on the EU market
Basis for benchmark, which represents the average performance level of 51% of the European products belonging to a specific category product
Applied to newly built office buildings
Should represent average European newly built office buildings, constructed and used in Europe
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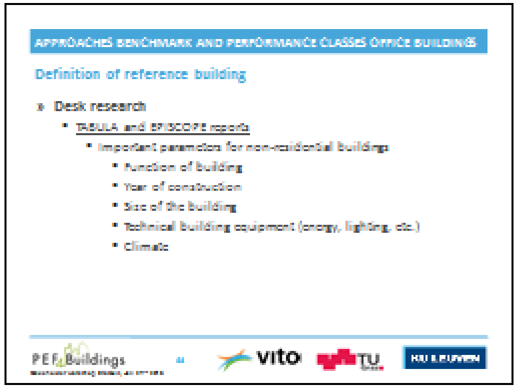
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
TABULA and EPISCOPE reports
Important parameters for non-residential buildings
Function of building
Year of construction
Size of the building
Technical building equipment (energy, lighting, etc.)
Climate
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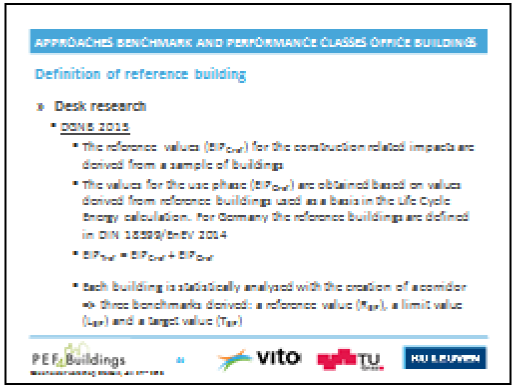
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
The reference values for the construction related impacts are derived from a sample of buildings
The values for the use phase are obtained based on values derived from reference buildings used as a basis in the Life Cycle Energy calculation. For Germany the reference buildings are defined in DIN 18599/EnEV 2014
Each building is statistically analysed with the creation of a corridor
=> three benchmarks derived: a reference value, a limit value and a target value
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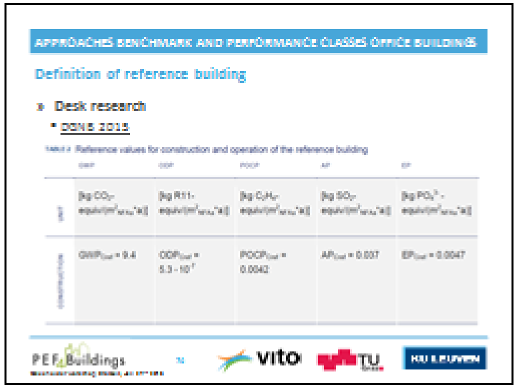
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Reference values for construction and operation of the reference building
GWP
ODP
POCP
AP
EP
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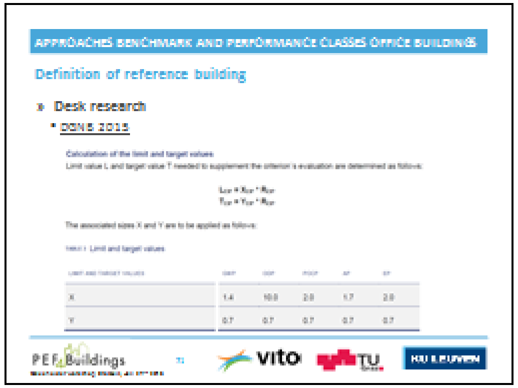
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Calculation of the limit and target values
Limit and target values
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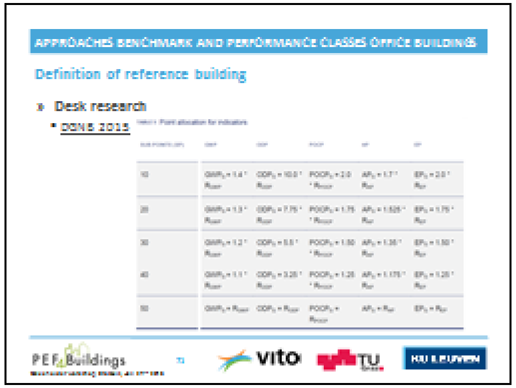
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Point allocation for indicators
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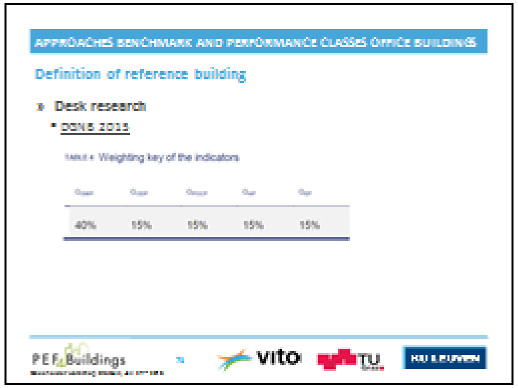
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Weighting key of the indicators
40%
15%
15%
15%
15%
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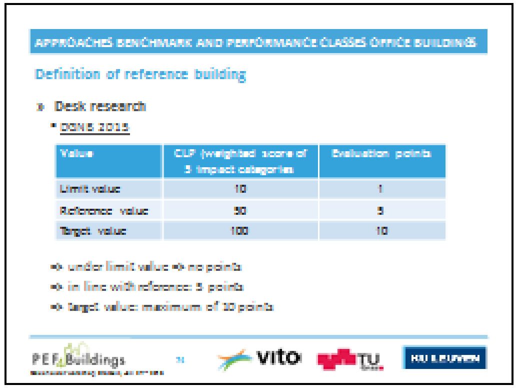
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Value
CLP (weighted score of 5 impact categories
Evaluation points
Limit value
10
1
Reference value
50
5
Target value
100
10
=> under limit value => no points
=> in line with reference: 5 points
=> target value: maximum of 10 points
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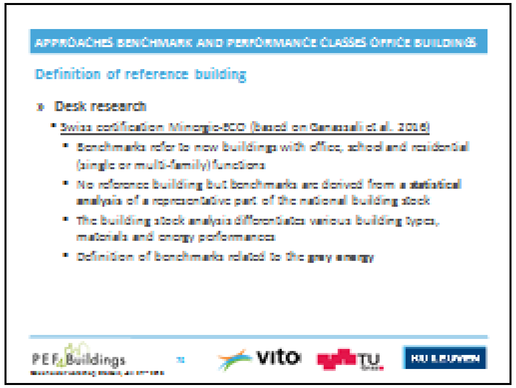
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO (based on Ganassali et al. 2016)
Benchmarks refer to new buildings with office, school and residential (single or multi-family) functions
No reference building but benchmarks are derived from a statistical analysis of a representative part of the national building stock
The building stock analysis differentiates various building types, materials and energy performances
Definition of benchmarks related to the gray energy
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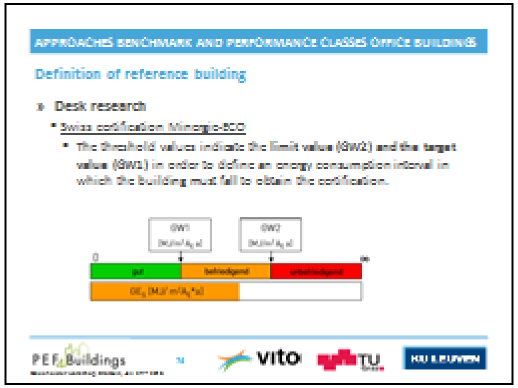
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO
The threshold values indicate the limit value (GW2) and the target value (GW1) in order to define an energy consumption interval in which the building must fall to obtain the certification.
GW1
GW2
0
gut
befriedigend
unbefriedigend
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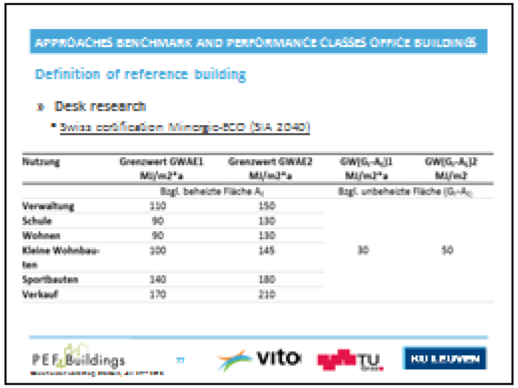
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO (SIA 2040)
Nutzung
Grenzwert GWAE1 MJ/m2*a
Grenzwert GWAE2 MJ/m2*a
Bzgl. beheizte Fläche
Bzgl. unbeheizte Fläche
Verwaltung 110 150
Schule 90 130
Wohnen 90 130
Kleine Wohnbauten 100 145
Sportbauten 140 180
Verkauf 170 210
30
50
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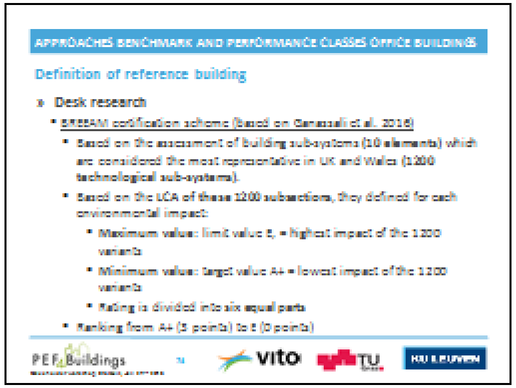
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
BREEAM certification scheme (based on Ganassali et al. 2016)
Based on the assessment of building sub-systems (10 elements) which are considered the most representative in UK and Wales (1200 technological sub-systems).
Based on the LCA of these 1200 subsections, they defined for each environmental impact:
Maximum value: limit value E, = highest impact of the 1200 variants
Minimum value: target value A+ = lowest impact of the 1200 variants
Rating is divided into six equal parts
Ranking from A+ (3 points) to E (0 points)
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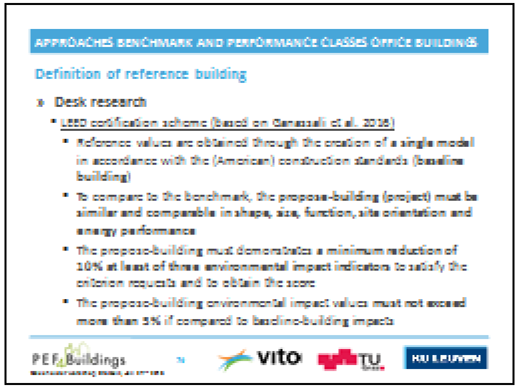
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
LEED certification scheme (based on Ganassali et al. 2016)
Reference values are obtained through the creation of a single model in accordance with the (American) construction standards (baseline building)
To compare to the benchmark, the propose-building (project) must be similar and comparable in shape, size, function, site orientation and energy performance
The propose-building must demonstrate a minimum reduction of 10% at least of three environmental impact indicators to satisfy the criterion requests and to obtain the score
The propose-building environmental impact values must not exceed more than 5% if compared to baseline-building impacts
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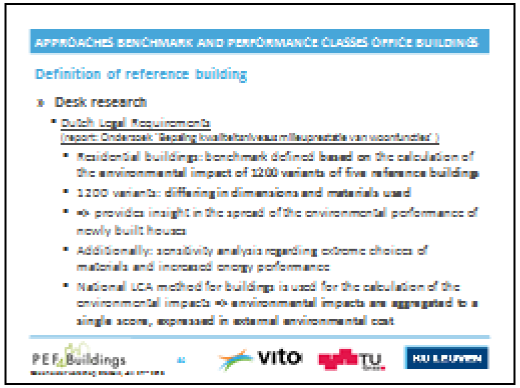
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Dutch Legal Requirements
(report: Onderzoek 'Bepaling kwaliteitsniveau milieuprestatie van woonfuncties')
Residential buildings: benchmark defined based on the calculation of the environmental impact of 1200 variants of five reference buildings
1200 variants: differing in dimensions and materials used
=> provides insight in the spread of the environmental performance of newly built houses
Additionally: sensitivity analysis regarding extreme choices of materials and increased energy performance
National LCA method for buildings is used for the calculation of the environmental impacts => environmental impacts are aggregated to a single score, expressed in external environmental cost
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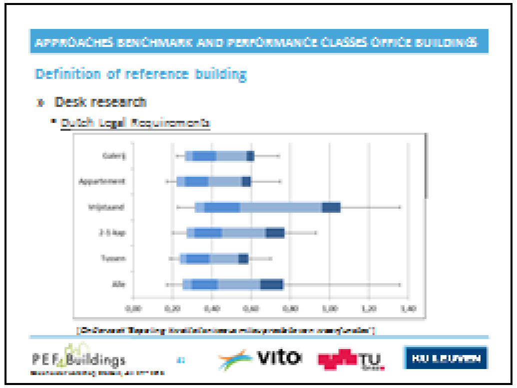
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Dutch Legal Requirements
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
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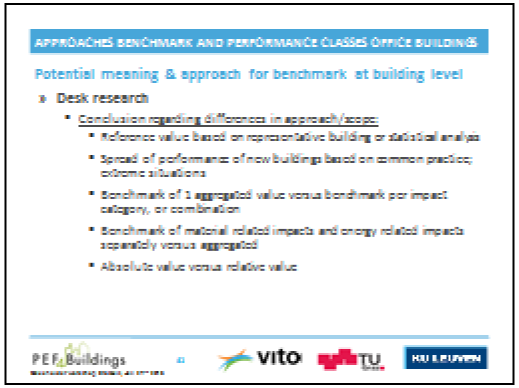
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
Conclusion regarding differences in approach/scope:
Reference value based on representative building or statistical analysis
Spread of performance of new buildings based on common practice; extreme situations
Benchmark of 1 aggregated value versus benchmark per impact category, or combination
Benchmark of material related impacts and energy related impacts separately versus aggregated
Absolute value versus relative value
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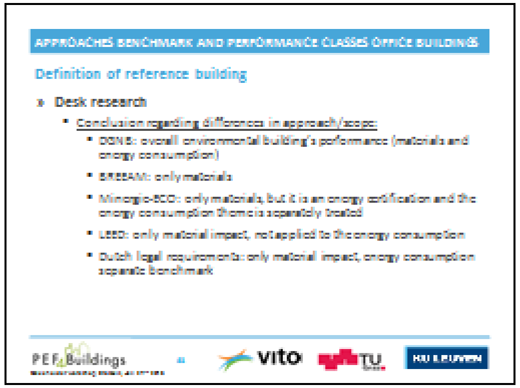
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Conclusion regarding differences in approach/scope:
DGNB: overall environmental building's performance (materials and energy consumption)
BREEAM: only materials
Minergie-ECO: only materials, but it is an energy certification and the energy consumption theme is separately treated
LEED: only material impact, not applied to the energy consumption
Dutch legal requirements: only material impact, energy consumption separate benchmark
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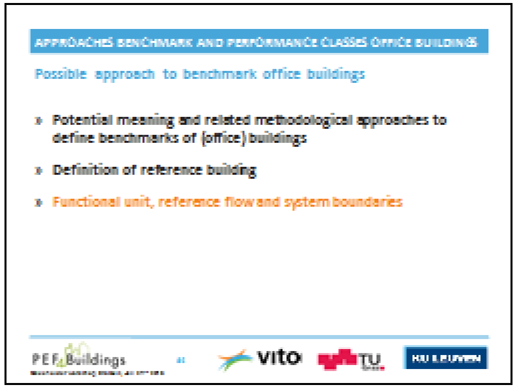
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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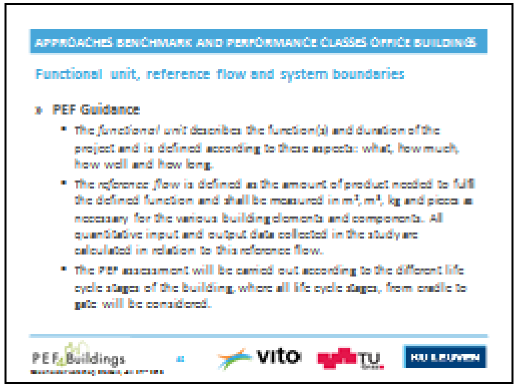
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
PEF Guidance
The functional unit describes the function(s) and duration of the project and is defined according to these aspects: what, how much, how well and how long.
The reference flow is defined as the amount of product needed to fulfil the defined function and shall be measured in m², m³, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.
The PEF assessment will be carried out according to the different life cycle stages of the building, where all life cycle stages, from cradle to gate will be considered.
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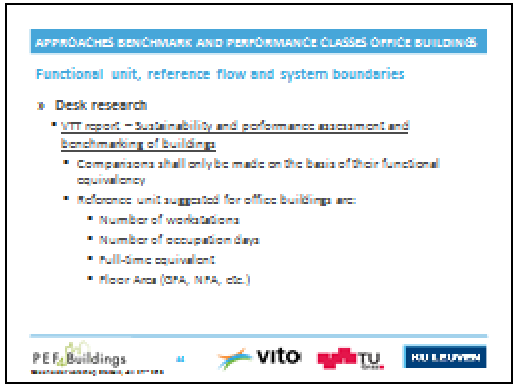
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
VTT report – Sustainability and performance assessment and benchmarking of buildings
Comparisons shall only be made on the basis of their functional equivalency
Reference unit suggested for office buildings are:
Number of workstations
Number of occupation days
Full-time equivalent
Floor Area (GFA, NFA, etc.)
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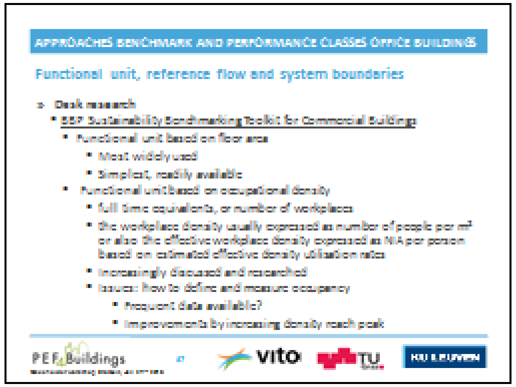
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
BBP Sustainability Benchmarking Toolkit for Commercial Buildings
Functional unit based on floor area
Most widely used
Simplest, readily available
Functional unit based on occupational density
full time equivalents, or number of workplaces
the workplace density usually expressed as number of people per m² or also the effective workplace density expressed as NIA per person based on estimated effective density utilisation rates
Increasingly discussed and researched
Issues: how to define and measure occupancy
Frequent data available?
Improvements by increasing density reach peak
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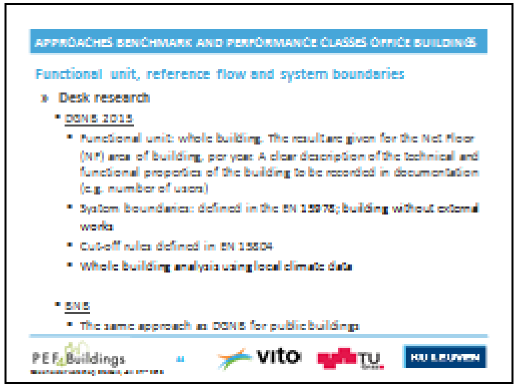
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
DGNB 2015
Functional unit: whole building. The results are given for the Net Floor (NF) area of building, per year. A clear description of the technical and functional properties of the building to be recorded in documentation (e.g. number of users)
System boundaries: defined in the EN 15978; building without external works
Cut-off rules defined in EN 15804
Whole building analysis using local climatic data
BNB
The same approach as DGNB for public buildings
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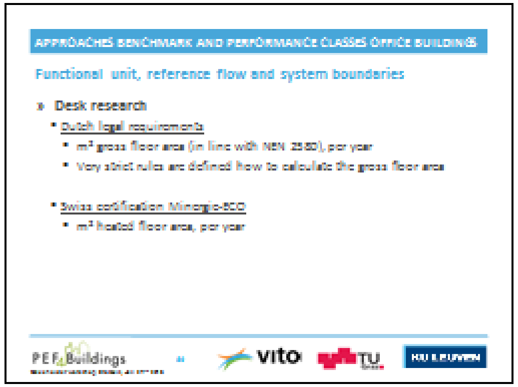
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
Dutch legal requirements
m² gross floor area (in line with NEN 2580), per year
Very strict rules are defined how to calculate the gross floor area
Swiss certification Minergie-ECO
m² heated floor area, per year
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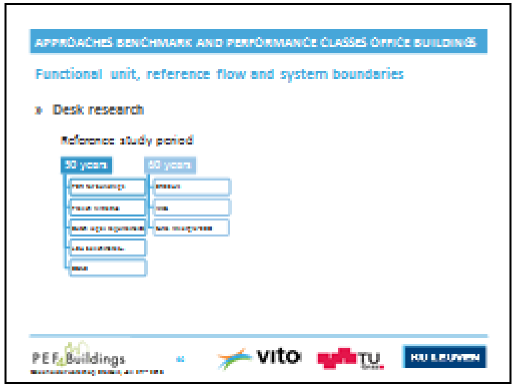
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
Reference study period
50 years
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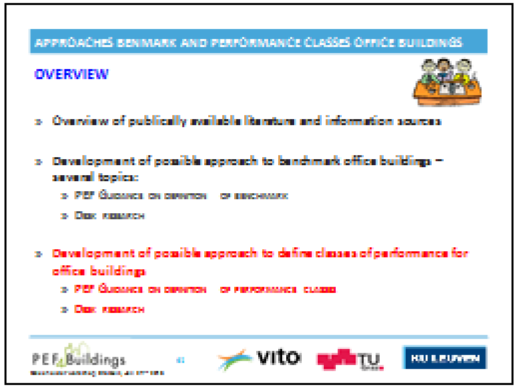
APPROACHES BENMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
PEF Guidance on definition of benchmark
Desk research
Development of possible approach to define classes of performance for office buildings
PEF Guidance on definition of performance classes
Desk research
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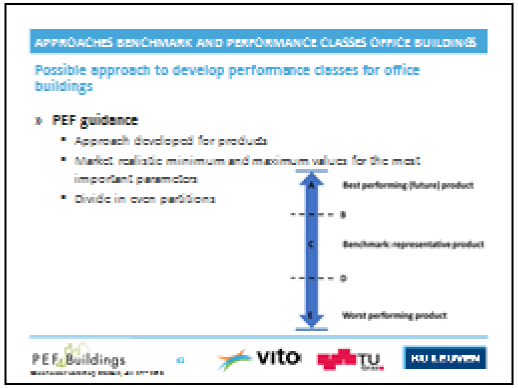
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
PEF guidance
Approach developed for products
Market realistic minimum and maximum values for the most important parameters
Divide in even partitions
Best performing (future) product
Benchmark representative product
Worst performing product
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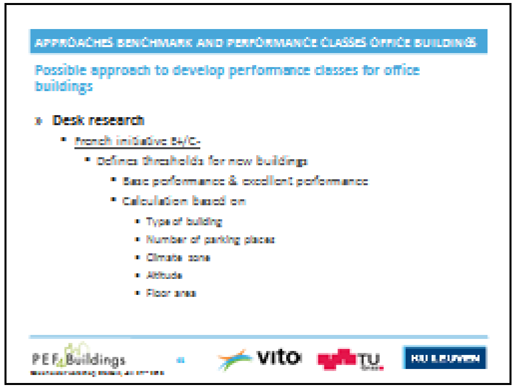
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
French initiative E+/C-
Defines thresholds for new buildings
Basic performance & excellent performance
Calculation based on
Type of building
Number of parking places
Climate zone
Altitude
Floor area
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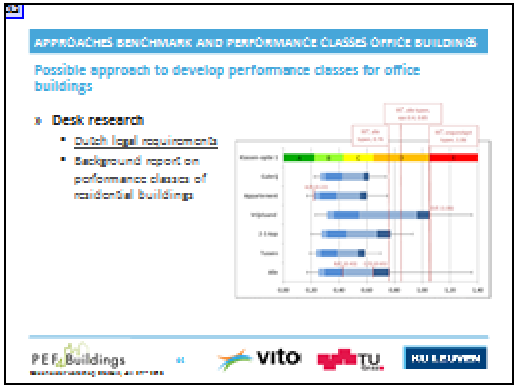
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
Dutch legal requirements
Background report on performance classes of residential buildings
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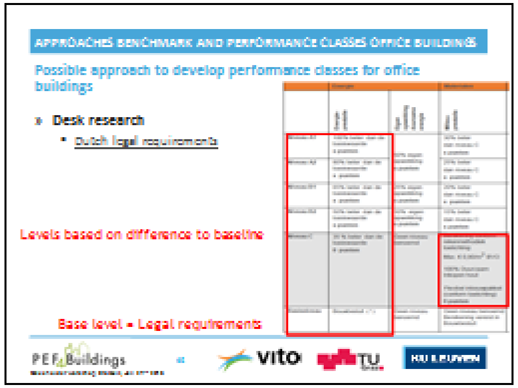
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
Dutch legal requirements
Levels based on difference to baseline
Base level = Legal requirements
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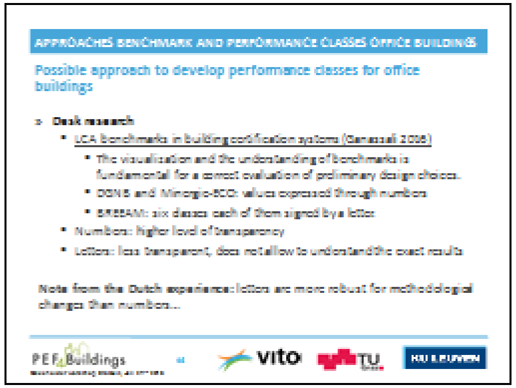
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
LCA Benchmarks in building certification systems (Ganassali 2016)
The visualization and the understanding of benchmarks is fundamental for a correct evaluation of preliminary design choices.
DGNB and Minergie-ECO: values expressed through numbers
BREEAM: six classes each of them signed by a letter
Numbers: higher level of transparency
Letters: less transparent, does not allow to understand the exact results
Note from the Dutch experience: letters are more robust for methodological changes than numbers…
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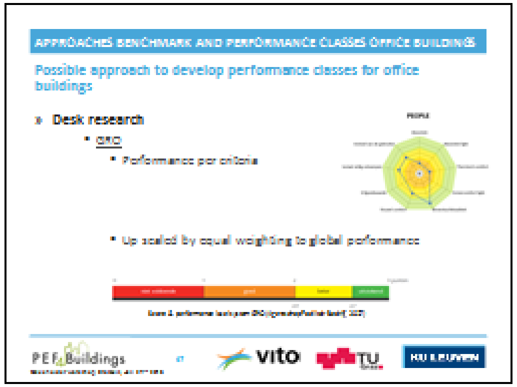
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
GRO
Performance per criteria
Up scaled by equal weighting to global performance
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AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 1: Reference building/benchmark
How to define reference buildings?
Question 1
Most projects are national, also the European/international projects we looked at differentiate buildings per country
Do we need (a) reference building(s)/benchmark per country, or per climate zone?
Could a geometry/layout be defined over Europe? Or do we need multiple geometries/layouts over Europe?
On which information should we base the definition of a reference building: statistical data?
How to deal with different construction techniques and different materials?
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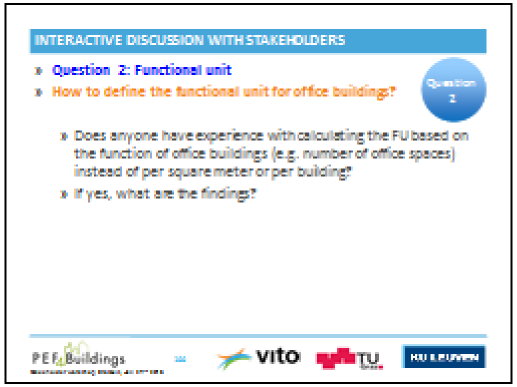
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 2: Functional unit
How to define the functional unit for office buildings?
Question 2
Does anyone have experience with calculating the FU based on the function of office buildings (e.g. number of office spaces) instead of per square meter or per building?
If yes, what are the findings?
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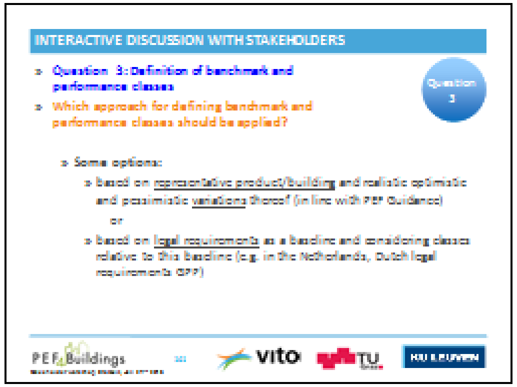
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 3: Definition of benchmark and performance classes
Which approach for defining benchmark and performance classes should be applied?
Question 3
Some options:
based on representative product/building and realistic optimistic and pessimistic variations thereof (in line with PEF Guidance)
or
based on legal requirements as a baseline and considering classes relative to this baseline (e.g. in the Netherlands, Dutch legal requirements GPP)
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INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 4: Reality check
How to perform reality check?
Question 4
The estimated environmental impacts as calculated in the design phase should be reflected by a reality check after the building is constructed and used.
How can this be achieved?
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AGENDA FOR STAKEHOLDER'S WORKSHOP
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LUNCH BREAK
TIME FOR LUNCH
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AGENDA FOR STAKEHOLDER'S WORKSHOP
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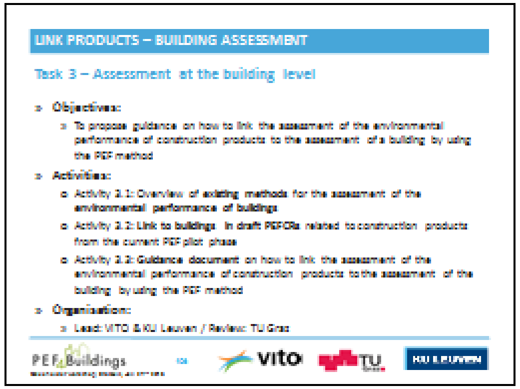
LINK PRODUCTS – BUILDING ASSESSMENT
Task 3 – Assessment at the building level
Objectives:
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method
Activities:
Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings
Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Organisation:
Lead: VITO & KU Leuven / Review: TU Graz
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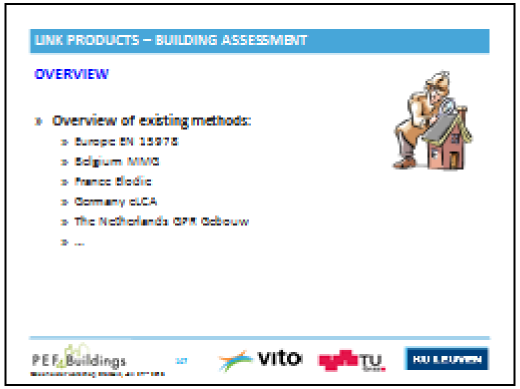
LINK PRODUCTS – BUILDING ASSESSMENT
OVERVIEW
Overview of existing methods:
Europe EN 15978
Belgium MMG
France Elodie
Germany eLCA
The Netherlands GPR Gebouw
...
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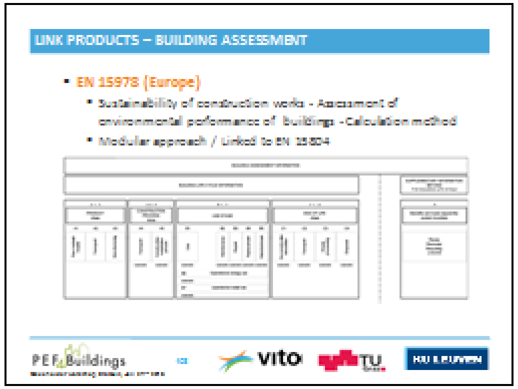
LINK PRODUCTS – BUILDING ASSESSMENT
EN 15978 (Europe)
Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method
Modular approach / Linked to EN 15804
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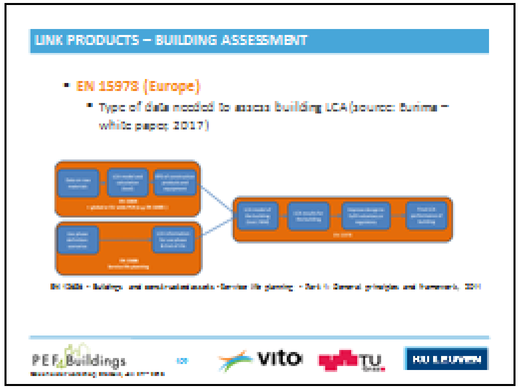
LINK PRODUCTS – BUILDING ASSESSMENT
EN 15978 (Europe)
Type of data needed to assess building LCA (source: Eurima – white paper, 2017)
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LINK PRODUCTS – BUILDING ASSESSMENT
MMG (Belgium)
Transparent methodology / assessment framework
Publications available on:
Broad environmental perspective
More than the 14 environmental impact categories
Based on existing frameworks
EN 15804, EN 15978, PEF Guide, ILCD Handbook
Applicable for the Belgian construction sector
Elements in line with the Belgian construction practices
In development (expected second half of 2018): inclusion of specific environmental profiles/ EPDs from the Belgian Federal EPD-database
To have an user-friendly tool
In development (expected in coming months): web based calculation tool
For architects (among others) to make them more aware of the environmental impact of their design choices
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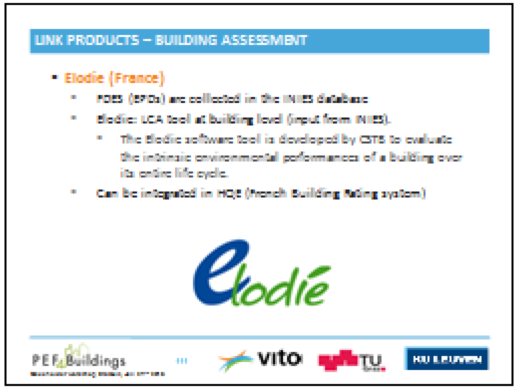
LINK PRODUCTS – BUILDING ASSESSMENT
Elodie (France)
FDES (EPDs) are collected in the INIES database
Elodie: LCA tool at building level (input from INIES).
The Elodie software tool is developed by CSTB to evaluate the intrinsic environmental performances of a building over its entire life cycle.
Can be integrated in HQE (French Building Rating system)
Elodié
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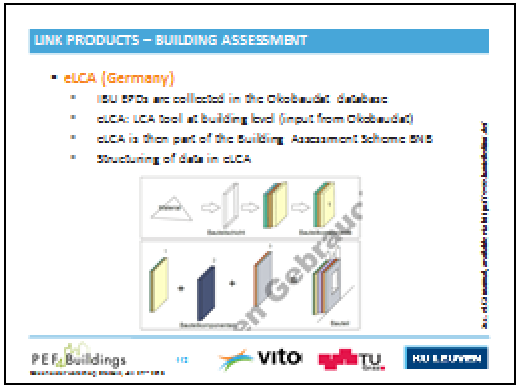
LINK PRODUCTS – BUILDING ASSESSMENT
eLCA (Germany)
IBU EPDs are collected in the Okobaudat database
eLCA: LCA tool at building level (input from Okobaudat)
eLCA is then part of the Building Assessment Scheme BNB
Structuring of data in eLCA
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LINK PRODUCTS – BUILDING ASSESSMENT
GPR Gebouw (the Netherlands)
Data are collected in the NMD database (Dutch National Environmental Database)
GPR Gebouw: LCA tool at building level (input from NMD)
GPR GEBOUW
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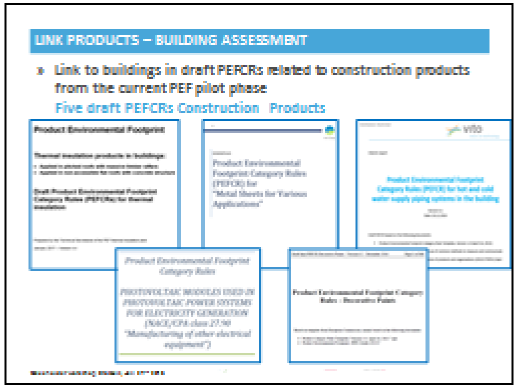
LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Five draft PEFCRs Construction Products
Product Environmental Footprint
Thermal insulation products in buildings
Draft Product Environmental Footprint Category Rules (PEFCRs) for thermal insulation
Product Environmental Footprint Category Rules (PEFCR) for "Metal Sheets for Various Applications"
Product Environmental Footprint Category Rules (PEFCR) for hot and cold water supply piping systems in the building
Product Environmental Footprint Category Rules
PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION (NACE/CPA class 27.90 "Manufacturing of other electrical equipment")
Product Environmental Footprint Category Rules : Decorative Paints


LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Product level with clear link to building level:
Piping systems: for 5-storey apartment building for 50 years (can be adjusted)
Insulation materials: 1 m² for 50 years (building)
Paints: 1 m² for 50 years (building)
Metal sheets: 1 m² (upscalable to building level – scenarios use phase to be added)
To be included in use phase of building: equipment energy:
Photovoltaic module: 1 kWh
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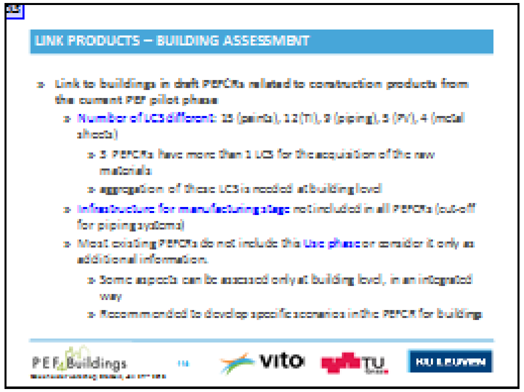
LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Number of LCS different: 15 (paints), 12 (TI), 9 (piping), 5 (PV), 4 (metal sheets)
3 PEFCRs have more than 1 LCS for the acquisition of the raw materials
aggregation of these LCS is needed at building level
Infrastructure for manufacturing stage not included in all PEFCRs (cut-off for piping systems)
Most existing PEFCRs do not include the Use phase or consider it only as additional information.
Some aspects can be assessed only at building level, in an integrated way
Recommended to develop specific scenarios in the PEFCR for buildings
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LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
An overall scenario for dismantling/demolishing should be developed for the building level. At the moment for products only 2 PEFCRs include some basic scenarios
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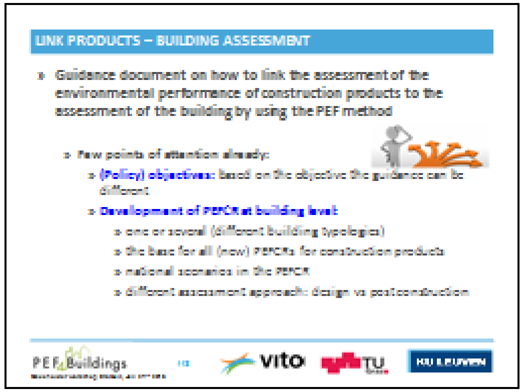
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
(Policy) objectives: based on the objective the guidance can be different
Development of PEFCR at building level:
one or several (different building typologies)
the base for all (new) PEFCRs for construction products
national scenarios in the PEFCR
different assessment approach: design vs postconstruction
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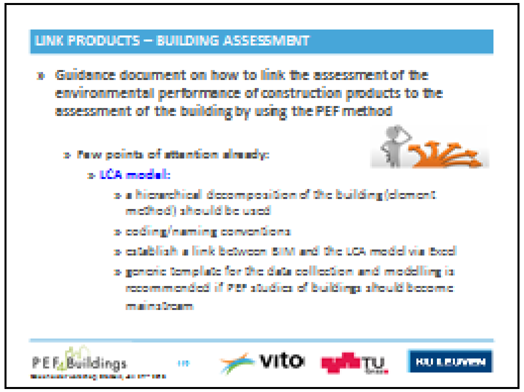
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
LCA model:
a hierarchical decomposition of the building (element method) should be used
coding/naming conventions
establish a link between BIM and the LCA model via Excel
generic template for the data collection and modelling is recommended if PEF studies of buildings should become mainstream
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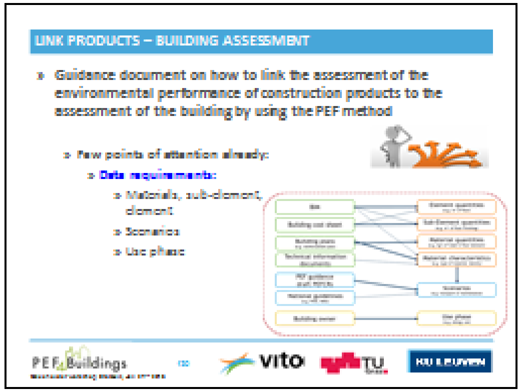
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Data requirements:
Materials, sub-element, element
Scenarios
Use phase
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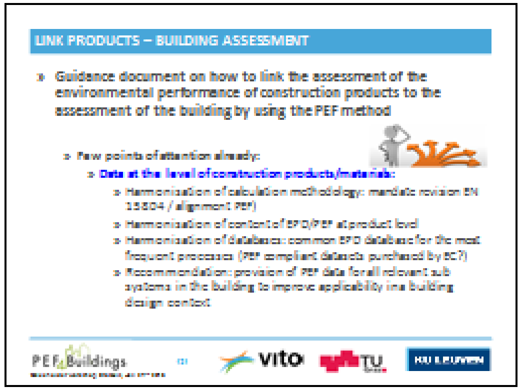
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Data at the level of construction products/materials:
Harmonisation of calculation methodology: mandate revision EN 15804 / alignment PEF)
Harmonisation of content of EPD/PEF at product level
Harmonisation of databases: common EPD database for the most frequent processes (PEF compliant datasets purchased by EC?)
Recommendation: provision of PEF data for all relevant sub systems in the building to improve applicability in a building design context
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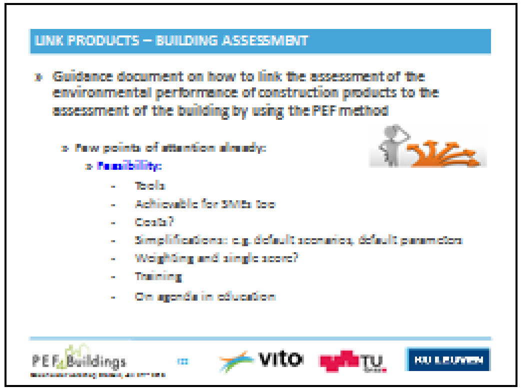
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Feasibility:
Tools
Achievable for SMEs too
Costs?
Simplifications: e.g. default scenarios, default parameters
Weighting and single score?
Training
On agenda in education
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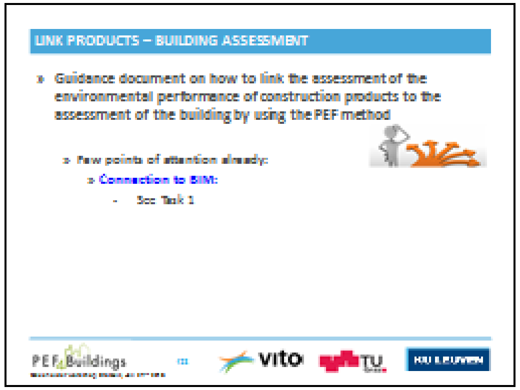
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Connection to BIM:
See Task 1
PEF4Buildings
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AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
PEF4Buildings
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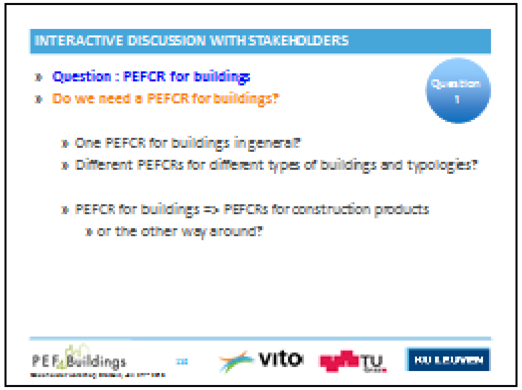
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question : PEFCR for buildings
Do we need a PEFCR for buildings?
Question 1
One PEFCR for buildings in general?
Different PEFCRs for different types of buildings and typologies?
PEFCR for buildings => PEFCRs for construction products
or the other way around?
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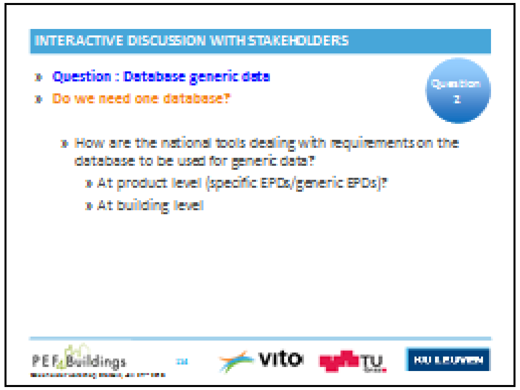
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question : Database generic data
Do we need one database?
Question 2
How are the national tools dealing with requirements on the database to be used for generic data?
At product level (specific EPDs/generic EPDs)?
At building level
PEF4Buildings
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PEF4Buildings


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PEF4Buildings

Client: European Commission
DG Environment
Dir B, Circular Economy and Green Growth
Unit B1, Sustainable Production, Products and Consumption

PEF4Buildings

Study on the Application of the PEF Method and related guidance documents to a newly office building (ENV.B.1/ETU/2016/0052LV)

Deliverable D6: Guidance document for the assessment at the building level

AUTHORS: VITO (BELGIUM), KU LEUVEN (BELGIUM) AND TU GRAZ (AUSTRIA)

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DISCLAIMER:

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LIST OF ACRONYMS

BIM	Building Information Model
CFF	Circular Footprint Formula
EC	European Commission
EPD	Environmental Product Declaration
GPP	Green Public Procurement
LCA	Life Cycle Assessment
PCR	Product Category Rules
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules

INTRODUCTION

This report is focussing on the **assessment at the building level**. This report will be integrated as an Annex to the final study report for this project for the European Commission (DG ENV).

The report is focussing on the **task 3** (Deliverable D6) of the contract No 07.0201/2016/746615/ETU/ENV.B.1 "Study on the application of the PEF method and related guidance documents of a new office building".

The aim of task 3 is to propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method. This analysis starts from the results achieved for the new office buildings from Task 1 but is extended to other possible typologies of buildings.

This project report on Deliverable D6 consists of 4 main chapters:

- Chapter 1 – Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings;
- Chapter 2 – Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase;
- Chapter 3 – Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method;
- Chapter 4 – Conclusions and recommendations.

CHAPTER 1 ACTIVITY 3.1: OVERVIEW OF EXISTING METHODS FOR THE ASSESSMENT OF THE ENVIRONMENTAL PERFORMANCE OF BUILDINGS

1.1. INTRODUCTION

There are several assessment methods available to analyse the environmental footprint or environmental performance at the building level. The aim of this activity is to make an overview of important assessment methods with specific focus on the links these assessment methods have with environmental product declarations for construction materials. The assessment methods that are briefly discussed and presented are:

- **Europe:** Harmonised European standards designed to assess the sustainability of construction works (CEN/TC 350), with main focus on the EN 15643-2: 2011 (Framework for assessment of environmental performance of construction works), EN 15978: 2011 (Methodology for environmental assessment of buildings) in relation to EN 15804:2013 (Environmental Product Declarations);
- **Belgian context** with clear links to European framework: Material based environmental profiles of building elements (MMG) in combination with the Belgian EPD program (product environmental declarations);
- **French context** with clear links to European framework: Different softwares exist linked to the French EPDs “Fiches de Données Environnementales et Sanitaires (FDES)”;
- **German context** with clear links to European framework: both the BNB and the DGNB system are analysed;
- **Dutch context** with clear links to European framework: an Assessment Method for the Environmental Performance of Construction and Civil Engineering Works (GWW) in combination with the Dutch EPD program (product environmental declarations).

During activity 3.1 we made a SWOT analysis of the different methods in their current state of play, mainly in terms of pros and cons when linking the assessment at the level of the construction products to the building assessment.

1.2. OVERVIEW OF EXISTING METHODS

1.2.1. EUROPE (EN 15978)

The document EN 15978 provides the calculation method for the environmental performance assessment of new and existing buildings, developed within the framework of CEN TC 350 (CEN, 2011).

In order to make the assessment at the building level, input is needed at the levels of:

- The performance of the different materials (input from EN 15804 – core rules for the product category of construction products, 2013);
- Scenarios for the use and end-of-life phase (input from EN 15686 - Buildings and constructed assets -- Service life planning -- Part 1: General principles and framework, 2011).

The EN 15978 is built up according to a modular approach (see *Figure 1*). Thanks to its modular set up of the life cycle of the building to be studied, processes influencing the buiding's environmental performance during its life cycle shall be assigned to the module of the life cycle where they occur. EN 15978 defines 4 groups of modules:

- Module A (from A1 to A5) relating to the product stage and construction stage;
- Module B (from B1 to B7) relating to the use stage of the building;
- Module C (from C1 to C4) covering de-construction/demolition, transport to waste processing, waste processing (including incineration) and disposal (incl. landfilling);
- Module D covering benefits and loads beyond the system boundary related to reuse, recycling and (energy) recovery of the building products.

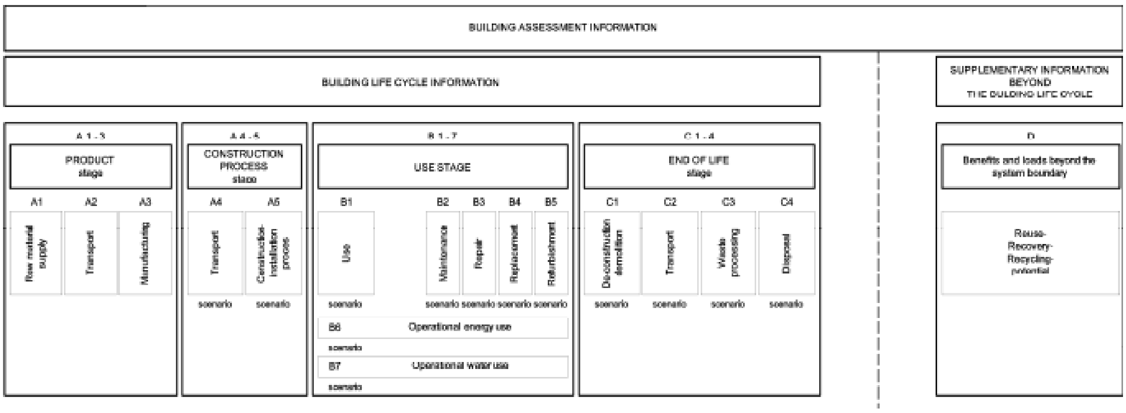

Figure 1: Modular approach EN 15978

Figure 2 present the type of data needed to assess the building LCA according to the EN 15978.

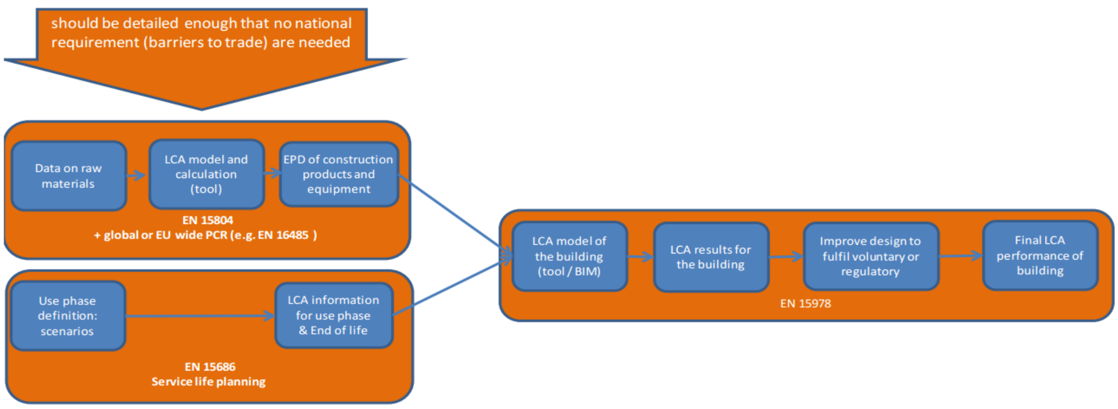

Figure 2: Type of data needed to assess building LCA (European Insulation Manufacturers Association (EURIMA), 2017)

Due to the new amendment of CEN TC 350 / EN 15804, the existing prescribed methods in EN 15804: 2012 + A1: 2013 will have to be aligned with PEF as much as possible (it should be ready in 2019). The EN 15978 will also be revised afterwards.

Expectations are that this revised EN 15978 will be an important framework for the future with regard to the assessment of the environmental performance of buildings and infrastructure.

In addition, the experiences of the PEF pilot phase have led to new insights and knowledge, so that the existing indicators and methods as published in the PEF method 2013 will be updated in the coming years (this should be ready in 2020).

1.2.2. BELGIUM (MMG / TOTEM)

There is no private EPD programme operator in Belgium. Instead, the Federal Public Administration of Health and Environment (FPS) has prepared a legislative document (Royal Decree) which lays down the rules for the uptake of specific EPDs in a federal database. Manufacturers are free to submit EPDs to this national database. Besides this product-building approach, the Royal Decree also contains a measure against greenwashing. If a manufacturer decides to put an environmental claim on his product, he is obliged to make an EPD publically available in the national database from 2016 on (Federal Public Service (FPS), 2017). The Royal Decree refers to the EN 15804 yet includes an article that ensures that from 2017 on also module A4, C and D become mandatory, as well as the whole set of environmental indicators of the EC PEF method for reasons of having a robust set of indicators. The Belgian database for EPDs has been released mid-2017. The objective is to publish the EPDs online and to be able to use them directly in building LCA assessments.

The building LCA tool TOTEM (Tool to Optimise the Total Environmental impact of Materials) was launched in February 2018 (totem, 2018). This user-friendly web based calculation tool was developed mainly for architects, to allow them to make more conscious design choices by being able to compare the environmental impact of their (draft) building design and variations thereof. The tool is based on the Belgian Milieugerelateerde Materiaalprestaties van Gebouwelementen (MMG) method (Openbare Vlaamse Afvalstoffenmaatschappij (OVAM), 2013). The MMG method is published online and fully transparent, assesses more than 14 environmental impact categories and is based on EN 15804 and EN 15978 norms, the PEF Guide and the ILCD Handbook. Building elements are defined in line with Belgian construction practices and the inclusion of the Belgian Federal EPD-database into the totem tool is expected in the second half of 2018. This method is described in more detail in deliverable D4 of this project (VITO, KU Leuven, & TU Graz, 2018b).

1.2.3. FRANCE (E+C-)

In order to move from a thermal to an environmental regulation framework, the French law encourages new buildings to be low energy (positive energy buildings, E+) and low Carbon (C-). Low energy buildings are encouraged through focusing on the reduction of non-renewable energy consumption, the development of efficient solutions and the use of renewable energy, while low carbon buildings will be achieved through considering the whole life cycle of buildings and optimizing the balance between energy reductions and accompanying increased environmental burdens. A Methodology is developed for E+C- to calculate the cabon footprint of buildings (République française, 2017) and to define performance classes (République française, 2016). These are described in more detail in deliverable D4 of this project (VITO et al., 2018b).

Environmental Product Declarations (EPDs) are mandatory in France when manufacturers want to make an environmental claim. Those EPDs (also called “Fiches de Données Environnementales et

Sanitaires (FDES)" are collected in the INIES database and in the BDR database (Base de Données Réglementaires).

In France, currently 6 software packages are available that allow performing an LCA at the building level and are directly linked to the national EPD database INIES with FDES sheet. These are ClimaWin (BBS Slama), OneClick LCA (Bionova Ltd), ELODIE (CSTB), novaEQUER (IZUBA énergies), ThermACV (Logiciels PERRENOUD) and Béa (Bastide Bondoux) (République française, 2018). Elodie, for example, allows all EN 15804 environmental impact calculations using EPDs (FDES) as input data. Calculations are performed on all impacts which are part of EN15978.

1.2.4. GERMANY (BNB AND DGNB)

The German Sustainable Building Council (DGNB) together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) developed a voluntary certification system for sustainable buildings in 2007. The building certification system of DGNB is based on the CEN/TC350 approach.

During two years of co-operation between the Federal Ministry and the German Sustainable Building Council (DGNB), a first national catalogue of criteria was developed for an integrated analysis and assessment of sustainability aspects for buildings. The results were discussed with stakeholders from the construction sector by the "Round Table Sustainable Building" at the Federal Building Ministry and have been published since 2009 as the BNB (Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety (BMUB), 2014).

In Germany, the ÖKOBAUDAT[1] platform is provided as a standardized database by the Federal Ministry. The database offers both generic datasets and specific environmental declaration datasets from companies or associations. Data published in the database are publicly available at no charge and can be used for life cycle assessment of building components and buildings. The owner of the datasets remains responsible for the datasets (contents, values). In the ÖKOBAUDAT 2017-I (27.11.2017) – EN 15804 and BNB compliant data for more than 1000 different building products.

BNB

In 2011 Federal Ministry of Transport, Building and Urban Affairs (BMVBS) introduced the Guideline for Sustainable Building as a set of binding rules for the use of the Assessment System for Sustainable Building (BNB) for public buildings. The BNB is mandatory for federal construction works with a dedicated budget threshold. In addition, the Federal Building Ministry of Germany promoted the Assessment System for Sustainable Building (BNB) for public offices and administration buildings.
The method is described in more detail in deliverable D4 of this project (VITO et al., 2018b).

ÖKOBAUDAT (current version 2017-I from 27.11.2017) is the mandatory database for the BNB Assessment System and is utilized for the building LCA tool "eLCA", developed by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (Bundesinstituts für Bau-, Stadt- und Raumforschung, BBSR).

[1] http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/ oekobaudat.html

The workflow of the eLCA tool is illustrated in Figure 3.

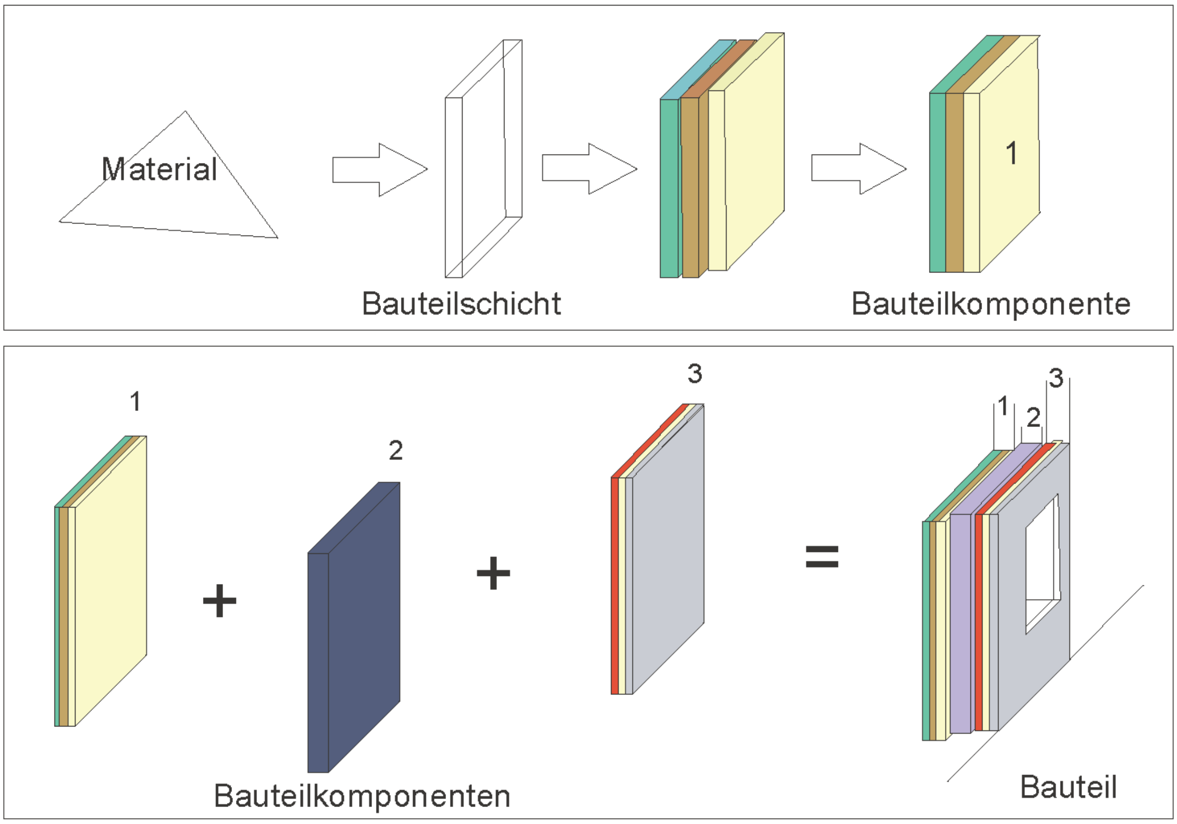

Figure 3: Structuring of the data inside the eLCA tool (Bundesinstitut für Bau- Stadt- und Raumforschung (BBSR), 2018)

DGNB

The focus of the application of the DGNB assessment systems are private buildings for different use types, such as Existing Buildings, New Construction (Educational Buildings, Offices, Healthcare Buildings, Retail Buildings, etc.), Districts or Interiors. In the DGNB method an explicit LCA calculation is mandatory, which is also based on the Okobaudat database. The method is described in more detail in deliverable D4 of this project (VITO et al., 2018b).

The goal of the environmental assessment is to quantify and document the environmental performance of the building under consideration by means of applying LCA methodology and to compare the results with a defined benchmark.

1.2.5. The Netherlands (GWW / GPR Gebouw)

In the Netherlands, an Assessment Method for the Environmental Performance of Construction and Civil Engineering Works (GWW) over their entire service life has been developed by Stichting Bouwkwaliteit (Stichting Bouwkwaliteit, 2014). This guideline is based on EN 15804, and by extension on EN 15978, although this last one is not followed explicitly. The method is described in more detail in deliverable D4 of this project (VITO et al., 2018b). Based on this method, the online calculation tool GPR Gebouw was developed.

Environmental data and EPDs are collected in the NMD database (the Dutch National Environmental Database), which are available in GPR Gebouw (GPR Gebouw, 2018). Another important advantage of GPR Gebouw is its integration with BREEAM-NL certification.

1.3. SWOT ANALYSIS

Table 1 shows the SWOT analysis of applying the various existing methods at the building level, based on the information described above.

Table 1: SWOT analysis of some existing methods at the building level

	Strengths	Weaknesses
EN 15978	• Designed at European level	• No tool available • Requires LCA knowledge • Still room for interpretation
MMG / TOTEM	• Very relevant due to design at national level • User-friendly tool, requires not much LCA knowledge • Scenarios in line with horizontal Belgian PCR (based on EN 15804, EN 15978)	• Not as relevant in other countries • Circularity is not included yet
E+C-	• Very relevant due to design at national level • User-friendly tools exist, requires not much LCA knowledge	• Not as relevant in other countries
BNB / eLCA	• Following the modular approach from CEN TC 350 • Very relevant due to design at national level • User-friendly tool, requires not much LCA knowledge • Predefinition of elements and use phase	• Not relevant for other countries or use types • “Black-box” tool • So far only “simplified” approach was applied; where e.g. HVAC-systems not included
DGNB / BNB	• Following the modular approach from CEN TC 350 • Very relevant due to design at national level in Germany • User-friendly tools available (SBS-online, etc.), requires not much LCA knowledge	• So far only “simplified” approach was applied; where e.g. HVAC-systems not included
GWW / GPR Gebouw	• Very relevant due to design at national level • User-friendly tool, requires not much LCA knowledge	• Not as relevant in other countries

	Opportunities	Threats
EN 15978	• To be used all over Europe • Implemented widely by the industry (manufacturers)	• Alignment needed with PEF
MMG / TOTEM	• Will be linked to national EPD database • Created for architects in design stage • Potential link with calculations on Energy Performance of Buildings (EPB) • Potential link with BIM software	• Possible difficulties including EPDs with different functional units
E+C-	• Is linked to national database (INIES) with FDES sheets • Easy link to FDES sheets because functional unit is defined per product group • Created for architects in design stage • Is linked to BIM models by EveBim	• Difficulties including EPDs with different functional units
BNB / eLCA	• Is linked to ÖKOBAUDAT database • Link with calculations on Energy Performance of Buildings (EPB) • Potential link with BIM software	• Builds on Gabi database
DGNB / SBS-online	• Is linked to ÖKOBAUDAT database • Link with calculations on Energy Performance of Buildings (EPB) • Potential link with BIM software	• Builds on Gabi database
GWW / GPR Gebouw	• Is linked to national EPD database (NMD) • Easy link to EPDs due to data coherence • Created for architects in design stage • Integrated in BREEAM-NL	• Update of the database maximally 2 times per year

1.4. Summary of main conclusions

National systems are very valuable since they usually take national PCRs into account and therefore have the highest potential of complying with the local realistic situation. Many European countries (e.g. Belgium, France, Germany and the Netherlands) have existing LCA tools at the building level. They are either already linked to their **national EPD database**, or are working on implementing that feature in the near future. In case national PCRs or EPD guidelines of construction products provide guidance on the definition of the **functional unit**, this results in an easy link between the EPDs of construction products and the LCA at the building level. If this is not the case, it can be difficult to align the functional unit.

Another aspect that has the potential to make an LCA at the building level easier, is creating a link with **BIM software**. This can make data gathering a lot easier and therefore greatly decrease the time and effort spent by the LCA practitioner. Although the construction sector is strongly driven by SMEs, for which adopting BIM software is not easy from a financial, logistics and learning point of view), and the use of BIM is increasing through Europe, but at an uneven pace.

CHAPTER 2 ACTIVITY 3.2: LINK TO BUILDINGS IN DRAFT PEFCRS RELATED TO CONSTRUCTION PRODUCTS FROM THE CURRENT PEF PILOT PHASE

2.1. INTRODUCTION

During activity 3.2 we further elaborated on the links between the existing (draft) PEFCRs related to construction products from PEF pilot phase and the PEF assessment at the building level.

The focus was mainly to verify if the preconditions that are needed to make the assessment at the building level by using PEF method are reflected on in the different existing (draft) PEFCs for construction products.

2.2. ANALYSIS OF DRAFT PEFCRS

2.2.1. DRAFT FINAL PEFCR THERMAL INSULATION – VERSION 4.4

The primary purpose of the PEFCR on thermal insulation is to provide a common set of rules to calculate the PEF-profile of thermal insulation products in their application (Technical Secretariat of the PEF thermal insulation pilot, 2016).

The thermal insulation products of Table 2 are included in the scope of this PEFCR.

Table 2: Thermal insulation products in scope of the PEFCR on thermal insulation (Technical Secretariat of the PEF thermal insulation pilot, 2016)

Product	Reference
Loose fill cellulose	ETA – EN 15101*
Unfaced cellular glass board	EN 13167: 2015
Unfaced EPS grey board	EN 13163: 2015
Faced PU board	EN 13165: 2015

* pending citation in European official journal

The declared unit for thermal insulation products in scope of this PEFCR is defined as follows: *"Thermal insulation of 1m² of a building element, with an insulation thickness that gives a thermal transmittance Uc of the element to be defined in the vertical rules, with a design life span of 50 years".* The calculation of the thermal transmittance (Uc) of the element shall be in line with the European standard EN ISO 6946:2007. For the calculation of the thermal transmittance the design lambda value (three digits after the comma shall be considered) of the insulation materials shall be used.

A PEF study compliant with this PEFCR shall be based on a "cradle-to-grave" assessment including all life cycle stages (see Figure 4). Thermal insulation products do not use water or energy during the use phase of the building. Both operational energy use (module B6) and operational water use (module B7), as indicated in Figure 4, are therefore excluded from the system boundaries.

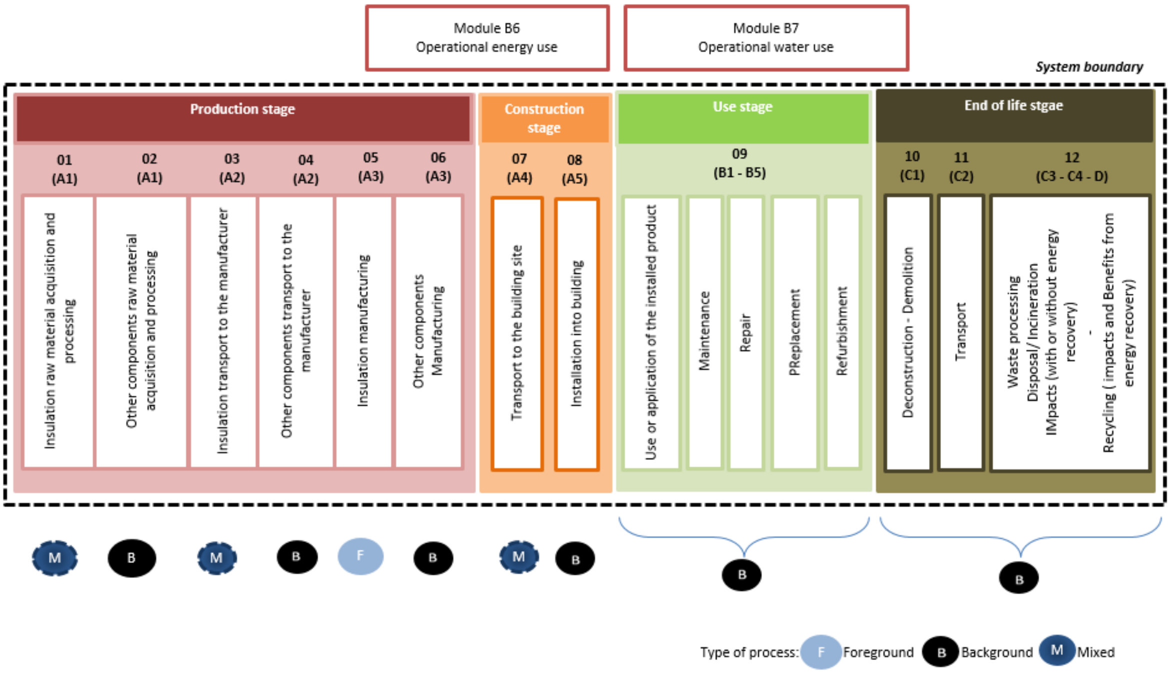

Figure 4: System boundary for thermal insulation products (Technical Secretariat of the PEF thermal insulation pilot, 2016)

The main function of thermal insulation is its heat resistance, reducing the need for heating a building and hence reducing the energy consumption while maintaining the required thermal indoor comfort level. Thermal insulation hence indirectly leads to environmental benefits compared to a non-insulated building. As the reduced heat demand is an indirect environmental benefit, it shall not be included in the product environmental footprint of the thermal insulation, but shall be communicated separately as additional environmental information.

2.2.2. Draft final PEFCR Hot and Cold Water Supply Piping Systems in the Building – Version 5.5

At this stage of the development of the PEFCR (Technical Secretariat PEF pilot on piping systems, 2016) the assessment has been done on copper piping systems with press fittings and plastic piping systems with press and expansion fittings. Other types of fittings are out of the scope of this PEFCR.

The functional unit (FU) of the hot and cold water supply piping systems in buildings is defined as:
"The pressure supply and transport of hot and cold drinking water, from the entrance of a well-defined apartment building to the tap, by means of a hot and cold drinking water piping system installation supplying a house as defined in EN 806-3 (5-story apartment building with one apartment per floor (100 m2 each, plus cellar), with a design life time of 50 years".

In order to make the PEF assessment a **reference "building system"** shall be considered: a 5-story apartment building with one apartment (100 m^2 each) per floor plus cellar, with all the facilities, like bath, shower, etc. clearly positioned in the apartments. The apartment building design shall be used for modelling the hot and cold water supply piping system. The life time of the hot and cold water supply piping systems is determined by the specific application in the building. The 50 years of life time is the minimum design life time according to the standard EN 806-3, and it is considered the time when the first refurbishment will take place and the piping systems are replaced. So the reference flow shall be related to the 50 years of design life time.

The 50 years of design life time is defined according to the Guidance Paper F (Concerning the Construction Products Directive 89/106/EEC), Durability and the Construction Products Directive (Revision December 2004). In accordance with EN 806 the calculated design life for a hot and cold water supply piping installation is also 50 years.

The technical performance of the piping system for hot and cold water supply in the building shall be according to EN 806 part 1, 2, 3, 4, 5. EN 806, Specifications for installations inside buildings conveying water for human consumption:

- Part 1: General;
- Part 2: Design;
- Part 3: Pipe sizing;
- Part 4: Installation;
- Part 5: Operation and maintenance.

The design parameters of the apartment building are visualized in

Figure 5. The appliances necessary inside the flats shall be based on the reference apartment shown in *Figure 5*.

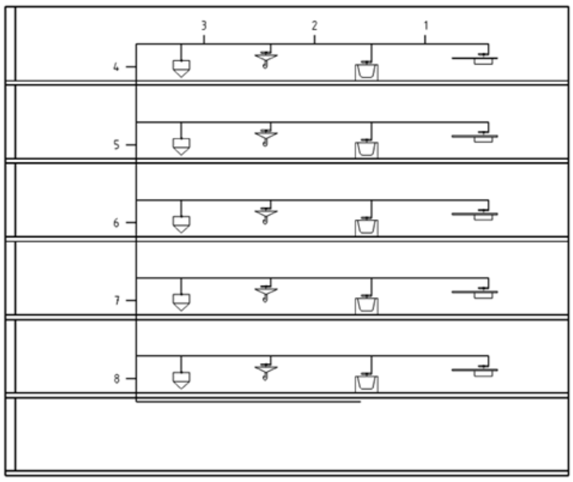

Figure 5: Design of the hot and cold drinking water supply piping systems for a 5-story apartment building according to the EN 806-3, Annex A

Figure 6: Architectural design of a representative 100 m² apartment

Figure 7 presents the schematic plumbing design for hot and cold water supply piping systems in buildings according to the representative product. The design has the precise length of pipes and approximate location of fittings. Any deviation from this design (if the technical performance of the system needs that of the local, legal and functional requirements) shall be justified in the PEF study. Justification needs to be fully reported in in the PEF report together with the reasons why the PEF applicant is deviating from the design presented in Figure 7.

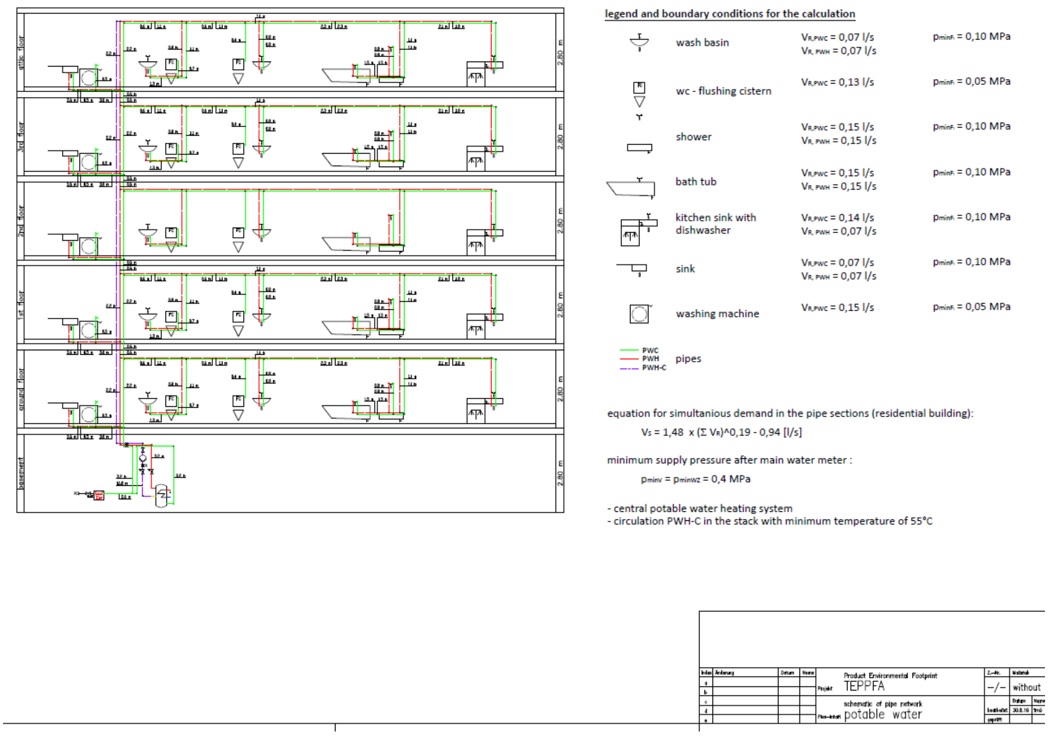

Figure 7: Schematic plumbing design for hot and cold water supply piping systems in buildings according to the representative product

The installation shall conform to current industry habits and the manufacturer's technical information and recommendations. The drawings give a clear description about the apartment. The list of planned facilities connected to the hot and cold water supply piping systems, which are not included in the reference flow, are as follows:

Kitchen:

- Hot and cold tap (sink);
- Dishwasher.

Bathroom: with hot and cold connections:

- Bath;
- Shower;
- Hand wash.

Bathroom: with cold water connection:

- WC.

Separate WC with hot and cold connections:

- Hand wash.

Separate WC with cold water connection:

- WC.

Utilities (washing room) with hot and cold connections

- Hand wash (sink).

Utilities (washing room) with cold water connection:

- Washing machine's connection.

The hot water producing device (boiler) is situated centrally in the cellar and is considered outside the system boundaries of the PEF study.

The following issues are excluded from the reference flow and the system boundaries:

- **Insulation of the piping system** for hot and cold water supply due to the following facts:
    - The construction products regulation mentions on page 1 point 4[2]:
      "Member States have introduced provisions, including requirements, relating not only to safety of buildings and other construction works but also to health, durability, energy economy, and protection of the environment, economic aspects, and other important aspects in the public interest."(European Commission, 2011);
    - This relates to individual national solutions about the insulation within the building structure, e.g. national laws, regulations or rules about the way of energy saving measures;
    - National design principles for pipe insulation have taken care about national climates. Therefore requirements for insulation thickness and thermal conductivity are not harmonised;
    - Therefore the pipe insulation is not covered, because regional and/or national aspects do not allow to create an average "value" for the pipe insulation across Europe.
- **Water meter and shut off valves** due to the following facts:
    - Water meters are mainly mandatory and have to fulfil various requirements in accordance to the modelling for equipment design (MED), but the dimensioning of the water meter is bound to the max possible volume flow, which is directly linked to the number of persons living in these flats.

[2] REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC (Text with EEA relevance

    - The number and type of shut valves are bound to local, regional or national installation codes. Therefore an average amount and type could not be judged and is not mentioned.
- **Technical specifications**:
    - A range of specific standards and regulations are in place across the EU which cover the requirements for the performance of piping systems used for the supply of drinking water.
    - Additional statutory requirements at member state level also apply to the health and hygiene aspects of all piping system materials which are in contact with drinking water.
    - For the purposes of this PEFCR it is assumed that systems meet all the relevant performance requirements and have been approved for drinking water applications approprite for the markets in which they are sold. Accordingly confirmation of compliance with these requirements does not form part of the scope of the PEFCR.

It is considered that in principle the methodology presented in this PEFCR is suitable for the calculation of the PEF of hot and cold water supply piping systems installed in other types and sizes of buildings.

In such cases however the following essential requirements shall be complied with:
- The environmental assessment shall be based on a piping system design and detailed BoC created for the specific project;
- The requirements for primary data as specified in the PEFCR must be strictly adhered to;
- The scope is limited to Copper, Multilayer (polymer/aluminium/polymer) and PEX hot and cold water supply piping systems;
- Default values for transportation distances should be adjusted relative to the specific locations of the project site and manufacturing plant;
- The results of this kind of product environmental footprint assessment can only be used for providing the environmental impact data for the piping system selected for a specific project;
- The results of the benchmark cannot be manipulated so as to be scaled to different size of buildings.

The above guidance applies to the provision of environmental impact data for the piping system selected for a specific project. Since there is no benchmark at the level of specific customised projects, any comparisons is not allowed. Any comparison with the benchmark can only be made under full compliance with this PEFCR document including the functional unit.

2.2.3. DRAFT FINAL PEFCR PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION – VERSION 0.15

The draft PEFCR Photovoltaic modules used in photovoltaic power systems for electricity generation (version 0.15) provides Product Environmental Footprint Category Rules (PEFCRs) for product environmental footprints (PEFs) assessments of photovoltaic modules (Technical Secretariat of the PEF photovoltaic electricity generation pilot, 2016).

A photovoltaic module basically consists of 48, 60 or 72 photovoltaic cells (156 x 156 mm^2 crystalline technology), or a monolithically integrated semiconductor layer (thin film technology), a

substrate and a cover material (glass, plastic films), the connections (used for the interconnection of the cells), the cabling (used for the interconnection of the modules) and the frame (in case of panels). It is either mounted on a building or on the open ground. Mounting is considered as part of the product, the balance of system components inverter and alternating current (AC) cabling (connection to the grid) are not part of the product analysed within this PEF pilot.
The photovoltaic module analysed is installed in Europe and the value chain of the module covers production worldwide (grouped in China, Europe, Asia & Pacific (APAC) and the USA).

The functional unit shall be defined as 1 kWh (kilowatt hour) of DC electricity generated by a photovoltaic module. The reference flow is the photovoltaic module, expressed in the maximum power output measured in kWp (kilowatt peak) under standard conditions. The functional unit is defined according to the following four criteria listed in the PEF Guide.

The function(s) / service(s) provided ("what"):

- DC electrical energy measured in kWh (provided power times unit of time) at the outlet of the DC connector attached to the junction box of the PV module

The magnitude of the function or service ("how much"):

- 1 kWh of DC electrical energy

The expected level of quality ("how well"):

- DC electrical energy at the photovoltaic module at a given voltage level.

The amount of service provided over the lifetime ("how long"):

- amount of DC electrical energy produced with the photovoltaic module of a given maximum power output during the service life of 30 years.

The product system of the electricity production with a PV module consists of three stages: manufacturing, use and end of life (Figure 8). The manufacturing of PV modules shall cover raw material extraction to wafer, cell and module production in case of crystalline silicon modules, the supply chain of semi-conductors (micromorphous silicon, cadmium sulphide, cadmium telluride, gallium and other materials used in thin film technologies) in case of thin film PV modules, and the supply chain of carrier and connection materials (such as glass, silver, junction box and frame in case of PV panels). The product system shall also include the mounting system required to fix the PV modules on a slanted roof because its demand depends on the conversion efficiency of the module. The inverter and the AC cabling shall not be part of the product system. The use phase shall include electricity production and the maintenance efforts (cleaning). The end of life shall cover the dismantling of the modules including transport to a recycling facility and the recycling process itself.

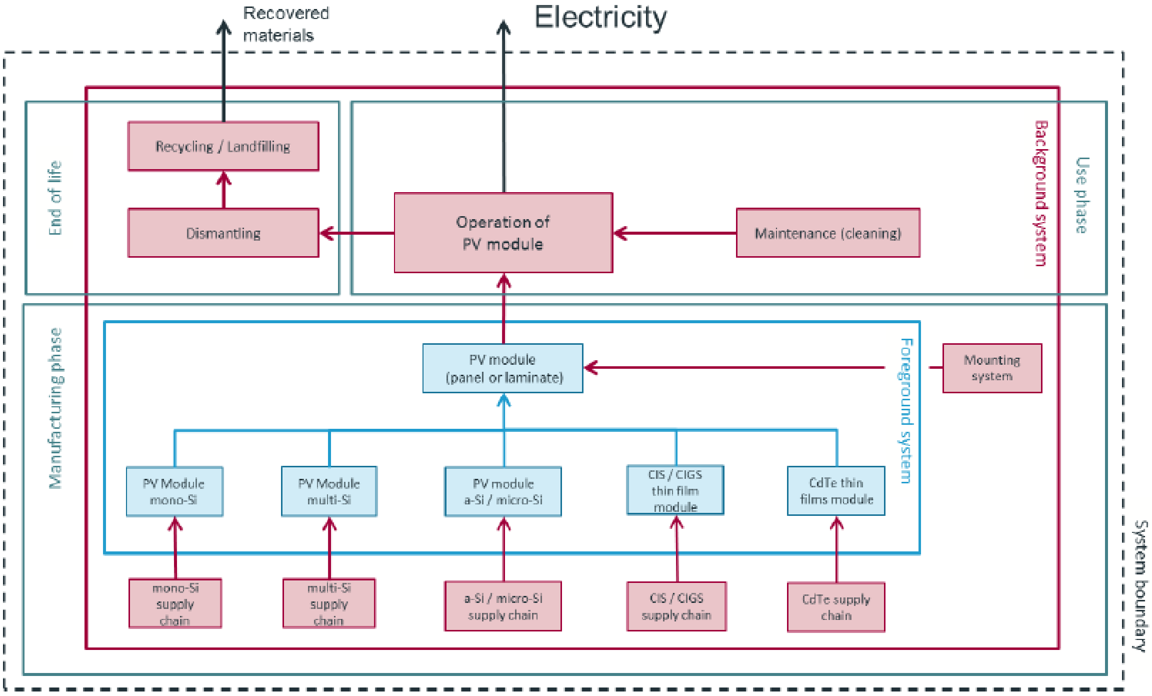

Figure 8: System Diagram: Product system of electricity produced with a photovoltaic module using mono-Si, multi-Si, a-Si / micro-Si, CdTe and CIS / CIGS technology. Processes to be modelled using primary data are shown in blue. (Technical Secretariat of the PEF photovoltaic electricity generation pilot, 2016)

The following life cycle stages shall be distinguished in the product system of electricity produced with a photovoltaic module (European Commission 2016):

- raw material acquisition and pre-processing;
- production of the main product;
- product distribution and storage 5;
- use stage;
- end-of-life stage.

The processes included in the manufacturing phase in Figure 9 encompass the first three life cycle stages listed above. These life cycle stages should be modelled separately to represent the specific situation by also taking account of data availability.

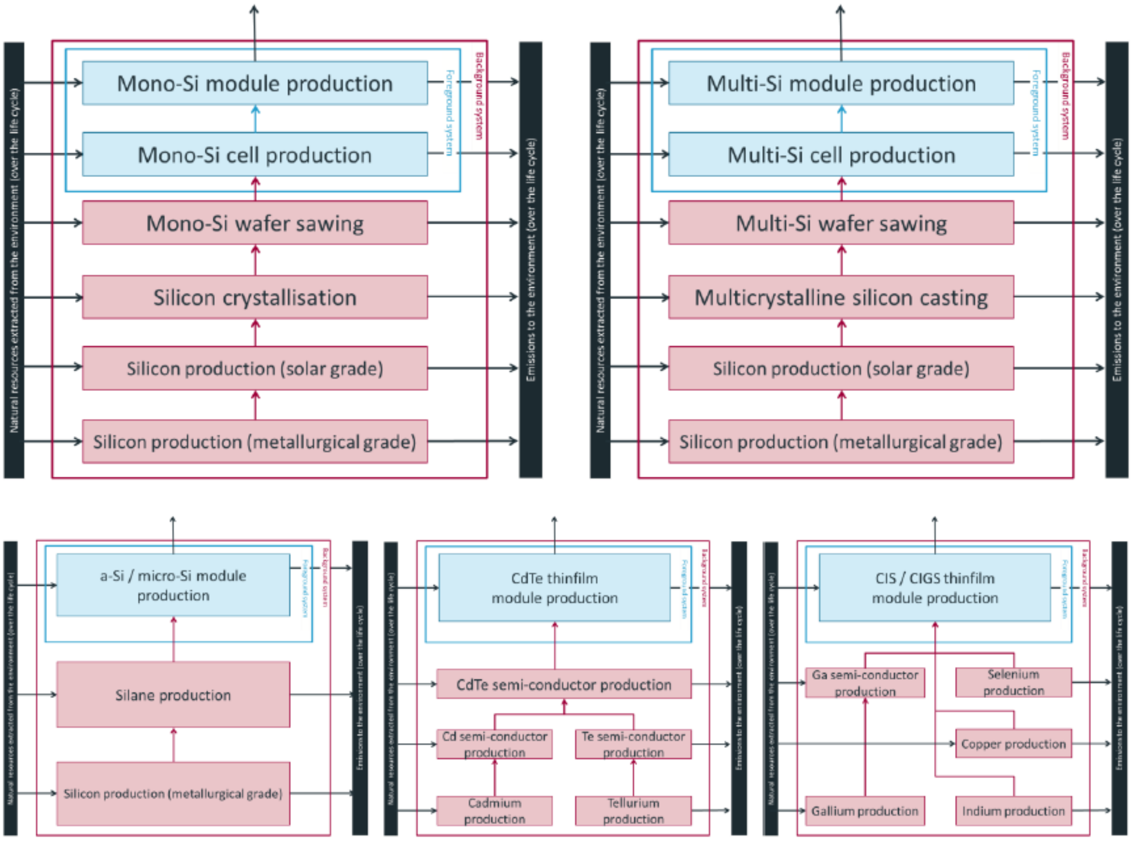

Figure 9: Excerpt of the mono-Si, multi-Si, a-Si / micro-Si, CdTe and CIS / CIGS supply chain. Processes to be modelled using primary data are shown in blue. (Technical Secretariat of the PEF photovoltaic electricity generation pilot, 2016)

The end-of-life stage shall include the dismantling of the photovoltaic module and the mounting structure including the transport to a recycling plant. According to WEEE directive (EU Parliament 2012), spent PV modules shall be treated and recycled (neither incinerated nor directly landfilled). With an expected lifetime of 30 years and installation of photovoltaic modules in significant amounts only starting a decade ago, there have been no significant volumes of end-of-life PV modules. Hence practical, verifiable experience on industrial scale recycling processes is missing for the majority of the technologies. However, lab scale testing and recycling of production scrap has shown that the WEEE requirements will be met once processes are implemented on industrial scale. The end-of-life stage of PV modules shall be modelled based on current practice. Recycling and potential future environmental benefits and impacts of PV modules shall only be accounted for to the extent to which PV module recycling is taking place today (based on EU statistics[7]). Otherwise the PV modules shall be assumed to be disposed of in a landfill. As there is significant uncertainty around the regulation of reuse of electricity generating equipment (especially in view of product and consumer safety), reuse of PV modules shall not be considered.

Three additional indicators shall be used to complement the environmental profile:

- renewable cumulative energy demand;
- non-renewable cumulative energy demand;
- radiotoxicity potential of nuclear waste.

The three additional indicators shall be presented separately from the default impact category indicators. These indicators shall be used in the life cycle impact assessment prior to normalization only. They shall not be used in benchmarking.

2.2.4. Draft final PEFCR Metal Sheets for Various Applications – Version 0.9

The draft PEFCR metal sheets (version 0.9) provides Product Environmental Footprint Category Rules (PEFCRs) for product environmental footprints (PEFs) for metal sheets as intermediate products (Bollen et al., 2016).

A metal sheet is a product manufactured at an industrial site with specific properties (e.g. mechanical properties, surface properties, conductivity etc.). It is typically an intermediate product that requires further transformation to an end-use product within the following application sectors (non-exhaustive list):

- building and construction applications;
- transport;
- appliances;
- packaging;
- engineering.

Any surface treatment or finishing of the intermediate product is included in the scope and depends on the individual specification of the product as it will be sold on the market. The function of a metal sheet within an end-use product is usually multiple. Examples of these functions are: structural integrity, weather protection, physical separation, shaping, sealing and aesthetics (non-exhaustive list).

An "intermediate" metal sheet is typically subject to additional manufacturing steps in order to be transformed into the final product (e.g. metal sheet undergo machine or manual working operations such as forming, bending, seaming , joining, welding to make a building's roof covering or facade). A corresponding bill of materials is listed in ANNEX II of the PEFCR.

A metal sheet is an intermediate product that can be used in many different end applications. The grade of metal, thickness of the sheet and the surface finish will be dependent on the specific end use. Examples are given in this PEFCR of "representative products", but it should be stressed that these examples do not specify exact technical parameters, and these examples should not be used as criteria for benchmarking. These representative examples for end applications can be found in ANNEX I of the PEFCR:

- Four for the subcategory "building applications":
    - one for copper roofing;
    - one for lead roofing;
    - one for aluminium roofing;
    - one for steel flooring.
- Two for the subcategory "appliances":
    - aluminium body sheets;
    - steel body sheets.

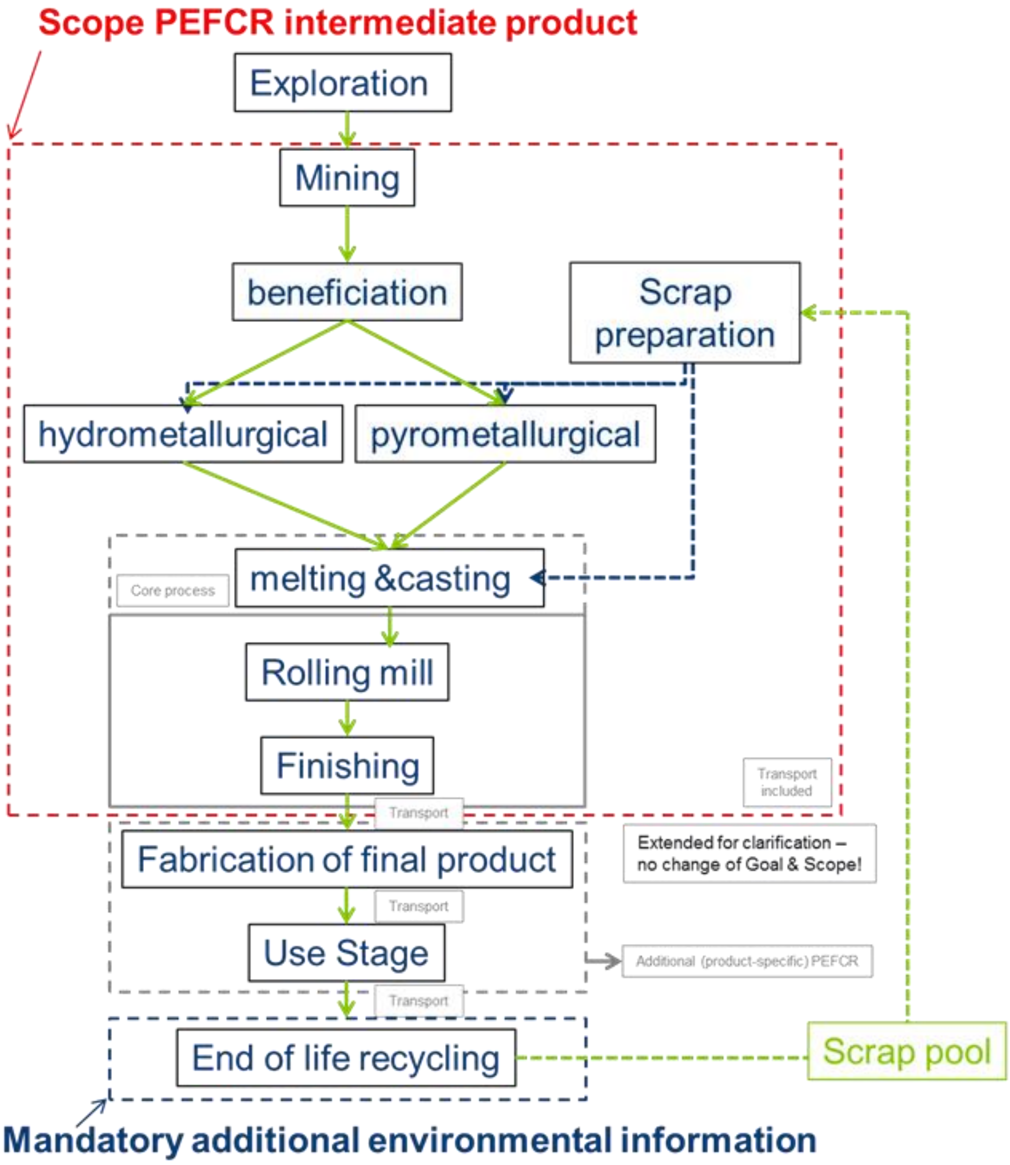

Figure 10: Scope metal sheets

2.2.5. DRAFT FINAL PEFCR DECORATIVE PAINTS – VERSION 6.2

The PEFCR Decorative Paints (Technical Secretariat Decorative Paints, 2016) defines the functional unit relative to the function of the building, namely the amount of packaged paint needed to protect and decorate 1 m² of a specified substrate for 50 years, at a certain specified quality level (minimum 98% opacity)[3]. Since the paint might not last that long, several repaints may be necessary to last for the full lifetime of the building, 50 years.

[3] In conformance with the Construction WG pilots to follow 50 years for the referenced lifetime of the building.

The PEFCR Decorative Paints includes the substrate (the walls, doors, etc.) from the system boundaries, since it is a different product that will of course be included in the assessment at building level. Other aspects that are excluded are the commuting of employees (both of the paint factory and the professional painters); administrative services (research and development, commercial activities etc.); and capital goods such as machinery used in the paint production process, buildings (factories, offices, warehouses, and shops), and office equipment.

No less than 12 life cycle stages are defined, as shown in the system diagram in Figure 11. Transportation stages are covered, but the modelling deviates (transport type and distance vs. fuel consumption and emission). For PEF4Buildings it is therefore not feasible to follow the primary data approach.

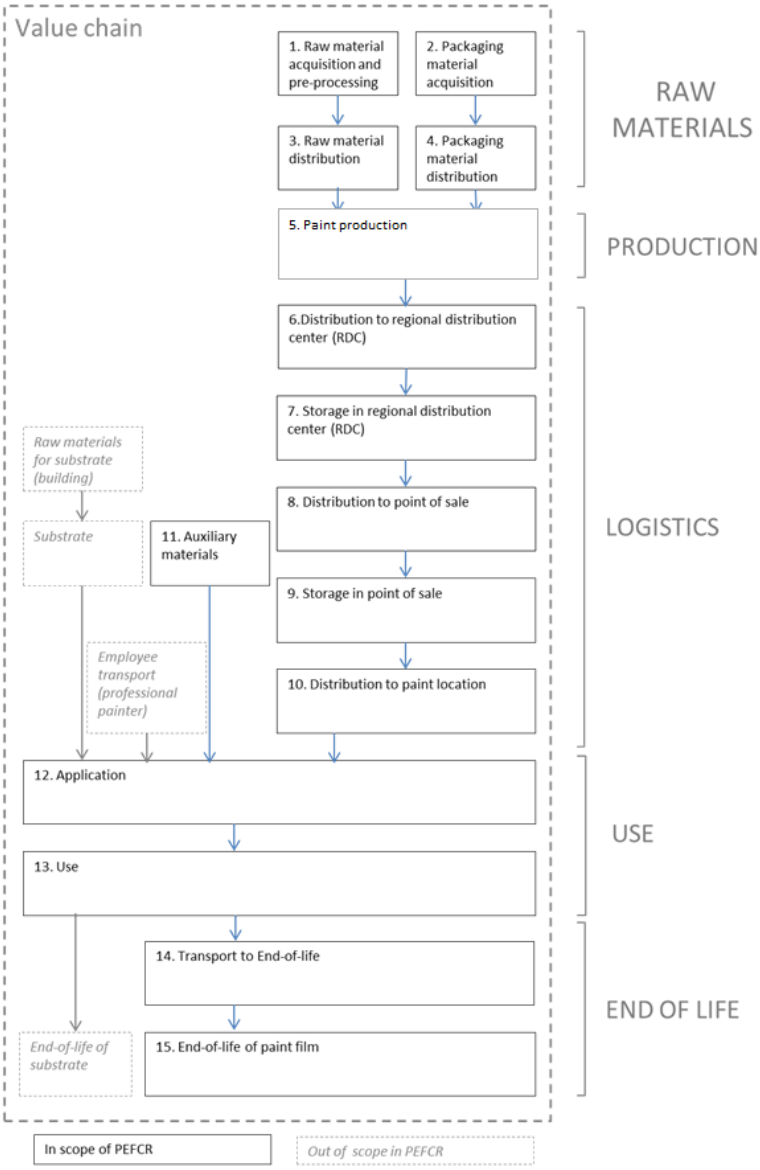

Figure 11: System diagram of decorative paints

PEF studies on decorative paints shall only report the total climate change (the sum of fossil, biogenic, and land use and land transformation climate change), since climate change was not identified as one of the most relevant impact categories for decorative paints. In order to avoid underreporting of the impact of VOC emissions, the characterization factors for the flow VOC (unspecified) for climate change shall be implemented as provided by CML 2001 in November 2009 (CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) 7,5 kg CO2-Equiv.). The PEFCR does not apply the biodiversity issue paper for now, since no well-defined methodology is available at the moment.

Primary data is required for paint production, storage in RDC, storage in point of sale, application, use, and transport to end-of-life. For all other processes, default secondary data is provided.

Repainting is necessary over the full life cycle of the building. The impact of the paint and other processes necessary for repainting are allocated to its respective life cycle stages in the same way as the paint and processes that are applied the first time, not in a separate life cycle stage such as B4 (Replacements).

At the end-of-life of the paint, it is transported an average distance by truck to the treatment location and is either incinerated (when applied on a wooden substrate) or landfilled (when applied on a mineral substrate). Multi-functionality is rarely relevant for the production of paint.

2.3. SUMMARY OF MAIN CONCLUSIONS

In order to avoid misalignment between assessment on construction products and building level, it is recommended to consider the **same life cycle stages** for the PEFCRs of both. Currently, the number of life cycle stages considered is different in the various construction PEFCRs: 15 (paints), 12 (thermal insulation), 9 (piping systems), 5 (photovoltaic module) and 4 (metal sheets). Several PEFCRs have more than one life cycle stage for the acquisition of the raw materials. Since most current LCAs of buildings are aligned with **EN norms** related to construction products (EN 15978/EN15804), we recommend to consider these life cycle stages, as shown in Table 3.

Table 3: Life cycle stages for the assessment at building level

LCS name	The following shall be included
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment

PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL
PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

The application of **cut-off rules** in certain pilots can result in a difference in the system boundaries of the various construction materials. For example, infrastructure for manufacturing stage is excluded for piping systems based on the cut-off rule, while it is included for the other current PEF pilots on construction products. These irregularities should be avoided when doing an environmental assessment at the building level.

Moreover, more attention should be paid to the inclusion and application of the **use phase** of the construction products and the building. For some construction products pilots, the use phase is excluded or considered only as additional information. When assessing at the building level, some aspects of the use phase are easier to consider. The development for specific scenarios at the building level is recommended.

Also for the **dismantling/demolishing** of the building, an overall scenario should be developed at the building level. Currently only 2 PEFCRs of the construction products include some basic scenarios for this.

CHAPTER 3 ACTIVITY 3.3: GUIDANCE DOCUMENT ON HOW TO LINK THE ASSESSMENT OF THE ENVIRONMENTAL PERFORMANCE OF CONSTRUCTION PRODUCTS TO THE ASSESSMENT OF THE BUILDING BY USING THE PEF METHOD

3.1. INTRODUCTION

Based on the results of Activity 3.1, Activity 3.2 and the results from Task 1 (PEF assessment of two office buildings cases) the project team developed some recommendations and guidance on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method.

The guidance and recommendations do not only focus on office buildings (and the results obtained in task 1) but are extended to other possible typologies of buildings. For the latter we will fully benefit from the experiences gained during the MMG project that VITO and KU Leuven are performing in Belgium and from our active participation in several working groups of within the CEN TC 350 framework.

3.2. GUIDANCE ON HOW TO LINK THE ASSESSMENT OF CONSTRUCTION PRODUCTS TO THAT OF BUILDINGS BY USING THE PEF METHOD

3.2.1. GOAL AND SCOPE DEFINITION

If PEF is to be used to assess the environmental footprint of a building first the goal and scope of the assessment should be unambiguous and clearly described.

1. Goal

During the first phase the goal of the PEF for buildings must be clearly formulated and the reference basis (functional unit) must be defined to allow a correct analysis from the building system's perspective. It is important to make clear agreements on the goal and on how the results will be used and communicated.

Reasons for carrying out the PEF at building level

The objective of the PEF assesment at building element level will be to calculate the environmental footprint of buildings. This will give a better understanding of the environmental performance of materials used in buildings for all PEF environmental impact categories, taking into account the entire life cycle of the buildings.

LCA at building level by using PEF can be used for a wide variety of policy objectives:

- Allow subsidies for retrofitting or new construction;
- Select between demolition or retrofitting;
- Authorise construction permits following the calculated environmental impacts;

- Eco-design of building;
- To meet specific target values.

Summarised the objective of the PEF study at building level is:
- to analyse the environmental performance of the building over all the life cycle phases;
- to identify the most important impact-generating life cycle phases, processes and elementary flow to be able to focus on improvement activities;
- potentially: to obtain a PEF certification. In this framework it is recommended to develop PEFCR(s) for building(s).

Recommended: PEFCR(s) for building(s):
- A PEFCR at building level that forms the basis for all (new) PEFCRs for construction products is recommended. The PEFCR at building level should ensure:
  - That life cycle stages are consistently defined across PEFCRs of all construction product categories;
  - Alignment between PEFCR at building level and PEFCRs at the construction product level.
- Regionalisation: Based on experiences with assessments of the environmental performance of buildings, it might be needed to develop separate guidance/scenarios at member state level, or at the level of the regions: Northern countries, central Europe and southern Europe, as different climatic zones and building construction practices exists in these regions. It is recommended to include national scenarios in the PEFCR for buildings.
- One or several PEFCRs can be developed, based on different building typologies.
- Design phase versus post construction phase:
  - Different rules for PEF studies to support the design process or required for a building permit. A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear guidelines to model the use phase are moreover crucial as this life cycle stage is assumed to be the most relevant one for the majority of the buildings. One important parameter in this context is the reference study period and related references service lives.
- It is recommended to include in a PEFCR for buildings a definition of processes that are / are not under operational control of the building commissioner. A more extended consultation with relevant stakeholders should take place to define how primary versus secondary data should be used when making PEF assessments at building level.

Intended use of the results and the audience

In general, PEF at building level can be aimed at:
- Internal use: the results will be used internally for ecodesign purpose and to improve the building design for instance in the early design stages;
- External use: the results can be used externally. In this framework a PEF verification process is recommended. Specific communication rules and formats needs to be developed.

2. Scope

In the scope definition of the PEF, the following items should be considered and clearly described (in line with the developed PEFCR(s) for building(s):
- the building to be assessed (subject);

- the functions of this building;
- the functional unit;
- the building system(s) boundaries;
- allocation procedures;
- cut-offs rules;
- data gaps;
- types of impact and methodology of impact assessment, and subsequent interpretation to be used;
- data requirements;
- data quality requirements;
- assumptions;
- limitations;
- type of critical review and/or verification, if any;
- type and format of the report required for the PEF study.

The scope should be sufficiently well-defined to ensure that the breadth, the depth and the detail of the PEF study are compatible and sufficient to address the goal and in compliance with the developed PEFCR(s) of building(s).

Subject

Depending on the typology of the building, it is recommended to develop specific PEFCR(s) for each of them:

- Agricultural buildings;
- Commercial buildings;
- Residential buildings;
- Medical buildings;
- Educational buildings;
- Government buildings;
- Industrial buildings;
- Military buildings;
- Parking structures and storage;
- Religious buildings;
- Transport buildings;
- Etc.

It is recommended to define a reference building (or asses how many reference buildings should be defined to cover the building typology) for each typology for which a PEFCR will be developed.

Functional unit and reference flow

According to the PEF method, the **functional unit** describes the function(s) and duration of the building and shall be defined according to these aspects: what, how much, how well and how long.

According to the PEF method, the **reference flow** is defined as the amount of product needed to fulfil the defined function and shall be measured in m^2, m^3, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.

Providing a clear reference flow for the assessment of buildings will greatly improve comparability of PEF studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit that takes into account the function of the buildings, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all Member Sates use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends m² floor area per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.

Further, it is recommended to assess the complete building and its elements: foundations, building envelope, inner walls and intermediate floors, including all finishings as well as technical equipment such as electricity, HVAC, sanitary equipment and elevators. Furniture, desks, IT equipment, kitchen and parking space should be excluded. Most importantly, clear rules should be defined in a PEFCR(s) for buildings on what shall and shall not be included when the PEF is used for either benchmarking or comparative assertions.

System boundaries

The PEF Guidance (European Commission (EC), 2017) indicates that the **system boundaries** shall include a system diagram clearly indicating the processes and life cycle stages that are included in the product system. The diagram shall include an indication of the processes for which company-specific data are required.

A system diagram needs to be presented that clearly indicates the processes and life cycle stages that were included in the building system boundaries for the PEF assessment. We recommend to define the system boundaries for the PEF studies from the perspective of the designer/architect. This means that everything that the designer/architect can influence shall be included in the system boundaries. A recommended proposal for the system boundaries is presented in Figure 12.

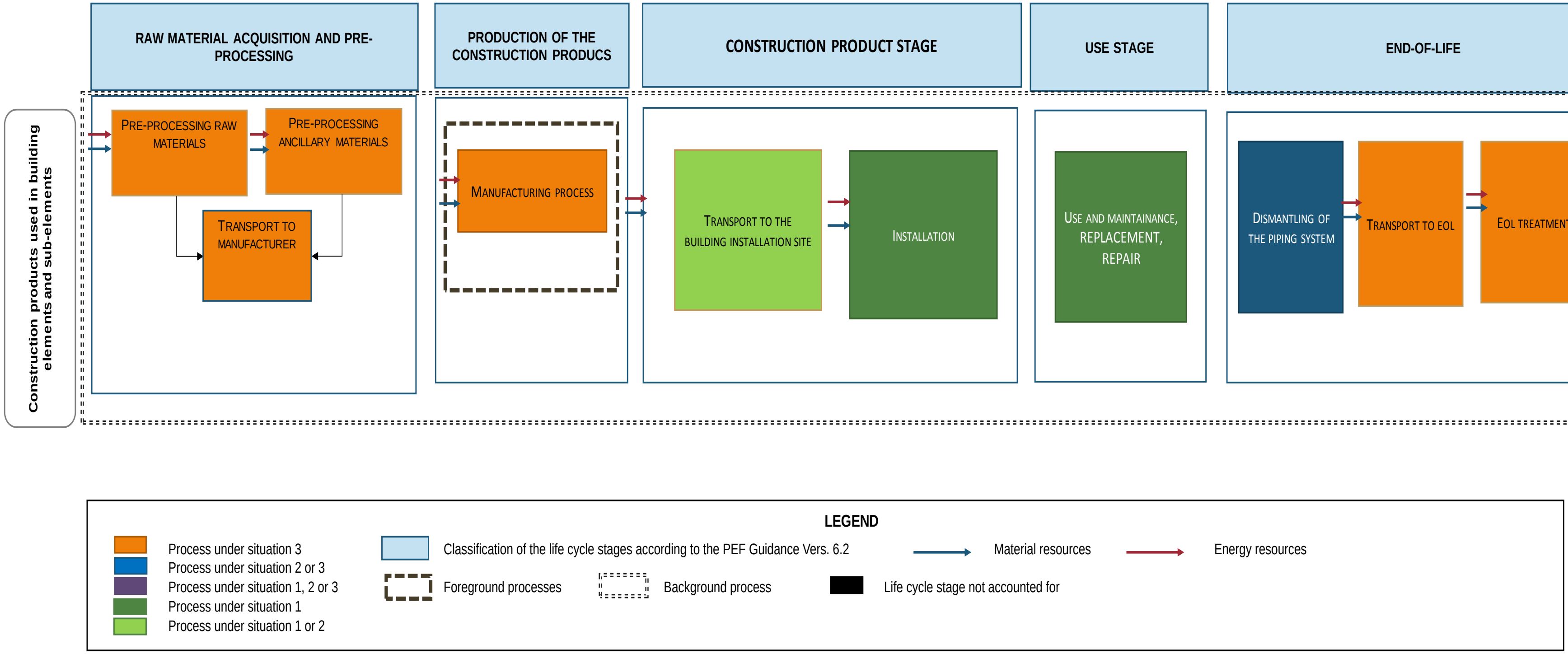

Figure 12: System boundary diagram for assessment at building level

Life cycle stages that we recommend to include in the system boundaries are presented in Table 4. The definition of the life cycle stages is based on a cross-analysis of the life cycle stages defined in the draft PEFCRs for the construction products already developed, but also in the EN norms related to construction products (EN 15978/EN15804). The details of this analysis can be found in Annex 5 of Deliverable D3 of this project (VITO, KU Leuven, & TU Graz, 2018a).

Table 4: Life cycle stages for the assessment at building level

LCS name	The following life cycle stages shall be included in the building assessment
PEF_A1	Pre-processing and acquisition of raw materials and packaging of raw materials
PEF_A2	Transport of the raw (engineering) materials to the production site
PEF_A3	Manufacturing of the construction products and the related packaging
PEF_A4	Transport to building site
PEF_A5	Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
PEF_B1	Use stage
PEF_B2	Maintenance
PEF_B3	Repair
PEF_B4	Replacement
PEF_B5	Refurbishment
PEF_B6	Operational energy use
PEF_B7	Operational water use
PEF_C1	Dismantling
PEF_C2	Transport to EoL
PEF_C3/C4	Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

Allocation procedures

Allocation procedures are needed when dealing with systems involving multiple products. The materials and energy flows as well as associated environmental releases shall be allocated to the different systems according to clearly stated procedures described in the PEFCR(s) of the building(s), which shall be documented and justified.

At **building level**, the PEFCR(s) for building(s) shall be clear on the procedures releated to the allocation of impacts of re-used building elements (mainly important during renovation projects) by setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building).

At **product level** the allocation need to follow the approach for the handling of multi-functional processes in the latest version of the PEF Guidance document.

Cut-off rules

As specified in the latest version of the PEF Guidance document (European Commission (EC), 2017), the criteria for the exclusion of inputs and outputs (cut-off rules) are intended to support an efficient calculation procedure. They shall not be applied in order to hide data.

Cut-off rules need to be clearly defined in the PEFCR(s) for building(s) conform the latest version of the PEF Guidance document. It is recommended that the defined cut-off rules at buliding level shall be aligned with the cut-off rules for construction products in the respective PEFCR(s) at product level.

Data gaps

When applying the PEF method to buildings some challenges are encountered due to data gaps. The data gaps occurring in these studies are of two types:

- Data gaps due to lack of information;
- Data gaps due to lack of datasets (modelling alternatives).

Generally, the data gaps related to the lack of information are:

- Incomplete information related to the building elements, layers and materials due to incomplete documentation (BIM, plans and other sources);
- Unavailability of scenarios – e.g. for construction stage scenarios;
- Lack of information on the final (as-built) status of the buildings.

With respect to these data gaps and due to the lack of modelling alternatives, the following approach is suggested to be taken and needs to be described in the PEFCR(s) of building(s): whenever no sufficiently representative specific or generic data are available for a certain process, it should be filled with a data collection and/or a selection of available datasets that is a best available proxy. Any data gaps should be filled using the best available generic or extrapolated data. Proxies that are prescribed are not considered as data gap.

Methodology for life cycle impact assessment and hotspot analysis

The methodology for life cycle impact assessment will be the same as the methodology that is presented in the latest version of the PEF Guidance document.

Data requirements (see also in next sub-chapter on life cycle inventory)

It shall be identified and described in the several PEFCR(s) for building(s) which data are needed in order to meet the goal of the PEF study, and which level of detail is required for the different data categories. The different data sources that will be used shall be stated. It is recommended to present PEF compliant default data in the respective PEFCR(s) of building(s).

The data requirements are dependent on the questions that are raised in the study. Efforts do not need to be put in the quantification of minor or negligible inputs and outputs that will not significantly change the overall results of the study. It is recommended that these processes will be described in the respective PEFCR(s) of building(s).

Data quality requirements

As data quality requirements are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.

Assumptions and limitations

All assumptions made during the course of the PEF assessment at building level and the limitations of the PEF study will be commented in a PEF report. The results of the PEF assessment needs to be interpreted in agreement with the goal and scope.

Type of critical review and/or verification

It is recommended that the results of the PEF assessment will be critical reviewed and/or verified, in keeping with the rules as described in latest version of the PEF guidance document and the respective PEFCR(s) at building level.

Type and format of the report required for the PEF study.

It is recommended that the results of the PEF assessment will be fairly, completely and accurately reported to the intended audience, in keeping with the rules as described in the latest version of the PEF guidance document and the respective PEFCR(s) at building level.

3.2.2. LIFE CYCLE INVENTORY (LCI)

The inventory analysis involves data collection and calculation procedures to quantify the inputs and outputs that are associated with the bulidings. This includes use of resources, releases to air, water and soil. Procedures of data collection and calculation should be consistent with the goal and the scope of the study. The results of the inventory analysis may constitute the input for the life cycle assessment as well as an input for the interpretation phase.

Input and output data have to be collected for each process that is included in the system boundaries. After collection, the data for the different processes have to be normalized to the functional unit and aggregated.

We would like to make some recommendations and guidance on the following topics in this framework:

- LCA model;
- Data requirements;
- BIM as tool.

LCA/PEF model

The aim of the LCA models is to assess buildings with the PEF method for both the level of the building materials and building elements. The aim is moreover to use PEF studies – available in the future – at different scale levels (e.g. building materials, building sub-elements, building elements) in PEF assessment studies of buildings. In order to allow for these linkages, a hierarchical decomposition of the building (element method) should be used in order to:

- Systematically model a building avoiding any data gaps and/or double counting;

- Easily exchange information between different parties involved in the PEF assessment (consultants, designers, building contractors, etc.);
- Exchange information between the various levels in the model, i.e. building material, sub-elements, elements and buildings.

Level of analysis

When looking at a building level we recommend the following hierarchical levels of the building, and situations when applying datasets to the model of the building (ISO 12006-2 (ISO, 2015)) .

- Level 0 – Building;
- Level 1 – Building element;
- Level 2 – Building sub-element;
- Level 3 – Building material.

The analysis of the impact of a building can be done at several levels, such as at the level of the entire building, per building elements, sub-elements or materials. These levels of analysis are however not in direct relation with the level of dissagregation of the datasets used to develop the model. Following the PEF method, the focuss of the analysis is on the hotspots that need to be identified at the level of the impact categories, life cycle stages and processes. For for the identification of the most relevant impact categories and life cycle stages the analysis is straight forward. It is therefore recommended to clearly define the level of analysis within the PEFCR(s) for building(s).

Definintion of level -1 in the framework of the level of analysis

In defining level-1 it is relevant to determine the perspective of the developer of a building (such as an architect), as this will be the level where the results of the PEF assessment at building level can be used. Thus, from a building developer's view point, he/she will look at the products that will be delivered at the construction site, be it raw materials (sand), prefab elements (prefab walls, reinforcing steel), parts of a building element (window frames, glazing) or even complete building elements (condensing boiler). The selection of materials to be used for constructing the building is also done at this level, and it is therefore reommended to set level -1 at this level.

Defining level-1 as the level of products delivered at the construction site didn't make the analysis in task 1 easier though, as currently the existing datasets are available at a different disaggregation level. The examples Table 5 show how level-1 can be at different hierarchical levels of a building, and can also have various levels of dissagregation when it comes to datasets.This situation will idealy change in the future, where datasets will be available at the right level of disaggregation, with the CFF formula already inbuilt, to allow their easy use in the model.

It is recommeded to to clearly define the level -1 for the level of analysis within the PEFCR(s) for building(s).

Table 5: Example on Level -1 definition for some specific cases

Hierarchical level number	Name of the building level	Example 1	Example 2	Example 3
Level 0	Building			
Level 1	Building elements	Internal glazed wall	Concrete storey floor 45 cm	CoolingMachine
Level 2	Building sub-elements	AluminiumFrame	ConcretePrefabFloor	
Level 3	Building materials	1 material used	3 materials used	
	Comments	1 dataset used (as only 1 available)	For each material at least 2 datasets used to model to allow application of the CFF formula.	1 dataset used (no CFF applied as not possible)

Coding conventions

As buildings are complex entities, also the PEF model is highly complex consisting of large amounts of data. Due to this complexity, the risks of errors are high and as mentioned before, a systematic approach is necessary. An important learning from Task 1, was using coding/naming conventions and systematically apply these to all elements, sub-elements and building materials in the building. It is recommended to clearly describe the definition and the correct coding terminology and naming conventions in the PEFCR(s) for building(s).

Parametrisation

Parametrisation of the LCA/PEF model shall be introduced in order to avoid manual remodelling during each iteration. Generally, the number of parameters is related to the complexity of the building, respectively the number of building elements, sub-elements and materials within the spreadsheet data collection. Parameters shall be used to define the ratios at material, sub-element, element and building level (amounts) but also for the CFF parameters (A, B, R1, R2, R3), and for specific scenarios, such as distance to EoL.

The use of these parameters allows the adaptation of the LCA/PEF model during the iterative process of the PEF assessment on building level by supporting easy changes and to push certain values to the corresponding parameters in the specific LCA/PEF software.

The naming of the parameters, but also of the intermediary flows created for each sub-element and element shall follow a consistent coding convention based on the OmniClass codes. The way they have been systematically developed and used are described in Annex 1 and 2 of task 1 (Deliverable 3) but it is recommended to publish them in the respective PEFCR(s) for building(s) too.

Element and material specific ratios

The concept of using element and material specific ratios, to describe density and proportion of a certain construction material contained within a sub-element or element, is recommended.

Link between LCA/PEF model and BIM

It is recommended to establish a link between BIM and the LCA/PEF model via Excel, applicable for different building case studies. This was found not feasible in the time given for the assessment of the two buildings in Task 1.

Data requirements

In order to assess the environmental performance of buildings, different types of information are needed (Figure 13).

The complexity of the model implies a time-consuming process to establish the model. A generic template for the data collection and modelling is therefore recommended if PEF studies of buildings should become mainstream.

The challenges and issues related to data collection that people meet while using LCA at the building level are also valid for PEF. PEF specific issues are mainly the availability of PEF compliant generic datasets and the quality of the existing generic datasets (not always PEF compliant).

During the life cycle inventory, information about the elements, sub-elements and materials regarding specifications and quantities of the different entities is needed. Besides quantities, material specific characteristics (e.g. density of the material) are needed to define the complete dataset. Entity quantities can be extracted from a Building Information Model (BIM), building plans, technical information sheets, PEF compliant default data, and the building cost sheet.

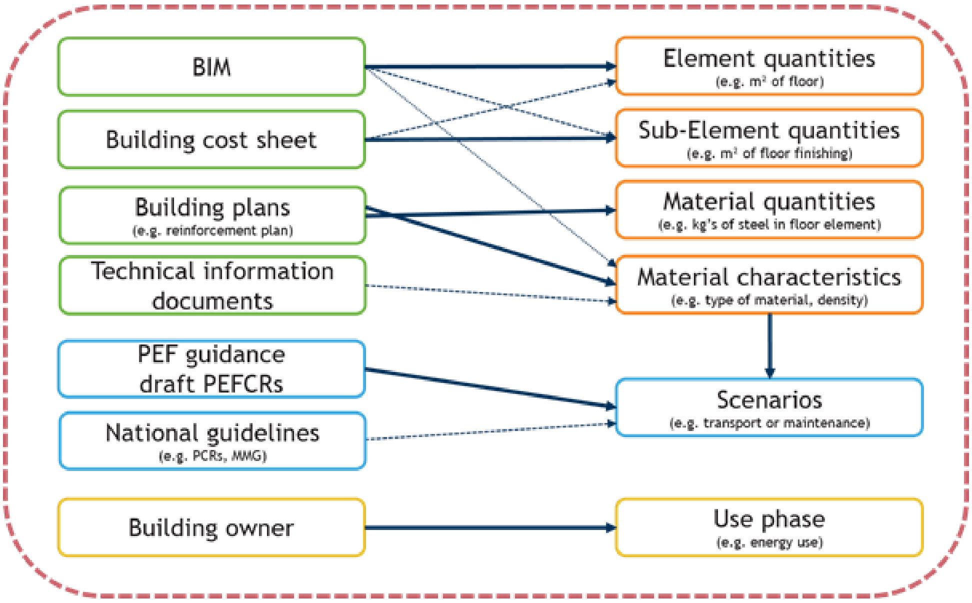

Figure 13: Data gathering

Data at the level of construction products/materials

Many EPDs for products and materials already exist and are publicly available. Less information is available for equipment and components for building installations (plumbing, electricity, HVAC, etc.). A direct link between LCA tools at the building level is often missing, but many building assessment tools are evolving in that direction.

The current EPD system is strongly related to national markets. This is mainly due to program operators and specific national legislation. This creates a burden for the industry and could be seen as a barrier to trade.

Recommendations from project team in this framework:

- Harmonisation of calculation methodology: mandate revision EN 15804 / alignment PEF;
- Harmonisation of content of EPD/PEF at product level:
  - Harmonisation in PEFCRs/PCRs amongst product groups;
    - Alignment in terms of life cycle stages and scenarios;
    - Link to building level consistently for all product groups.
- Harmonisation of databases:
  - Development of a common EPD database for the most frequent processes, e.g. using PEF compliant datasets purchased by EC.
- Language of the PEFs/EPDs: English?
  - INIES: FDES (only in French);
  - IBU: most often in German.
- Regarding the life cycle inventory, a more extensive list of generic datasets is needed to model an entire building and that the current datasets do not allow to apply the CFF formula without adapting the datasets. It is therefore recommended to:
  - Provide a database with construction materials in line with PEF;
  - Integrate the CFF formula in the datasets.

- Recommendation: provision of PEF compliant data for all relevant sub systems in the building to improve applicability in a building design context.

Data at the level of scenarios

Secondly, information is needed about the scenarios that apply during the different life cycle stages.

It is recommended to define scenarios for transport and end-of-life stages in the respective PEFCRs or PEF guidance at building level. For the end-of-life, reference is often made to the EPDs where information on end-of-life scenarios at product level can be found. PEFCR for buildings should include default scenarios in case no specific information is available. Default scenarios can vary from country to country: distinction could be made based on geographical spread:

- Northern countries;
- Western Europe;
- Southern countries

Information that is related to the operational use phase consists of energy and water use in the assessed building. For existing building this can be obtained from the building owners. In case of an assessment of a new building, this data could be obtained via building simulations. It is recommended to define these scenarios for the operational use phase in the respective PEFCRs or PEF guidance at building level.

Scenarios considering maintenance (including cleaning, small and big maintenance) and replacement should be determined by the respective PEFCRs or PEF guidance at building level.

For the reference service life time of the building, most often scenarios are available (50 or 60 years). Specific requirements for the service life of the building are in most cases defined by the client. In the absence of such requirements, it is recommended to work with a standard assessment period of 60 years (alternatives may be defined at the level of the respecitive PEFCR(s) for building(s)). The average life expectancy of buildings is usually longer than 60 years, but it is assumed that after 60 years, the building will most likely be renovated so thoroughly that, apart from the structure, relatively few of the original materials will still be present. Offices and shops are subject to major renovation even faster than dwellings, but the structural elements in principle tend to remain for at least 60 years, which explains why the 60 year of reference service life time is recommended. The fact that offices and shops tend to be renovated more quickly can be taken into account by applying a (much) shorter service life for the non- structural elements (e.g. non-load-bearing interior walls) and all finishes (e.g. false ceilings, floor coverings). It is recommended to define the reference service life time within the respective PEFCRs or PEF guidance at building level.

BIM as tool

The added value of coupling Building Information Modelling (BIM) with LCA/PEF at building level is that it reduces the time needed for the data gathering process by generating automatically many of the quantity data needed. In the sustainability evaluation of a building, BIM supports the data gathering and promises potentials for an iterative design optimization approach. However, important aspects to consider of a BIM models quality are:

- the completeness of the building model (modelled and un-modelled building elements);

- the Level of Geometry (LOG) for modelled geometries and elements, as well as;
- the Level of Information (LOI) regarding e.g. specification of material information.

All of these aspects can differ widely regarding on the modelling practice and workflow.

In this framework some recommendations are formulated:

- BIM could provide a centralized model where a lot of the needed data is gathered and thus support LCA purposes by including LCA data in BIM;
- Important aspects to consider regarding the suitability and workflow of using BIM models:
  - Completeness and accuracy of the model – Level of Development;
  - Level of Geometry (LOG) of building elements, as well as;
  - Level of Information (LOI) for element and material specifications;
- Standardisation of building element structure as well as building element classifications on European level, suitable for application in BIM models and LCA;
- Development of BIM-ready datasets, e.g. environmental data aggregated on different levels depending on the planning stage the assessment should be carried out in. E.g. data of building elements in early design stages, detailed data on level of sub-elements and material composition for design development, tender stage and beyond;
- Based on the findings of this study, a more flexible parameter structure for the amounts of elements and materials has to be found to further support a parametric approach applicable to other buildings while acknowledging the constraints in BIM and LCA software's functionality.
- It is recommended to specific BIM requirements to allow a better data provision for PEF (LCA) purposes and identify ways of integrating LCA data into BIM.

3.2.3. Life Cycle Impact Assessment (LCIA) and Interpretation

For the LCIA, we can summarise the recommendations as follows:

- The LCA/PEF model in combination with the BIM model will allow to assess the environmental performance of the building in a fairly easy way;
- It is recommended to use the latest version of the PEF Guidance document for LCIA and interpretation (hotspot analysis);
- It would be helpful if in future if specific LCA/PEF softwares would allow to perform a hotspot analysis directly in the respective software;
- It is recommended to use a specific LCA software that allows for the hotspot analysis (as required by the latest version of the PEF guidance document) to be directly extracted from the software: most relevant impact categories, life cycle stageds and process contribution of the processes in the life cycle stages. For the hotspot analysis, it would be helpful if all life cycle stages are modelled in a disaggregated form (i.e. transport per building material) in the PEF/LCA model;
- To analyse the impact of a certain building element, e.g. one square meter of floor, for BE2226 for instance (task 1 – Deliverable D3) the results from SimaPro had to be taken back to the spreadsheet where information to make this disaggregation on the level of building elements is available already and could thus be executed with limited effort. As this information, of impact of a certain building element, is important especially during a building design process, it is suggested to consider this for future LCA/PEF models to even better support the LCIA phase and the interpretation.
- The inclusion/exclusion of the toxicity impact category clearly influences the results to a significant extent (see task 1 – Deliverable D3). As weighting adds an additional level of uncertainty to the LCIA, it is recommended to investigate the influence of the weighting to

the results. This can be done either by testing the robustness of the results when several weighting sets are used, or either by extending the identification of the most relevant life cycle stages and processes to a longer list of impact categories (not limiting it to the most relevant impact categories or increasing the minimum level of three impact categories as now required by the latest version of the PEF Guidance document).

3.2.4. FEASIBILITY TO PERFORM LCA AT BUILDING LEVEL

Performing an LCA at the building level requires a lot of time, effort and knowledge. Certain aspects can make this exercise a lot easier, some things to consider are:

- **Calculation tools**: The provision of user-friendly tools can greatly improve the efficiency of performing an LCA at the building level, especially if the tool is linked to a relevant EPD database.
- **SMEs** have less resources available than large organisations. Future guidelines and tools should be develop taken into account the feasibility for small and medium sized companies within the built environment as well.
- **Costs** easily rise when performing an LCA at the building level. In some countries, free calculation tools and general data are available, while in other countries, subscription fees are asked to use certain software.
- **Simplifications**: A building LCA is very complex. Simplifications such as defining default scenarios and default parameters (e.g. implemented in tools, see above) can make the LCA more manageable, while still providing realistic and representative results.
- **Weighting and single score**: In order to ensure comparability and to make interpretation of the results more easy, weighting of different impact categories into one single score is an option, e.g. into euros by applying monetisation.
- **Training**: in order to make sure guidelines and potential tools are adopted, training should be foreseen.
- **Education**: in order to make sure guidelines and potential tools are adopted, building assessment from an environmental point of view should be part of education programmes.

3.3. SUMMARY OF MAIN CONCLUSIONS

Today only a few assessment tools can calculate all PEF-required environmental impacts. However, all PEF categories could be integrated into these tools in future to avoid burden shifting.

Most of the current assessment tools are focused on the construction phase because there is a lack of information from environmental profiles on building processes (maintenance, repair, refurbishment etc.). All life cycle stages should be taken into account.

Access to environmental profiles of products and processes should be improved using digital formats. The PEF-compliant datasets from the EC could be a good way to facilitate this access.

There is a need for communication between architecture tools (CAD systems and BIM systems) and EPD databases to make LCA of buildings.

CHAPTER 4 SUMMARY OF MAIN CONCLUSIONS AND RECOMMENDATIONS

4.1. MAIN CONCLUSIONS FOR THE ASSESSMENT AT THE BUILDING LEVEL

National systems are very valuable since they usually take national PCRs into account and therefore have the highest potential of complying with the local realistic situation. Many European countries (e.g. Belgium, France, Germany and the Netherlands) have existing LCA tools at the building level. They are either already linked to their national EPD database, or are working on implementing that feature in the near future. In case national PCRs or EPD guidelines of construction products provide guidance on the definition of the functional unit, this results in an easy link between the EPDs of construction products and the LCA at the building level. If this is not the case, it can be difficult to align the functional unit.

Another aspect that has the potential to make an LCA at the building level easier, is creating a link with **BIM software**. This can make data gathering a lot easier and therefore greatly decrease the time and effort spent by the LCA practitioner. Although the construction sector is strongly driven by SMEs, for which adopting BIM software is not easy from a financial, logistics and learning point of view, and the use of BIM is increasing through Europe, but at an uneven pace.

In order to avoid misalignment between assessment on construction products and building level, it is recommended to consider the same **life cycle stages** for the PEFCRs of both. Currently, the number of life cycle stages considered is different in the various construction PEFCRs: 15 (paints), 12 (thermal insulation), 9 (piping systems), 5 (photovoltaic module) and 4 (metal sheets). Several PEFCRs have more than one life cycle stage for the acquisition of the raw materials. Since most current LCAs of buildings are aligned with EN norms related to construction products (EN 15978/EN15804), we recommend to consider the following life cycle stages:

- PEF_A1: Pre-processing and acquisition of raw materials and packaging of raw materials
- PEF_A2: Transport of the raw (engineering) materials to the production site
- PEF_A3: Manufacturing of the construction products and the related packaging
- PEF_A4: Transport to building site
- PEF_A5: Construction - processes necessary for the construction of the building, including all ancillary materials, EoL of the packaging material disposed, any losses during construction)
- PEF_B1: Use stage
- PEF_B2: Maintenance
- PEF_B3: Repair
- PEF_B4: Replacement
- PEF_B5: Refurbishment
- PEF_B6: Operational energy use
- PEF_B7: Operational water use
- PEF_C1: Dismantling
- PEF_C2: Transport to EoL
- PEF_C3/C4: Disposal at EoL (sorting towards the EoL treatment, recycling, incineration and landfill of all materials at the EoL of the life of the building)

The application of **cut-off rules** in certain PEF pilots can result in a difference in the system boundaries of the various construction materials. For example, infrastructure for manufacturing stage is excluded for piping systems based on the cut-off rule, while it is included for the other current PEF pilots on construction products. These irregularities should be avoided when doing an environmental assessment at the building level.

Moreover, more attention should be paid to the inclusion and application of the **use phase** of the construction products and the building. For some construction products pilots, the use phase is excluded or considered only as additional information. When assessing at the building level, some aspects of the use phase are easier to consider. The development for specific scenarios at the building level is recommended.

Also for the **dismantling/demolishing** of the building, an overall scenario should be developed at the building level. Currently only 2 PEFCRs of the construction products include some basic scenarios for this.

Today only a few **tools** can calculate many environmental impacts. However, all PEF categories could be integrated into IT tools in future to avoid burden shifting. Most of the current assessment tools are focused on the construction phase because there is a lack of information from environmental profiles on building processes (maintenance, repair, refurbishment etc.). All life cycle stages should be taken into account.

Access to environmental profiles of products and processes should be improved using digital formats. The PEF-compliant **datasets** from the EC could be a good way to facilitate this access.

There is a need for communication between architecture tools (CAD systems and BIM systems) and EPD databases to make PEF/LCA of buildings.

4.2. MAIN RECOMMENDATIONS TO USE PEF FOR THE ASSESSMENT AT THE BUILDING LEVEL

4.2.1. METHODOLOGICAL ASPECTS

We recommend to develop a **PEFCR(s) at building level** in the future. In this framework the following recommendations can be summarised:

- A PEFCR at building level that forms the basis for all (new) PEFCRs for construction products is recommended. The PEFCR at building level should ensure:
    - That life cycle stages are consistently defined across PEFCRs of all construction product categories;
    - Alignment between PEFCR at building level and PEFCRs at the construction product level.
- Separate PEFCR(s) for different building typologies. It is recommended to develop in each PEFCR some necessary general rules, and then specific rules related to the different typologies;
- It is recommended to define a reference building (or asses how many reference buildings should be defined to cover the building typology) for each typology for which a PEFCR will be developed. It is recommended to define the rules in the PEFCR(s) for building(s) based on experience of experts and on a huge number of studies (not just assessing a representative building);
- It is recommended to include national scenarios in the PEFCR(s) for buildings in future;

- A differentiation in rules/guidelines is needed for PEF studies for design support/building permissions and ex-post construction. Clear guidelines to model the use phase are moreover crucial as this life cycle stage is assumed to be the most relevant one for the majority of the buildings. One important parameter in this context is the reference study period and related references service lives. It is recommended to make distinction within the PEFCR(s) between:
  - Design stage (no specific data available);
  - Buildings in operation stage (specific data available).
- To avoid difficulties with PEF studies at product level (not being adapted to the building level – for instance due to inappropriate functional/declared unit), it is recommended that the PEFCR(s) at product level are aligned with the PEFCR(s) at building level.
- It is recommended to include in a PEFCR for buildings a definition of processes that are / are not under operational control of the building commissioner. A more extended consultation with relevant stakeholders should take place related define how primary versus secondary data should be used when making PEF assessments at building level.
- Providing a clear reference flow for the assessment of buildings will greatly improve comparability of PEF studies. From a scientific point of view, the project team would recommend to define an appropriate functional unit that takes into account the function of the buildings, e.g. full time equivalents per year. However, energy performance requirements of buildings already established in all Member Sates use m² floor area for all benchmarks defined in current certification schemes of buildings. Therefore, taking practical implications into account and in order to allow consistent analyses of buildings, the project team recommends m² floor area per year as the most appropriate reference flow. When opting for m² floor area, it is recommended to define clear and strict rules on how to define the floor area: e.g. gross, net or heated floor area.
- Further, it is recommended to assess the complete building and its elements. Most importantly, clear rules should be defined in a PEFCR(s) for buildings on what shall and shall not be included when the PEF is used for either benchmarking or comparative assertions.
- Life cycle stages that we recommend to include in the system boundaries are presented in Table 4 of this report.
- Allocation recommendations:
  - At building level, the PEFCR(s) for building(s) shall be clear on the procedures related to the allocation of impacts of re-used building elements (mainly important during renovation projects) by setting up the principles for the allocation of impacts between previous system boundaries and next system boundaries is necessary (such as the reuse of pile foundation of previous building).
  - At product level the allocation need to follow the approach for the handling of multi-functional processes in the latest version of the PEF Guidance document.
- Cut-off rules need to be clearly defined in the PEFCR(s) for building(s) conform the latest version of the PEF Guidance document. It is recommended that the defined cut-off rules at building level shall be aligned with the cut-off rules for construction products in the respective PEFCR(s) at product level.
- The methodology for life cycle impact assessment and for hotspot analysis is recommended to be the same as the methodology that is presented in the latest version of the PEF Guidance document.

4.2.2. Data Collection and Modelling

The following recommendations can be summarised:

- The challenges and issues that people meet while using LCA at the building level are also valid for PEF. PEF specific issues are mainly the availability of PEF compliant generic datasets and the quality of the existing generic datasets (not always PEF compliant);
- The data requirements are dependent on the questions that are raised in the study. Efforts do not need to be put in the quantification of minor or negligible inputs and outputs that will not significantly change the overall results of the study. It is recommended that these processes will be described in the respective PEFCR(s) of building(s).
- As data quality requirements are seen as crucial for benchmarking purposes in LCA, it is recommended to follow the same approach as in PEFCRs. This ensures the necessary data quality and therefore the representativeness of defined benchmarks.
- Since the PEF endorses the use of the CFF formula it is recommended that all generic datasets allow the application of the CFF formula. This should be a recommendation for further development. The purchased PEF compliant datasets the Commission bought is already a first step in that direction.
- For the modelling of the building, we recommend a hierarchical decomposition of the building in line with the element method for cost control. It was found that this rigid hierarchical structuring was not only very helpful but seen as crucial in order to:
  - Systematically model a building avoiding any data gaps and/or double counting;
  - Easily exchange information between partners involved in the design of the building;
  - Exchange information between the various level in the model, i.e. building material, sub-elements, elements and buildings.
- When looking at a building level we recommend the following hierarchical levels of the building, and situations when applying datasets to the model of the building (ISO, 2005).
  - Level 0 – Building;
  - Level 1 – Building element;
  - Level 2 – Building sub-element;
  - Level 3 – Building material.
- It is recommended to clearly define the level of analysis within the PEFCR(s) for building(s).
- It is recommended to clearly define the level -1 for the level of analysis within the PEFCR(s) for building(s).
- The data collection process proved to be an intensive process where a high level of detail is needed to enable an accurate assessment (task 1 – Deliverable D3). This level of detail is currently not available in design documents. It is therefore recommended to make this data more readily available in a single or limited number of documents if PEF studies of buildings become current practice in the future.
- A generic template for the data collection and modelling is recommended if PEF studies of buildings should become mainstream. This template can be annexed to the PEFCR(s) to be developed.
- Regarding the life cycle inventory, it was found that a more extended list of generic datasets is needed to model an entire building and that the current Ecoinvent datasets did not allow to apply the CFF formula without adapting them. It is therefore recommended to:
  - provide a database with construction materials in line with PEF;
  - Integrate the CFF formula in the datasets.
- With regard to data needs requirements for PEF studies of buildings no clear rules exist yet. In our study we assumed that the Product stage consists of processes in Situation 3, while Construction products stage and Use stage are mainly in Situation 1 and 2, as defined in

DNM of the latest version of the PEF Guidance document. Considering that no products are directly produced at building level, the use of specific data is not mandatory. For the goal of task 1 (Deliverable D3) it was considered in agreement with the Commission that there is no added value to put time and effort in collecting specific data as this would require a lot of time and endanger the other parts of the project. We nevertheless acknowledge that the use of specific data would enhance the data quality and should be used in future when specific PEF compliant datasets will be available for construction products.

- As buildings are complex entities, also the PEF model was highly complex consisting of large amounts of data. Due to this complexity, the risks of errors are high and as mentioned before, a systematic approach is necessary. An important learning in this context, was using coding/naming conventions and systematically apply these to all elements, sub-elements and building materials in the building. It is recommended to clearly describe the definition and the correct coding terminology and naming conventions in the PEFCR(s) for building(s).
- BIM can be an important source with added value that made the PEF study at building level feasible within the foreseen timeframe, so recommended to use for PEF assessment at building level. However it is recommended to specify BIM requirements to allow a better data provision for PEF (LCA) purposes and identify ways of integrating LCA data into BIM.
- It is recommended to introduce parametrisation in the PEF/LCA model to avoid manual remodelling during each iteration.
- The concept of using element and material specific ratios, to describe density and proportion of a certain construction material contained within a sub-element or element, is recommended;
- Harmonisation of calculation methodology: mandate revision EN 15804 / alignment PEF;
- Harmonisation of databases:
  - Development of a common PEF database for the most frequent processes, e.g. using PEF compliant datasets purchased by EC.
- Regarding the life cycle inventory, a more extensive list of generic datasets is needed to model an entire building and that the current datasets do not allow to apply the CFF formula without adapting the datasets. It is therefore recommended to:
  - Provide a database with construction materials in line with PEF;
  - Integrate the CFF formula in the datasets.
- Recommendation: provision of PEF compliant data for all relevant sub systems in the building to improve applicability in a building design context.
- Development of BIM-ready datasets, e.g. environmental data aggregated on different levels depending on the planning stage the assessment should be carried out in. E.g. data of building elements in early design stages, detailed data on level of sub-elements and material composition for design development, tender stage and beyond;
- Based on the findings of this study, a more flexible parameter structure for the amounts of elements and materials has to be found to further support a parametric approach applicable to other buildings while acknowledging the constraints in BIM and LCA software’s functionality.

4.2.3. INTERPRETATION OF RESULTS

For the LCAI assessment and the hotspot analysis, we can summarise the following recommendations:

- The LCA/PEF model in combination with the BIM model will allow to assess the environmental performance of the building in a fairly easy way.
- It is recommended to use the latest version of the PEF Guidance document for LCIA and interpretation (hotspot analysis).
- It is recommended to use PEF/LCA softwares that allow to directly extract the LCIA results at the level of the building, at the level of the life cycle stages, at the level of the element in each life cycle stage, and at the level of the material/process. It would be helpful if in future the PEF/LCA software would allow to do the hotspot analysis (identification of the most relevant impact categories, life cycle stages and processes) directly in the software.
- The inclusion/exclusion of the toxicity impact category can clearly influence the results to a significant extent, especially for the second case study. As weighting adds an additional level of uncertainty to the LCIA, it is recommended to investigate the influence of the weighting to the results. This can be done either by testing the robustness of the results when several weighting sets are used, or either by extending the identification of the most relevant life cycle stages and processes to a longer list of impact categories.
- It is recommended that the results of the PEF assessment will be critical reviewed and/or verified, in keeping with the rules as described in latest version of the PEF guidance document and the respective PEFCR(s) at building level.
- It is recommended that the results of the PEF assessment will be fairly, completely and accurately reported to the intended audience, in keeping with the rules as described in the latest version of the PEF guidance document and the respective PEFCR(s) at building level.

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ANNEXES

Annex 1 – Minutes of 2nd Stakeholder Workshop in Brussels, including feedback of stakeholders

Date and location

PEF4Buildings – 2nd Stakeholder Workshop at EC
Date: Monday 29th of January 2018
Time: 10 am to 4 pm
Venue: Premises of European Commission (Brussels)

Agenda

1. **10:00 – 10:30:** Registration and welcome coffee
2. **10:30 – 10:40:** Introduction by EC
3. **10:40 – 10:50:** PEF4Buildings project in a nutshell
4. **10:50 – 11:15:** Brief summary of the results of the PEF assessment of two office buildings
5. **11:15 – 12:15:** Possible approaches for benchmark and classes of performance for office buildings
6. **12:15 – 13:00:** Interactive discussion with stakeholders
7. **13:00 – 14:00:** Lunch break / networking
8. **14:00 – 14:45:** Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
9. **14:45 – 15:30:** Interactive discussion with stakeholders
10. **15:30 – 16:30:** Closing of the meeting – Coffee – Networking

Representatives from the following organisations participated

Aetic Architectes
Afnor
AGV Glass Europe
Aliaxis/ PEF pipes pilot
ArcelorMittal
Archipelago ar'te
Austrian Chamber of Commerce
BASF
Belgian Brick Association
Belgian Building Research Institute
BIBM
BRE
BRE and CEN TC 350 WG1
CEMBUREAU, the European Cement Association

CEN/ TC 350
CEN/ TC 350 / DIN
Cerame-Unie
Colruyt Group
Construction Products Europe
DGNB (German Sustainable Building Council)
DHUP
EPPA
EUMEPS
Eurima
Eurogypsum
European Aluminium
European Calcium Silicate Producers' Association
European Parliament
European Partnership for Energy and the Environment (EPEE)
European Steel Association (EUROFER)
Fachverband Steine-Keramik
Federal Public Service of Health and Environment, Belgium
French Federation Tiles & Bricks (FFTB)
Gesamtverband der Aluminiumindustrie e.V.
Glass for Europe
GFE / AGC
IBO GmbH
Knauf Insulation
KU Leuven
Ministry for and Ecological and Solidarity Transition – Ministry of Territorial Cohesion, France
NIBE
PEP Ecopassport
PlasticsEurope
PU Europe
Rockwool
Saint Gobain
Solinnen
Thinkstep
Treeze Ltd
TU Graz
UECBV
VELUX Group
VITO/ EnergyVille
VITO
WeLoop
Wienerberger

Minutes

1. Registration and welcome coffee

2. M. Galatola, EC, DG Environment: Introduction to PEF, PEF4Buildings and the relation to other approaches (e.g. Level(s)). Comment from J. Lindblom (DG ENV): End of Level(s) phase by end of 2019.

3. C. Spirinckx, VITO: (see slides) Introduction of PEF4Buildings team; Agenda overview; PEF4Buildings in a nutshell: Overview and introduction to project tasks 1 to 4. (see slides)
   Project planning and important dates: **Deadline for written feedback** by stakeholders is **09/02/2018**.

4. K. Allacker, KU Leuven: (see slides) Results of the PEF assessment of the case study buildings (see slides). However, it is important to keep in mind that the results of the two studies, in terms of numerical values for each impact category, are not the main objective of this project. The focus is on the assessment methodology and challenges and learnings from application on building level. Presentation of functional unit, system boundaries, definition of life cycle stages, case studies, element method used to structure inventory, data used to compile life cycle inventory.

Q= Questions; A=Answer; S=Statement

Q1 (*unknown*): How can we have negative impacts in PEF_A1 if we don't have module D?
A1 (P4B project team): Because you can have recycled content for the new product, which allows to have negative impact, depending on (recycled) materials used.

Q2 (WeLOOP): At which level EoL scenarios are defined? Is there any recycling scenario considered in the modelling?
A1 (KU Leuven): Recycling scenarios per material. For scenarios, we followed PEFCRs where available, else we used Belgian/Austrian PCRs. Considering data, the datasets that were available are used, with proxies added where needed.

Q3 (BRE and CEN TC350 WG1): 1) How did you use EN 15978? As it is being revised at the moment. Purpose to align indicators within EN 15978, 15804 and PEF – which is okay. 2) Did you change definition of Life Cycle Stages and excluded module D? What are implications of defining the LCS as done in the PEF4Buildings study? 3) Did you attempt to analyse one building in two different ways?
A3.1 (DG ENV): No link/immediate connection to mandate and work done in Cen TC 350. No need to align with what is done in the PEF4Buildings project at this point.
A3.2. (VITO): Not excluded module D, but modelled in a way to include information usually contained in module D and allocate these to PEF_A1 acc. to the Circular Footprint Formula (CFF). Thus partly included in the beginning (PEF_A1) and in the end (PEF_C3/C4).
A3.3. (KU Leuven): Not so much difference in modelling of buildings, but big difference in how results are aggregated and presented (interpretation phase). In the design phase, it is easier to have a smaller list of elements/materials for interpretation reasons.

Q4 (CEN TC 350/DIN): How was assessment done for total use of energy, which would have been excluded in EN 15978 assessments.

A4 (KU Leuven): Discussion referring to assessment during design vs. ex-post assessment. Data that was available for energy use was aggregated and it was not possible to split. Moreover, lighting in the Austrian case is also used for heating of the building.

Q5 (VELUX): These studies intended to be used to improve building impact, however trade-off between construction and use stage. Have you done analysis between implications of comparing construction and use phase? Tendency to compare them 1:1, independent of uncertainty contained in these results (especially for use phase related results)
A5 (KU Leuven): was not part of this study. This issue also arises in the benchmarking discussion.

Q6 (CEN TC 350/DIN): Which five PEFCRs were used for the assessments? What other (generic) data was used? (from databases, e.g. the German database, or Life cycle databases (GaBi, Ecoinvent) Did you find differences in applicability of this data?
A6.1 (VITO): Hot and cold water supply piping, thermal insulation, decorative paints, metal sheets, and photovoltaics. For other not covered by PEFCRs we used European PCRs where available, national PCRs and scenarios indicated there. Generic data was mainly taken from EcoInvent but had to be customised, some ELCD data (as PEF compliant datasets were only published at a time when they could no longer be implemented in the study).
A6.2 (DG ENV): Data learnings: proof that harmonization of secondary datasets is important but difficult as wide margins for improvements of quality of data, quality of documentation. If you don't harmonize backbones of databases, it won't be possible to achieve comparable results.

Q7 (Treeze): Question to clarify the CFF and assignment of footprints to LCS (always 50/50)? Asks for clarification on water consumption indicators.
A7.1 (DG ENV): Footprint formula not always 50/50, now closer to market conditions (20/80, depending on material). Problem with water is about implementation of water method in software.

5. K. Allacker, KU Leuven and A. Passer, TU Graz: (See slides) Presentation of desk study/literature review. Overview of potential meaning and approach for benchmarking at building level. Details on definition of reference building (acc. approach of DGNB 2015, Minergie-ECO, BREEAM, LEED, Dutch legal requirements). Conclusions regarding differences in approach/scope. Functional unit, reference flow, system boundaries (VTT report, BBP report, DGNB 2015).
   L. Damen, VITO: Classes of performance (PEF guidance, French initiative E+/C-, Dutch legal requirements, GRO)

6. Interactive discussion with stakeholders (moderated by C. Spirinckx, VITO):
   Question 1: Reference building/benchmark. How to define reference buildings?
   S1 (DGNB): Most important to know purpose of benchmark later on. Different possibilities what you use benchmark for (minimal requirements vs. future goals), different ways of developing the benchmark possible. Important to talk about function of building – energy performance and comfort (important to specify what comfort? Thermal, visual, acoustic comfort? All have influence on how building is designed. Other design criteria (accessibility, etc.) – without definition of "function" it is hard to take next step and define benchmarks. Experience from DGNB suggests it is better to have different assessments for different criteria which are then combined in the final score (not all of which may be related to LCA criteria).
   Do you have a recommendation for the commission already?

S1 (VITO): Based on desk review and feedback from stakeholders the recommendations for the commission will be drafted.

Q (EURIMA): Have you assessed learnings/conclusions regarding benchmarks from Level(s) regarding benchmarks? As there it is stated to have different levels to assess and compare. Differences in benchmarks for e.g. portfolio management versus benchmarks used to implement policy.
A (DG ENV): Goal is to look at an LCA/PEF specific benchmark (while aware this only covers a part of the important aspects).

S (CEN TC350): Performance criteria of different countries, setting benchmarks against these criteria is important. BREEAM has benchmarks for different parameters.

S (Thinkstep/CEN TC 350): Decision important whether benchmark is based on e.g. energy consumption of existing buildings. Better to look forward at new buildings. Not focus too much on old buildings.
Besides, on European level things like electricity mix will influence benchmark/performance when comparing buildings – e.g. due to energy mix Scandinavian buildings could perform very well.

Q (Treeze): in Switzerland, starting point to establish benchmarks was “what goal do we need to achieve”? Based on 1Gt CO_2, or these days more likely the 2°C goals, they calculated the budget for buildings, per m² of buildings, per person. Recommendation to establish benchmarks starting from the requirements which goal/reduction is to be achieved.

S (DG ENV): When developing weighting system for PEF, they looked also at distance to target approach. However, we have not looked into the issue of benchmarking from the perspective of the political targets. That is an interesting concept.

S (European Environmental Bureau): Distance to target approach very attractive from environmental point of view. Regarding ways to define benchmarks, important not to go for one aggregated benchmark but be clear about purpose (e.g. architect who needs information to improve building design) and distinguish. Important to include adaptability, flexibility, replicability of elements in buildings and incorporate this in benchmark discussion – building “fit for purpose” over its life span. Sees limitations in that regard in LCA and PEF approach.

Q (EUMEPS) Important to look at long term targets (longterm roadmaps). How design decisions connect to high level targets, thus need to break them down to national targets. Diversity in classification methods is confusing for participants in the process. Important to harmonize in order to know what we are talking about.

S: (ECI) Buildings in future will have to be more productive. Buildings that pass on benefits. If only done on inventory base, we might miss opportunity to bring buildings forward in the future.

S (DGNB): E.g. if we use electricity mix of now to calculate operational phase we miscalculate (as this will change a lot). Sam issue in reference building used for

benchmarking. Indicating "potential" to do something, a specific measure, to assess future scenarios. Indicate e.g. potential to recycle an element/material.
Question is, how much investment in materials makes sense to have a well operating building over time. As ways of operating will change it is important to anticipate this. Just looking at material will not lead to best life cycle performance.

S (DG ENV): Energy mix will be different, recycling is unknown. How to combine the high uncertainty with the cradle to grave?

S (Velux): Could set limits for extreme situations an know that it will be between those limits (zero carbon versus no requirements). Now only looking at optimisation of the use phase.

S (Treeze): Looking at measures, dynamic systems to establish benchmarks for e.g. 2030 and then analyse buildings and check them against set benchmarks.

S (PU Europe): Benchmarks, complicated political environment. We can draw pathways for the European Union, having an agreement amongst 28 member states might be difficult. Suggests to fit benchmarks according to national context.

S (ECI): Only focusing on benchmarks that drive down resource use, we might miss opportunity to have buildings, which are productive but use more resources.

S (CEN TC350): Is there a benefit to having a standardized approach to determine your benchmark, as opposed to what the actual value of benchmark is.

S (DGNB): for use stage, they use dynamic benchmark based on type of use (of office. E.g. for office with a lot of meeting rooms is different than office with a lot of workplaces and hardly meeting rooms). This approach tries to incorporate the "occupational density", which is especially hard to specify during design stage otherwise. DGNB experience show this approach works well.
Importance to look at flexibility of building, especially regarding the service life of buildings. Current problem of market is that we have good quality buildings which are not flexible to adapt to market demands, thus are torn down after e.g. 20 years and replaced. This shows importance of flexibility, even though this is hard to standardize.

S (PU Europe): Development of "smartness" indicator within CEN?

Q (WeLOOP): In French approach there is experimentation phase, where people apply approach and from the sample results (e.g. two-year phase) are collected and grouped to establish an empirical benchmark. Experimentation phase where people can look on method and provide results to base benchmark based on this.

7. Lunch break

8. C. Spirinckx, VITO: (See slides) Link between the assessment of environmental performance of construction products and the assessment of the environmental performance on buildings by using the PEF method.
   Existing methods and tools; check of draft PEFCRs; preparation of recommendation and guidance on how to link assessment on product level with building level; relevant existing

approaches e.g. EN 15978 (Europe), MMG (Belgium), Elodie (France), eLCA (Germany), GPR Gebouw (Netherlands)
L. Damen, VITO: (See slides) Analysis and comparison of existing PEFCRs for construction products.
C. Spirinckx, VITO: (See slides) Conclusions and preliminary recommendations regarding provision of data (PEFCRs) on different levels, differences in application (assessment during design vs. post-construction/during use), software solutions (Note: No specific LCA software is endorsed for use), requirements towards LCA/PEF for buildings applicability, BIM for LCA/PEF.

9. Discussion with stakeholders: Do we need a PEFCR for buildings?

Q1 (CEN TC 350/DIN): We have to deal with the question of databases. Harmonization of calculation is necessary, maybe separate from the discussion on harmonized benchmarks. Maybe a harmonized approach towards benchmarking is more feasible, rather than fixed values for benchmarks. This should be up to market and good ideas from construction world.
Common calculation rules are important. Part of difficulties with PEF are scalability to certain types of buildings. Exercise should give light on applicability of PEF towards building assessment. Wondering whether data used from PEF pilots were useful to assess buildings. What was useful, what needs to be changed? If next to the CEN amendment, with the goal to harmonize. Common calculation rules which have to be same for EPD and PEF. If a PEFCR for buildings, tailored for PEF, is developed, this would move away from a harmonized approach, also in the context of the amendment of EN 15804/15978.

S (DG ENV): Some things will not be aligned. We are not going to develop PEFCRs for buildings. Under assumption, that mandate will be delivered as expected, the EC will follow and refer to CEN standards.
Back to calculation rules: still situation is that data quality, secondary datasets, etc. will not be used in EPDs. Thus there is a value in maintaining PEFCRs already developed for construction products, to get more information/guidance on modelling/scenarios. Wish is that next evolution of PCRs will move closer to PEF.

S (BRE and CEN TC350 WG1): Thanks for reassuring answer (tw. MG). Invites project team to share lessons learned from practicality of PEF application within CEN WG1. Emphasizes the direction to use building assessment as the driver for requirements towards building products (EPDs/PEFCRs), rather than other way around.

S (Thinkstep): sometimes manufacturer deliver system (full window: frame, glazing, etc.), sometimes only parts of system (e.g. window frame only).

S (EUMEPS): Difficulty with additional requirements at national level which need attention. Roadmap for stakeholders regarding strategic decisions would help. Also it would be valuable to get deeper insight into learnings from BIM application within PEF4Buildings project. What information was available – what did work, what did not?

S (European Steel Association): Benefits from PEF due to more clear specification of certain aspects still vague in EN 15804. Maybe too early for benchmarks as methodology is not fixed (for EN 15804/15978)

S (*unknown*): Regarding renovation scenarios, PEFCRs could help in decisions due to stricter guidelines on end of life scenarios.

S (AGC Glass Europe): If you want reproducibility you have to ensure databases are the same. One European database would be nice.

S (*unknown*): Group Indata, led by BBSR, to define digital format for EPD (ILCD+EPD). Target is to create European network where you can find all EPDs on one platform in digital format.

Q to stakeholders (DG ENV): Is there any movement to tackle issues of quality of data? In PEF tried to establish an approach to assess data quality. Main interest is to actually look at the data and see how data quality can be assessed and quantified. Is there a timeframe in 3,5,10 years where quality of data used will become part of EPD schemes?

S (Federal Public Service of Health and Environment Belgium): In Belgium 2-3 years ago studies on data quality were done. Not only interesting but necessary to dig into data quality. Most important burden is time, hence added cost, that comes with using high quality data. Difficult to implement as this would require additional time (cost) for establishing EPD in the first place, would hinder the market.

S (CEN TC 350/DIN): We have data on what drives the results and some data is not so relevant, for this data quality can differ and won't matter too much. New standard on data quality will be launched in CEN TC 350 – regarding generic data and product specific data. Complications on who will do the quality assessment for LCA data? Not manageable for LCA practitioner, required to have extra data verifier (related to data provider).

Q (DG ENV): Data provider responsible for data quality. Data peer-reviewed, should be quality assurance. Findings of major errors raise questions on current quality of peer review.

S (Thinkstep): Data quality depends on requirements and intended application of data. Commission need to "shout" more about data quality issues it identifies.

S (DGNB): Bigger influence is not coming from individual datasets in the model, more from the way modelling has been done for the building (e.g. completeness of model, way how datasets were linked, how aggregation was done, etc.). Does not mean that data quality does not matter, but influence is lower than stated in discussion now. Ensuring data quality won't solve the problem. People are using data in inappropriate way, for many reasons. People might need information in the moment they do assessment, at moment they can influence design/decision. If you have all information on building level it is too late to take decision as building is built already. More important to have good quality of assessment rather than of dataset.

S (Treeze): Thus, no need for one single European database.

S (DGNB): Depends on what you want to do. For e.g. early design stage scenarios you don't need single data source, as its different than for detailed assessment of full building.

S (DG ENV): No intentions to have single European database. Competition of data providers is good to ensure quality. Idea is to have list of database providers who provide the required quality of data (following certain calculation method, etc.).

S (EUMEPS): Better to start working on basis of existing approaches than aim at starting it from beginning. If looking one step further, e.g. declarations at product level.

S (*unknown*) About databases, distinction between background data and EPD data needs to be made. E.g. for Netherlands background data is fixed. Definitely advantage to have one database for background data.

S (ROCKWOOL): Otherwise agreement, no one European database for EPDs required. However, would be beneficial to have common standard for background data quality.

10. C. Spirinckx, VITO: Closing of meeting.

Additional feedback from stakeholders after stakeholder meeting

In Italic grey: comments from respective stakeholders.
After each comment: feedback from project team.

Velux
Thank you for a very interesting report, I am looking forward to the additional material that will be added in the final report.

- *I would suggest to rescope the conclusion a bit according to the development of TC350 PEF alignment and focus on how we can further strengthen that work to achieve a good platform for building assessment. As mentioned, EN 15978 is up for revision and any concrete inputs would probably be very useful.*
- *Making two LCAs on buildings, one traditional and one NZEB building is interesting – it would be further interesting if the buildings also had been assessed in the same geographical location thus to see positive and negative impacts of the NZEB concept compared to traditional constructions. As the energy systems are different for Austria and Belgium the results are not really comparable as it is.*
- *I would very much like some considerations on how to deal with the great uncertainties of future energy systems and future waste management systems and how to include this in the building assessment. Right now, the use phase will always be more important than materials and EoL due to the present highly polluting energy systems, but they are simultaneously under a great technological and political pressure to change within a short time frame (some targets are setting 2030 as a point of CO2 neutrality). Then the building's use phase of 50 years suddenly becomes rather different than expected today – and all our legislative requirements for the energy efficient use phase will be a gross overshoot and not give us real environmental benefits due to the high material investments in the construction phase.*

Again thank you for the report and the presentation.

Feedback from project team:

Thank you for your valuable feedback. Although you raised three important issues, none of these can be addressed within the PEF4Buildings project.

Comment 1: Although the project team understands the request to provide further input to the revision of EN 15978, that was not the goal of this project and hence was not studied as such. More specifically, this study did not check the outcomes of this project with EN 15978. Nevertheless, we think that the results of this project can be used for this purpose and hence can be considered as input for the revision of EN 15978.

Comment 2: the project team agrees that the analysis of both buildings in the same climatic context would be interesting to further derive learnings from that, but that is not feasible within the scope of this project. This would require quite a lot of additional work in order to accurately estimate the operational energy use of the buildings in a different climate than their actual climate. Dynamic energy simulations would be needed to estimate the operational energy use, while current assessment is based on real consumption.

Comment 3: The influence of the changing energy systems and waste management systems in future on the life cycle environmental impact of the building has not been assessed. The PEF method requires to assume current common practice for both energy and end-of-life processes. This project followed the PEF method as that was the goal and did not question this issue. We do recognise that changing energy mix might influence the life cycle impacts to an important extent and is in general an interesting issue to be investigated. However, this is beyond the scope of the PEF4Building project.

Rockwool

Further to your question to check the statements about the Dutch system:

First of all thanks for taking the Dutch approach explicitly into account. Most of the info is fine, except for two slides where I believe you mixed up the legal requirements (in the Bouwbesluit) for buildings and related to a building permit, with the voluntary Green Public procurement system for office buildings. Both make use of the same Bepalingsmethode, but use another system of benchmarking:

The Bouwbesluit applies to all buildings (dwellings, offices, hospitals etc), both new-built and renovations for which you need a permit. The Bouwbesluit requires a minimum value for the single-score indicator of the building LCA. The W/E report "Bepaling kwaliteitsniveaus milieuprestatie van woonfuncties" referred to on slide 94, 89 and 80, 81 are related to this and well-quoted.

GPP (Duurzaam Inkopen) applies to public office buildings and is strictly spoken not a legal requirement. Public buying is a private activity in NL. They don't use the A-E classes investigated for the Bouwbesluit, but quality classes A-C relative to the Bouwbesluit level. See annex in https://www.rijksoverheid.nl/documenten/rapporten/2016/07/01/bepaling-kwaliteitsniveaus-milieuprestatie-van-woonfuncties
This is mixed up in slide 65 and 95, see comments below.

Anyways, it will not change the conclusions and your PEFCR work.
Good luck with the finalisation.

Feedback from project team:
Thank you for clarifying this. We will make this clear in the final report and clearly distinguish between the legal requirements in the Netherlands, and voluntary GPP. The powerpoint presentation used during the second stakeholder workshop will however not be updated.

VITO

First of all let me congratulate you with the nice workshop you've organised. I was very glad to be able to participate at it.

I would like to take the opportunity to share some thoughts with you…
I leave it up to you whether you want to add this in the final report or not.

- ***Regarding the use of BIM:***
    - *BIM is – and will certainly be in the future – an important way of exchanging data. If a BIM model is available, it can facilitate data inventory considerately*
    - *As you've mentioned, it is not possible to cover all LCI data and parameters through BIM. It would be very instructive to have an overview of LCI data and parameters that is generally available through BIM and which data should be retrieved through other means.*
    - *The use of BIM is increasing through Europe, but at an uneven pace. Countries such as the UK, Finland and Norway are quite ahead over the rest of Europe, mainly because the use of BIM has been made mandatory for public and/or new buildings. Hence, an aligned policy to adopt BIM will play an important role in the near future (at least for new and public buildings; existing building will be far more difficult to inventory)*
    - *Nevertheless, don't forget that the construction sector is mainly made by SMEs, for which adopting BIM software (from a financial, logistics and learning point of views) is really not easy. It will take time!*
    - *This brings me to the following concluding question/remark: For which type of buildings (public/private; new/existing) and EU regions (in all EU or parts of it) will a PEF study be actually affordable/applicable, knowing that time = money and the investment of (often commercial) BIM software is often too high for SMEs within the building value chain?*
- ***Regarding PEF and Circular Economy:***
    - *A participant of the workshop (sorry, I don't know his name) argued that PEF4Buildings could play an important role to assess 'circularity' within the built environment. (note: I didn't answer at that moment, because the answer is quite technical, as you will see below)*
    - *I think it does (the circular footprint formula is after all an important component within the PEF methodology)…but only partly. The following methodological aspects are currently missing in the PEF (and also CEN) methodology (or at least unclear). Most of them have been discussed within the OVAM study "Design for Change", performed by VITO, KU Leuven and VUB in 2014-2015*
        1. *to take into account the unpredictability of the use and EoL phases, we suggest to take into account different (realistic and extreme) scenarios, instead of one fixed scenario. This may involve e.g. different transformation scenarios, involving a minimum, median or maximum number of replacements of building parts, but also different EoL practices*

differentiating current practices (often incineration, landfill and down-cycling) from (near future) circular practices (reuse, recycling/upcycling and composting/biodegrading). This scenario analysis will support decision-makers in the design stage to take sound decisions for the future.

ii. *Related to this, not all 'circularity/circular economy' aspects can be covered by an LCA, ergo a PEF study. 'the easiness to deconstruct a building (part)', 'the potential of a building layout/composition to be transformed', 'the capacity of a building element to be reused', etc. should be addressed in a quality assessment, prior or in parallel with the LCA study. Also, the financial benefits/constraints of designing and buildings for 'circularity' is not addressed in an LCA. Life cycle costing should be used to assess this. However, also here, some methodological choices within the existing standards should be questioned: such as the linear (financial) depreciation of the building (parts) along their life span and the real value of materials and building components after their use period. How to determine the latter is still under debate, primarily because of the fluctuation of materials/commodities. (in the H2020 BAMB project, these aspects are all integrated in a 'Circular Building Assessment' – to be presented on the Ecobuild fare in London, in April 2018)*

Feedback from project team:

Thank you for your valuable comments. We herewith want to provide some insights/feedback based on the learnings from this project.

Use of BIM - data inventory:

- We agree that BIM is indeed an important source of information for the life cycle inventory of the building. However, based on the learnings from the two BIM models in this project, BIM models can be build up in various ways. In order to make these useful for LCA studies, rules should be developed to guide the practitioner in how to build its BIM model if to be used for LCA studies. As this was not the aim of this project, such rules were not derived yet, but is seen as an important next step if the aim is to mainstream LCA in building practice.
- Regarding the data available in BIM and the additional information needed from other sources: this is reported in the report D3 where the modelling of and data sources for both buildings are explained in detail.
- Feasibility of PEF studies of Buildings throughout Europe and for all types of buildings: we understand your concern and indeed BIM models of small-scale buildings might not be the most time efficient. We think that LCA tools for buildings (see for example the Netherlands, France or Belgium) will be needed in future in all Member States. The way how buildings are modelled in these software might be different depending on the complexity of the building. More specifically, for large scale or complex buildings, this software might be coupled with BIM models, while for smaller or more simple buildings, the necessary data can be manually input in the software (or by using other CAD models)

PEF and circular economy:

- The issues raised relate to the PEF method and PEF Guidance document. As this project aimed at testing the PEF method and the PEF Guidance document at building level, the issues raised were not analysed. However, this input is valuable for further developments of the PEF method.
- Various aspects raised are however covered in LEVELs in which environmental impact (LCA) is coupled with other sustainability criteria.

French government - Ministry for the Ecological and Inclusive Transition

Thank you again for the organisation of this very interesting workshop on PEF4Buildings.As discussed, we would like to share some thoughts with you.
First of all, some comments on the presentation *- We would like to clarify information on EPDs in France (slide 110): Elodie is not the only tool for LCA at building level. Today, there are 6 software available to carry out a building LCA in accordance with the E+C- framework. So we would prefer not to quote Elodie alone.*
Some comments/answers to the questions *you raised in your document or during the meeting:*
- The goal of the method to be implemented should be clearly define. In France, the goal of the E+C- framework and the next national building regulation is to steer the building designer's choices (choice of energy, of material, shape of the building...) and to encourage the industrials to improve their processes.
- As regard the reference building: t would be logical to build the threshold with the overall goal of GHG reduction of each country. However to link the overall goals and the goals for the buildings with a LCA point of view is not that simple (we are facing some difficulties to do that for France); what is more, from a building regulation point of view, the reference should take into account the designer constraints, what he cannot change (climate, foundations, obligation of a car park...)
- As regards the link between EPDs and LCA at the building level. We have encountered difficulties with some EPDs that were not adapted for LCA at the building levels (inappropriate functional unit); besides, to ensure EPDs are homogeneous the 15804 norm should be clarified for each category of product in PCRs and those PCRs should be given a status, and their process of development scrutinized.

<u>Feedback from project team:</u>
Thank you for your appreciation of the workshop and sharing your thoughts.

- Elodie: Thank you for clarifying that Elodie is not the only tool for LCA at building level in France. We corrected this in the report and mention all six software tools available in France to date. The powerpoint presentation used during the second stakeholder workshop will however not be updated.
- Thank you for your inputs for the questions raised based on your expertise in France. These will be considered for the recommendations regarding benchmarking in our report.

Politecnico di Milano

I tried to answer the questions, in my opinion

1. How to define reference buildings?
Reference building(s)/benchmark per climate zone (for variation in the energy efficiency requirement) and per country (for variation in legislation requirement)
Probably it is not possible to define one reference building, but it is necessary to define different reference buildings related to different typology (geometry) and then define an average impact value among them
The reference building should be based on statistical data. It is not possible to select a real building. It is necessary to define a synthetical average building: so average sqm, average WWR, average S/V, and so on.
If the representative building is representative of the actual building stock, also for the energy consumption it is necessary to use average data, because a single building cannot be representative. But if the representative building has to define a target (related to actual

legislation), legal requirement limits should be used (but for energy carriers, statistical data are good), so the reference building is a baseline building (as in energy directive)
Statistical data on construction materials are not available. Maybe some reference related to research report

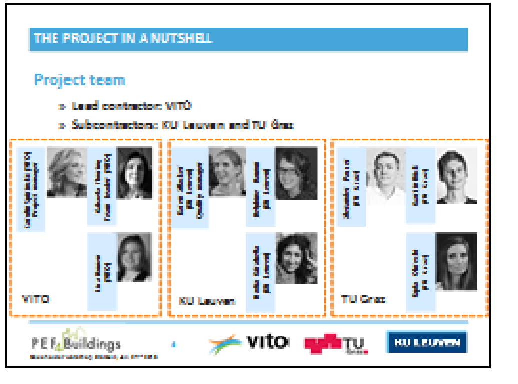
2. How to define the functional unit for office buildings?
In the energy certification, the reference unit is m^3
Square meter is a good reference for housing, because there is a standard height, but for office is not good because of different heights. Using the same reference of energy certification could be useful to allow comparison. Reading a value related to number of office is not simple for a designer. Instead read a value express in m2 or m3 is more simple for architect and construction engineers.
3. Which approach for defining benchmark and performance classes should be applied?
If the representative product is representative of actual building stock, it could be based on statistical data, buti if it is representative of new buidlings and is define for a limit value, the benchmark should be based on legal requirement as baseline (like in all Green Buildings Rating Systems, as LEED) and statistical data for characteristics not regulated.

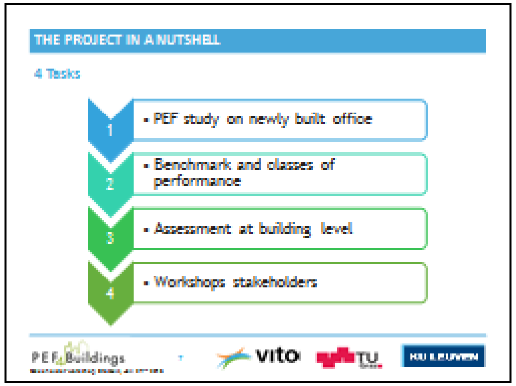
1. Do we need a PEFCR for buildings?
More defined rules for LCA of buildings probably are necessary, but it is a very hard work.
Rules have to be defined based on experience of experts and on a huge number of studies. Not just assessing a representative building.
Probably are necessary general rules, and then specific rules related to the different functions (housing, office, etc)

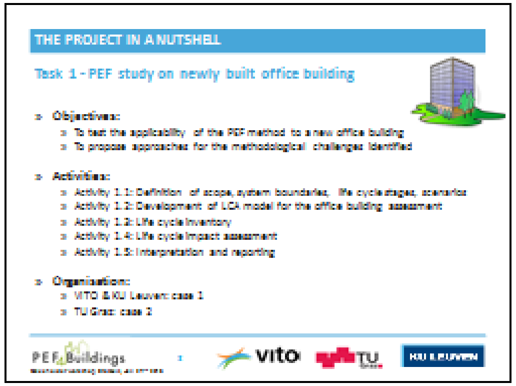
2. Do we need one database?
A database can guarantee more comparable results.

Feedback from project team:
The project team thanks for the valuable feedback on the questions raised. These will be considered for the recommendations regarding benchmarking and PEF method for buildings in our report.

Slides used during workshop




THE PROJECT IN A NUTSHELL
4 Tasks
1 • PEF study on newly built office
2 • Benchmark and classes of performance
3 • Assessment at building level
4 • Workshops stakeholders
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 1 - PEF study on newly built office building
Objectives:
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
Activities:
Activity 1.1: Definition of scope, system boundaries, life cycle stages, scenarios
Activity 1.2: Development of LCA model for the office building assessment
Activity 1.3: Life cycle inventory
Activity 1.4: Life cycle impact assessment
Activity 1.5: Interpretation and reporting
Organisation:
VITO & KU Leuven: case 1
TU Graz: case 2
PEF4Buildings
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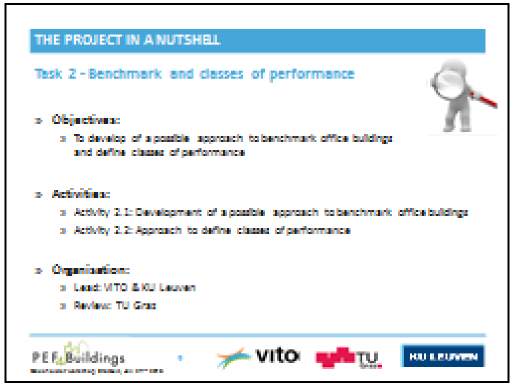
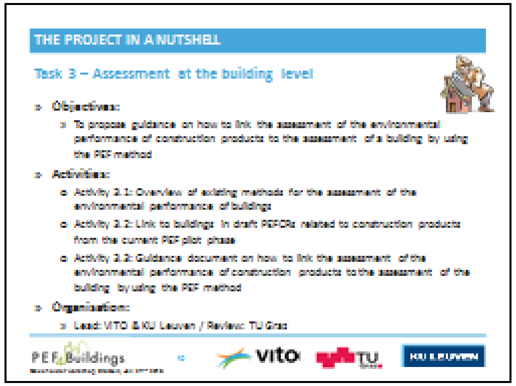
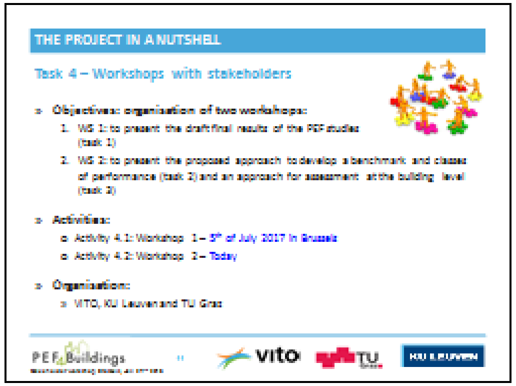
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 2 - Benchmark and classes of performance
Objectives:
To develop of a possible approach to benchmark office buildings and define classes of performance
Activities:
Activity 2.1: Development of a possible approach to benchmark office buildings
Activity 2.2: Approach to define classes of performance
Organisation:
Lead: VITO & KU Leuven
Review: TU Graz
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 3 – Assessment at the building level
Objectives:
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method
Activities:
Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings
Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Organisation:
Lead: VITO & KU Leuven / Review: TU Graz
PEF4Buildings
vito
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Task 4 – Workshops with stakeholders
Objectives: organisation of two workshops:
1. WS 1: to present the draft final results of the PEF studies (task 1)
2. WS 2: to present the proposed approach to develop a benchmark and classes of performance (task 2) and an approach for assessment at the building level (task 3)
Activities:
Activity 4.1: Workshop 1 – 5th of July 2017 in Brussels
Activity 4.2: Workshop 2 – Today
Organisation:
VITO, KU Leuven and TU Graz
PEF4Buildings
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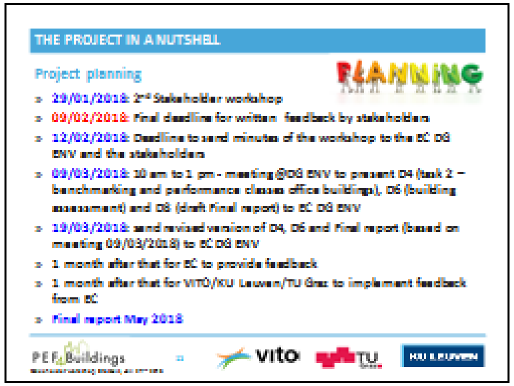
TU Graz
KU LEUVEN


THE PROJECT IN A NUTSHELL
Project planning
PLANNING
29/01/2018: 2nd Stakeholder workshop
09/02/2018: Final deadline for written feedback by stakeholders
12/02/2018: Deadline to send minutes of the workshop to the EC DG ENV and the stakeholders
09/03/2018: 10 am to 1 pm - meeting @DG ENV to present D4 (task 2 – benchmarking and performance classes office buildings), D6 (building assessment) and D8 (draft Final report) to EC DG ENV
19/03/2018: send revised version of D4, D6 and Final report (based on meeting 09/03/2018) to EC DG ENV
1 month after that for EC to provide feedback
1 month after that for VITO/KU Leuven/TU Graz to implement feedback from EC
Final report May 2018
PEF4Buildings
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TU Graz
KU LEUVEN


AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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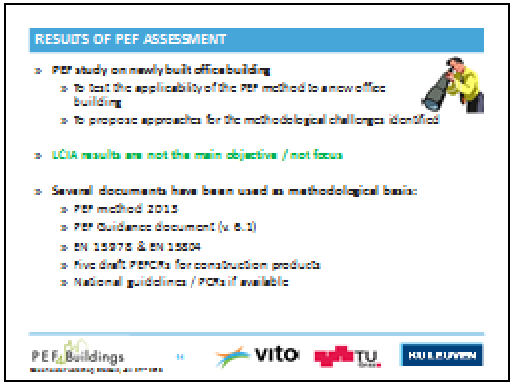
RESULTS OF PEF ASSESSMENT
PEF study on newly built office building
To test the applicability of the PEF method to a new office building
To propose approaches for the methodological challenges identified
LCIA results are not the main objective / not focus
Several documents have been used as methodological basis:
PEF method 2013
PEF Guidance document (v. 6.1)
EN 15978 & EN 15804
Five draft PEFCRs for construction products
National guidelines / PCRs if available
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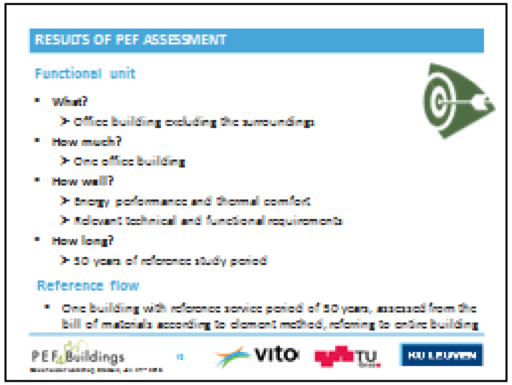
RESULTS OF PEF ASSESSMENT
Functional unit
What?
Office building excluding the surroundings
How much?
One office building
How well?
Energy performance and thermal comfort
Relevant technical and functional requirements
How long?
50 years of reference study period
Reference flow
One building with reference service period of 50 years, assessed from the bill of materials according to element method, referring to entire building
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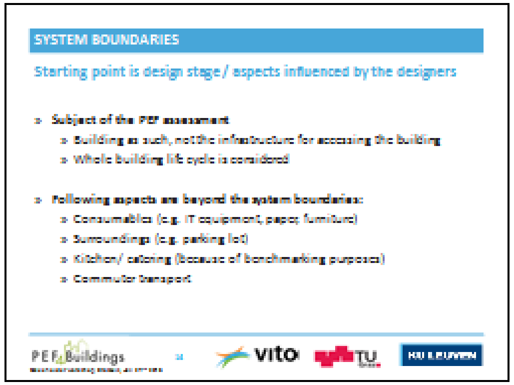
SYSTEM BOUNDARIES
Starting point is design stage / aspects influenced by the designers
Subject of the PEF assessment
Building as such, not the infrastructure for accessing the building
Whole building life cycle is considered
Following aspects are beyond the system boundaries:
Consumables (e.g. IT equipment, paper, furniture)
Surroundings (e.g. parking lot)
Kitchen/ catering (because of benchmarking purposes)
Commuter transport
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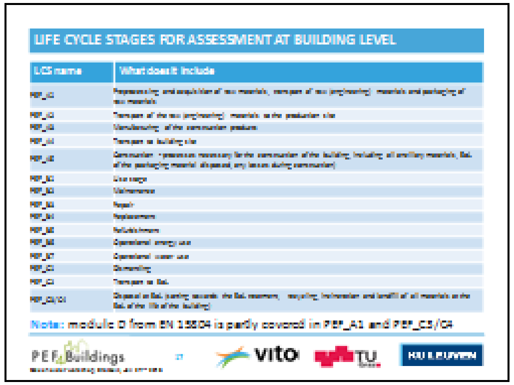
LIFE CYCLE STAGES FOR ASSESSMENT AT BUILDING LEVEL
LCS name
What does it include
Note: module D from EN 15804 is partly covered in PEF_A1 and PEF_C3/C4
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CASE STUDIES
Case study 1 – Belgium: BelOrta
Architect: AR-TE
Client: BelOrta scrl
Construction year: 2014
Context: suburban (St-Katelijne-Waver)
Net floor surface: 2000 m2
Energy performance: E69
Represents: BAU office, in use
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CASE STUDIES
Case study 2 – Austria: be 2226
Architect: Baumschlager & Eberle
Client: AD Vermietung OG
Construction year: 2013
Context: suburban (Millennium Park, Lustenau)
Net floor area: 2700 m²
Heating demand: 8 W/m² (covered by waste heat from users and appliances)
Represents: advanced building concept (passive, no heating/cooling)
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DATA INVENTORY – WORK FLOW
Structuring of the data collection
Main challenge: develop an approach to assess the building from PEFs/LCAs of construction products (available at different levels)
Hierarchical decomposition of the building
Building
Level 0
Building - Elements
Level 1
Building - sub-elements
Level 2
Building materials
Level 3
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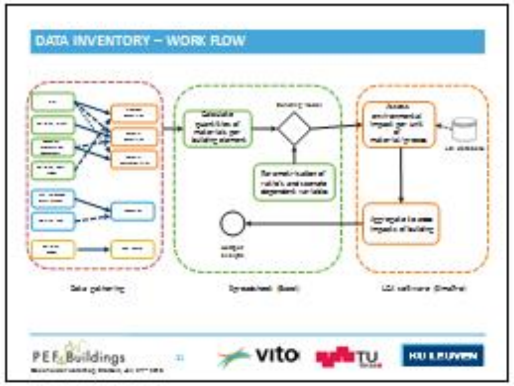
DATA INVENTORY – WORK FLOW
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LCIA RESULTS / HOTSPOTS
Characterised results
Results for both case studies
Highlight the effect of differences in modelling
Normalised and weighted results
Results for both case studies
Highlight the differences in hotspots
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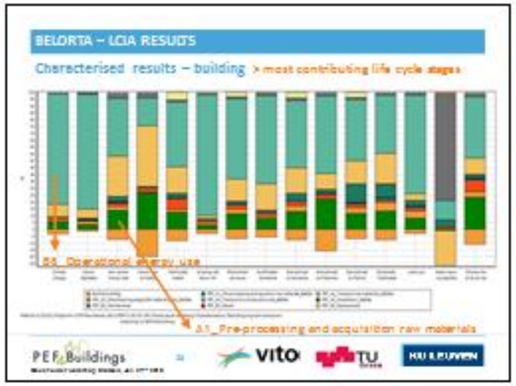
BELORTA – LCIA RESULTS
Characterised results – building > most contributing life cycle stages
B6_Operational energy use
A1_Pre-processing and acquisition raw materials
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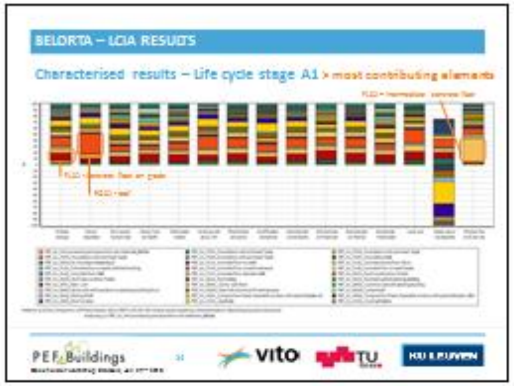
BELORTA – LCIA RESULTS
Characterised results – Life cycle stage A1 > most contributing elements
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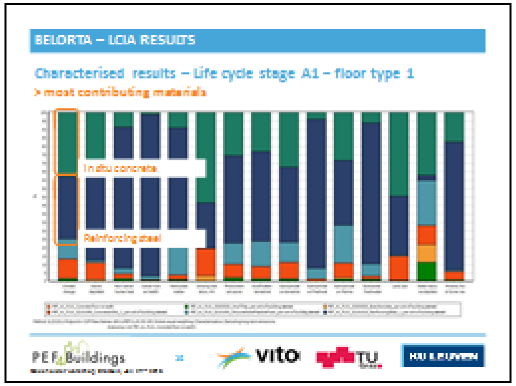
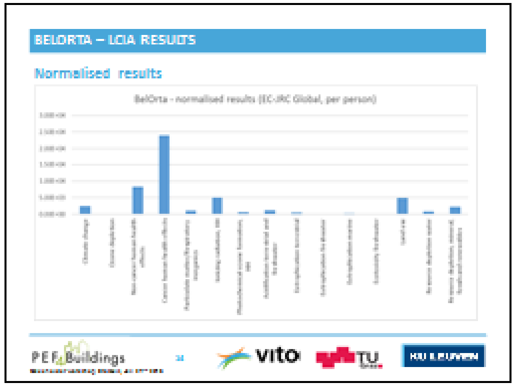
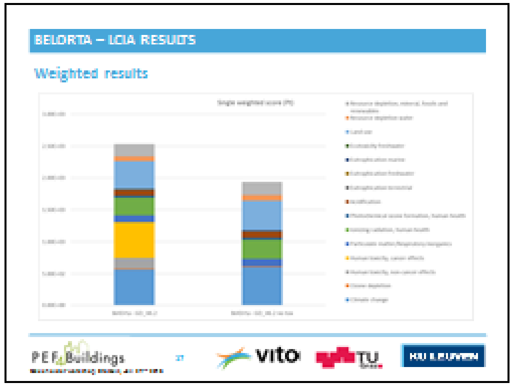
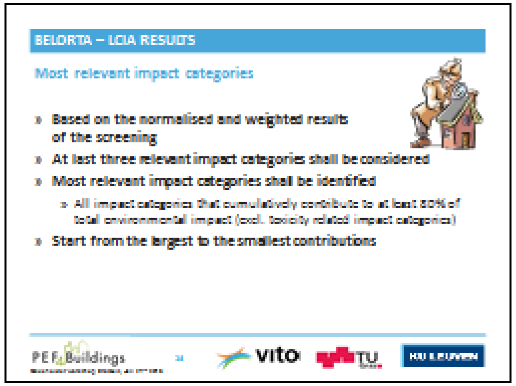
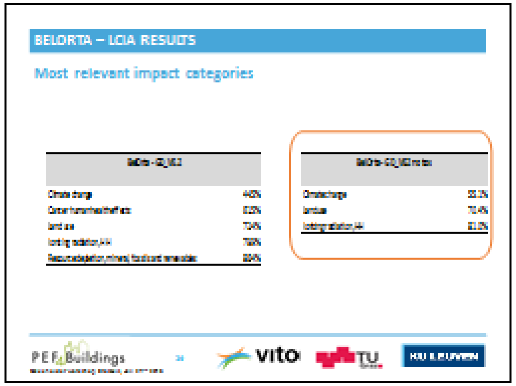
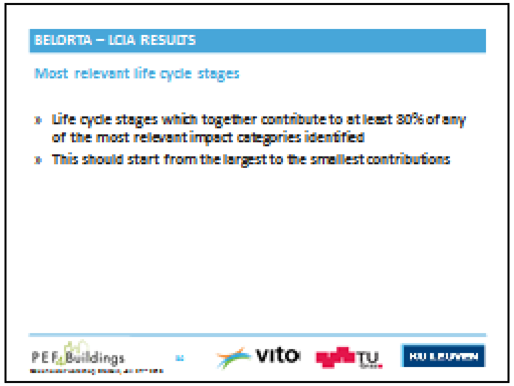

BELORTA – LCIA RESULTS
Characterised results – Life cycle stage A1 – floor type 1
> most contributing materials
In situ concrete
Reinforcing steel

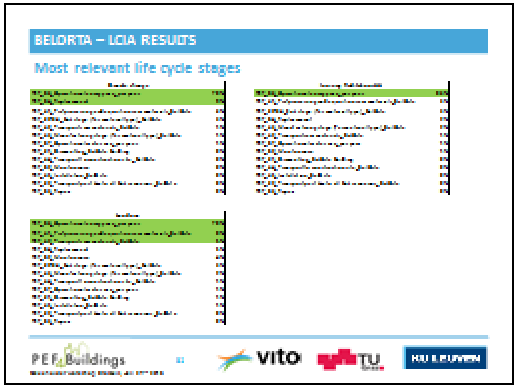

BELORTA – LCIA RESULTS
Normalised results
BelOrta - normalised results (EC-JRC Global, per person)


BELORTA – LCIA RESULTS
Weighted results


BELORTA – LCIA RESULTS
Most relevant impact categories
» Based on the normalised and weighted results of the screening
» At last three relevant impact categories shall be considered
» Most relevant impact categories shall be identified
» All impact categories that cumulatively contribute to at least 80% of total environmental impact (excl. toxicity related impact categories)
» Start from the largest to the smallest contributions


BELORTA – LCIA RESULTS
Most relevant impact categories


BELORTA – LCIA RESULTS
Most relevant life cycle stages
» Life cycle stages which together contribute to at least 80% of any of the most relevant impact categories identified
» This should start from the largest to the smallest contributions


BELORTA – LCIA RESULTS
Most relevant life cycle stages
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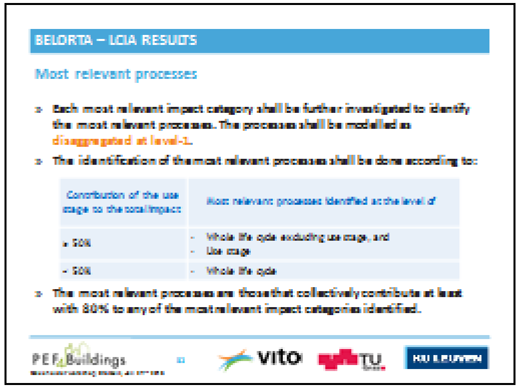
BELORTA – LCIA RESULTS
Most relevant processes
Each most relevant impact category shall be further investigated to identify the most relevant processes. The processes shall be modelled as disaggregated at level-1.
The identification of the most relevant processes shall be done according to:
Contribution of the use stage to the total impact
Most relevant processes identified at the level of
> 50%
- Whole life cycle excluding use stage, and
- Use stage
< 50%
- Whole life cycle
The most relevant processes are those that collectively contribute at least with 80% to any of the most relevant impact categories identified.
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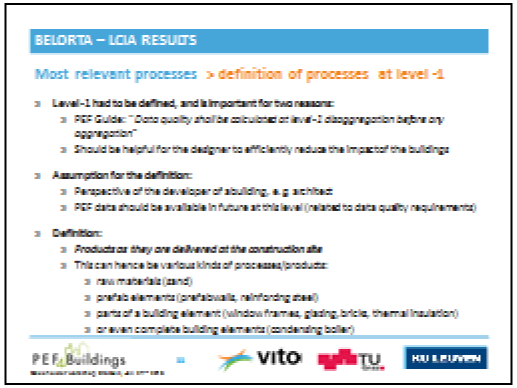
BELORTA – LCIA RESULTS
Most relevant processes > definition of processes at level -1
Level-1 had to be defined, and is important for two reasons:
PEF Guide: "Data quality shall be calculated at level-1 disaggregation before any aggregation"
Should be helpful for the designer to efficiently reduce the impact of the buildings
Assumption for the definition:
Perspective of the developer of a building, e.g. architect
PEF data should be available in future at this level (related to data quality requirements)
Definition:
Products as they are delivered at the construction site
This can hence be various kinds of processes/products:
raw materials (sand)
prefab elements (prefab walls, reinforcing steel)
parts of a building element (window frames, glazing, bricks, thermal insulation)
or even complete building elements (condensing boiler)
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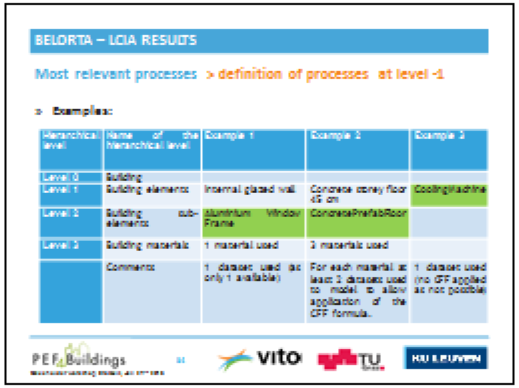
BELORTA – LCIA RESULTS
Most relevant processes > definition of processes at level -1
Examples:
Hierarchical level
Name of the hierarchical level
Example 1
Example 2
Example 3
Level 0
Building
Level 1
Building elements
Internal glazed wall
Concrete storey floor 45 cm
CoolingMachine
Level 2
Building sub-elements
Aluminium Window Frame
ConcretePrefabFloor
Level 3
Building materials
1 material used
3 materials used
Comments
1 dataset used (as only 1 available)
For each material at least 2 datasets used to model to allow application of the CFF formula.
1 dataset used (no CFF applied as not possible)
PEF4Buildings
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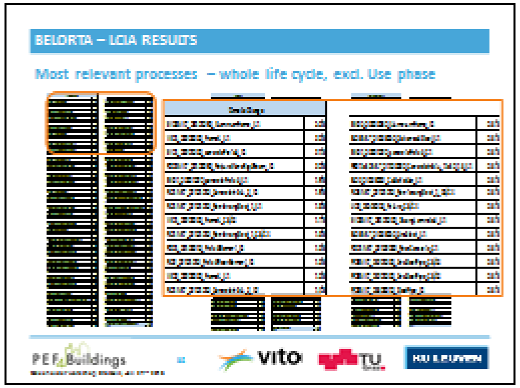
BELORTA – LCIA RESULTS
Most relevant processes – whole life cycle, excl. Use phase
PEF4Buildings
vito
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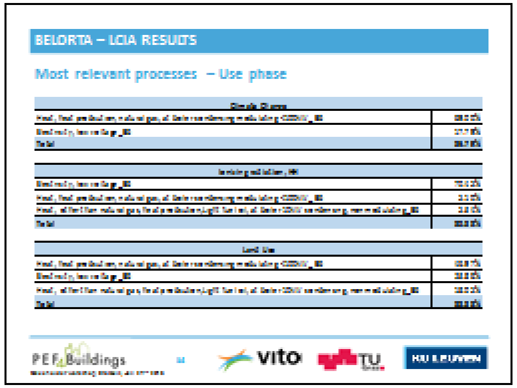
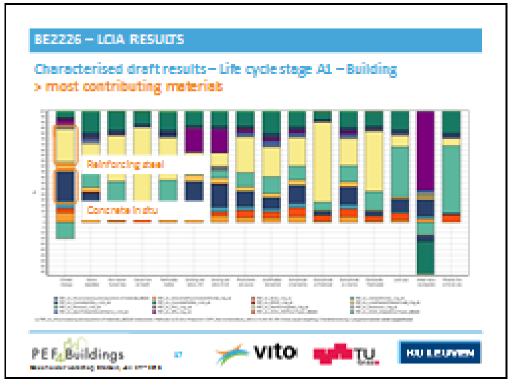

BELORTA – LCIA RESULTS
Most relevant processes – Use phase
PEF4Buildings
vito
TU
KU LEUVEN


BE2226 – LCIA RESULTS
Characterised draft results – Life cycle stage A1 – Building
> most contributing materials
Reinforcing steel
Concrete in situ
vito
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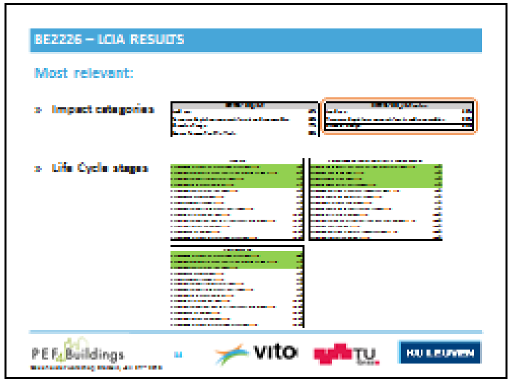
BE2226 – LCIA RESULTS
Most relevant:
Impact categories
Life Cycle stages
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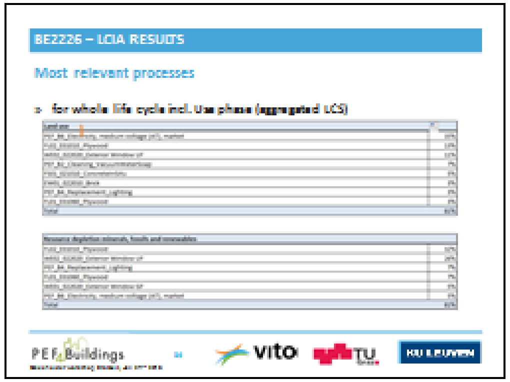
BE2226 – LCIA RESULTS
Most relevant processes
for whole life cycle incl. Use phase (aggregated LCS)
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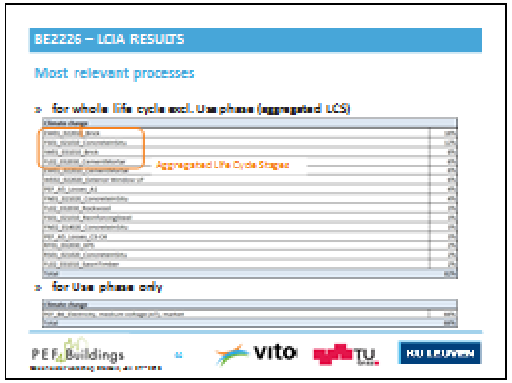
BE2226 – LCIA RESULTS
Most relevant processes
for whole life cycle excl. Use phase (aggregated LCS)
Aggregated Life Cycle Stages
for Use phase only
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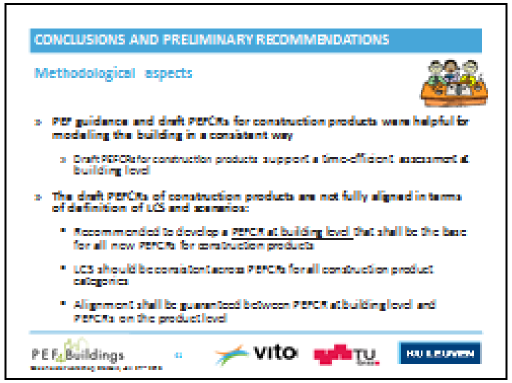
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
PEF guidance and draft PEFCRs for construction products were helpful for modeling the building in a consistent way
Draft PEFCRs for construction products support a time-efficient assessment at building level
The draft PEFCRs of construction products are not fully aligned in terms of definition of LCS and scenarios:
Recommended to develop a PEFCR at building level that shall be the base for all new PEFCRs for construction products
LCS should be consistent across PEFCRs for all construction product categories
Alignment shall be guaranteed between PEFCR at building level and PEFCRs on the product level
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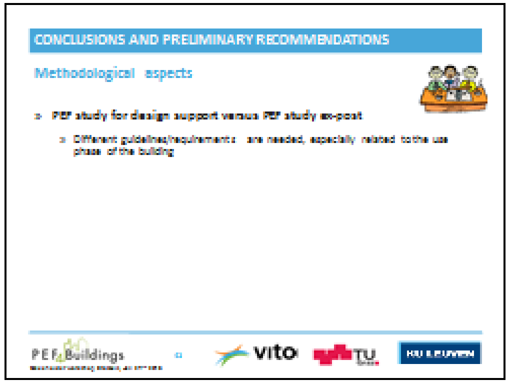
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Methodological aspects
PEF study for design support versus PEF study ex-post
Different guidelines/requirements are needed, especially related to the use phase of the building
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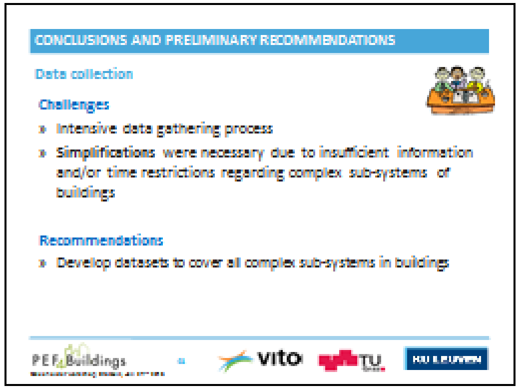
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Data collection
Challenges
Intensive data gathering process
Simplifications were necessary due to insufficient information and/or time restrictions regarding complex sub-systems of buildings
Recommendations
Develop datasets to cover all complex sub-systems in buildings
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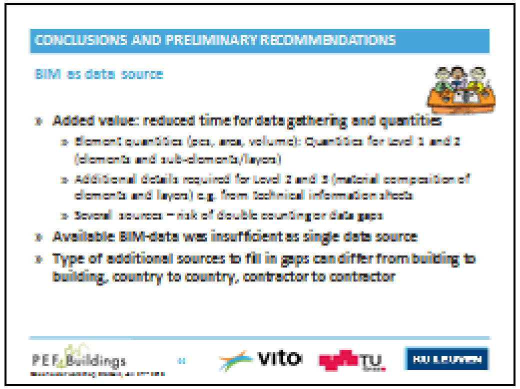
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
BIM as data source
Added value: reduced time for data gathering and quantities
Element quantities (pcs, area, volume): Quantities for Level 1 and 2 (elements and sub-elements/layers)
Additional details required for Level 2 and 3 (material composition of elements and layers) e.g. from technical information sheets
Several sources – risk of double counting or data gaps
Available BIM-data was insufficient as single data source
Type of additional sources to fill in gaps can differ from building to building, country to country, contractor to contractor
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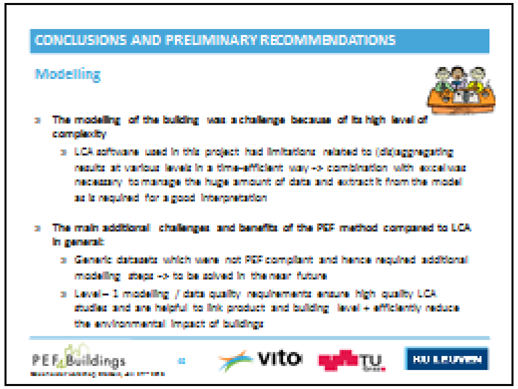
CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS
Modelling
The modelling of the building was a challenge because of its high level of complexity
LCA software used in this project had limitations related to (dis)aggregating results at various levels in a time-efficient way -> combination with excel was necessary to manage the huge amount of data and extract it from the model as is required for a good interpretation
The main additional challenges and benefits of the PEF method compared to LCA in general:
Generic datasets which were not PEF compliant and hence required additional modelling steps -> to be solved in the near future
Level – 1 modelling / data quality requirements ensure high quality LCA studies and are helpful to link product and building level + efficiently reduce the environmental impact of buildings
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AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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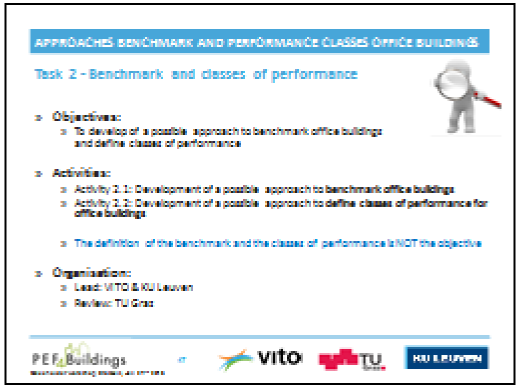
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Task 2 - Benchmark and classes of performance
Objectives:
To develop of a possible approach to benchmark office buildings and define classes of performance
Activities:
Activity 2.1: Development of a possible approach to benchmark office buildings
Activity 2.2: Development of a possible approach to define classes of performance for office buildings
The definition of the benchmark and the classes of performance is NOT the objective
Organisation:
Lead: VITO & KU Leuven
Review: TU Graz
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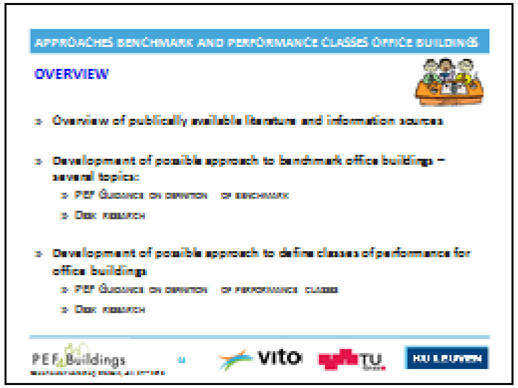
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
Development of possible approach to define classes of performance for office buildings
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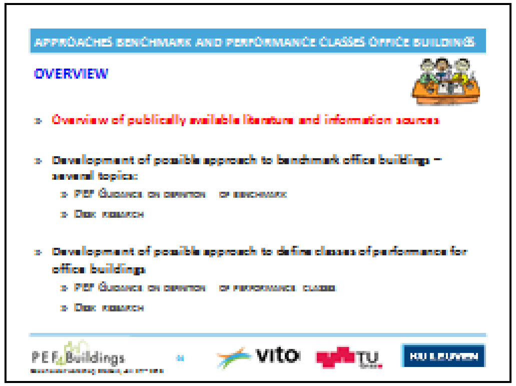
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
PEF Guidance on definition of benchmark
Desk research
Development of possible approach to define classes of performance for office buildings
PEF Guidance on definition of performance classes
Desk research
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
General methodological reports
1. VTT report - Sustainability and performance assessment and benchmarking of buildings
2. BPIE report - EUROPE'S BUILDINGS UNDER THE MICROSCOPE, A country-by-country review of the energy performance of buildings
3. Intelligent Energy Europe: TABULA and EPISCOPE reports
4. BBP - Sustainability Benchmarking Toolkit for Commercial Buildings
5. UN-Habitat - Building sustainability assessment and benchmarking – an introduction
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
National Sustainability Certification Schemes / LCA methods for Buildings
1. Ganassali et al. (2016) - LCA benchmarks in building's environmental certification systems
2. German building certification system of DGNB
3. German assessment system for sustainable building (BNB) for public offices and administration buildings
4. Belgian MMG – Material based environmental profiles of building elements
5. Belgian GRO
National Benchmarking Approaches
1. Dutch legal requirements GPP
2. French Initiative - Towards positive energy and low carbon buildings - The French Experimentation for new buildings
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APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Overview publically available literature and information sources
Literature review
European Sustainable Building Assessment Methods / Green Public Procurement
1. Level(s): building sustainability performance
2. EN 15978
3. EC - Green Public Procurement Criteria for Office Building Design, Construction and Management
4. Draft PCR 2.0 for open consultation (from Int. EPD programme)
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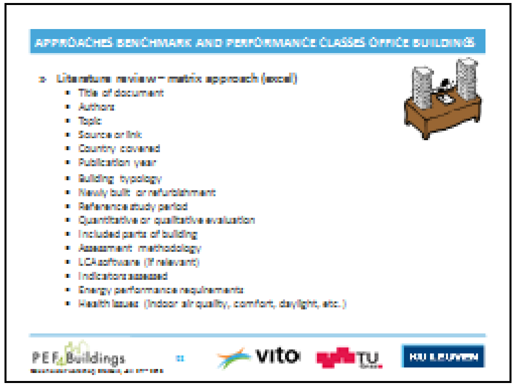
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Literature review – matrix approach (excel)
Title of document
Authors
Topic
Source or link
Country covered
Publication year
Building typology
Newly built or refurbishment
Reference study period
Quantitative or qualitative evaluation
Included parts of building
Assessment methodology
LCA software (if relevant)
Indicators assessed
Energy performance requirements
Health issues (indoor air quality, comfort, daylight, etc.)
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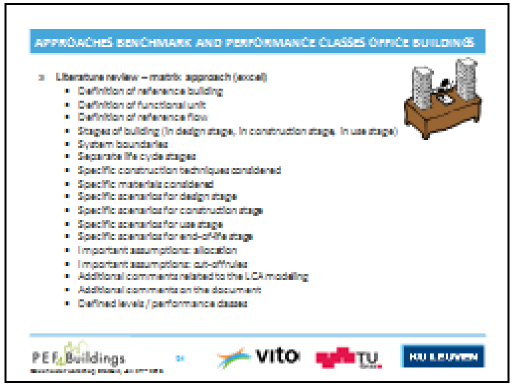
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Literature review – matrix approach (excel)
Definition of reference building
Definition of functional unit
Definition of reference flow
Stages of building (in design stage, in construction stage, in use stage)
System boundaries
Separate life cycle stages
Specific construction techniques considered
Specific materials considered
Specific scenarios for design stage
Specific scenarios for construction stage
Specific scenarios for use stage
Specific scenarios for end-of-life stage
Important assumptions: allocation
Important assumptions: cut-off rules
Additional comments related to the LCA modelling
Additional comments on the document
Defined levels / performance classes
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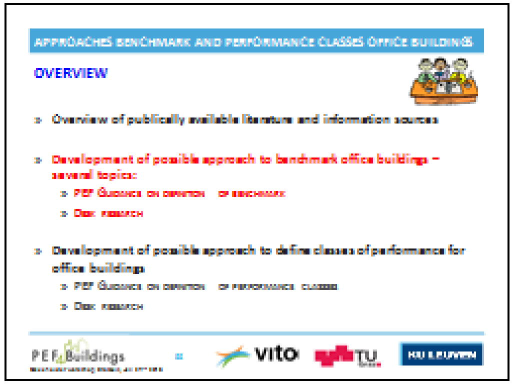
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
PEF Guidance on definition of benchmark
Desk research
Development of possible approach to define classes of performance for office buildings
PEF Guidance on definition of performance classes
Desk research
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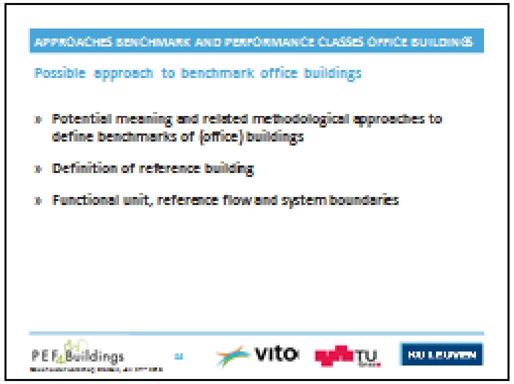
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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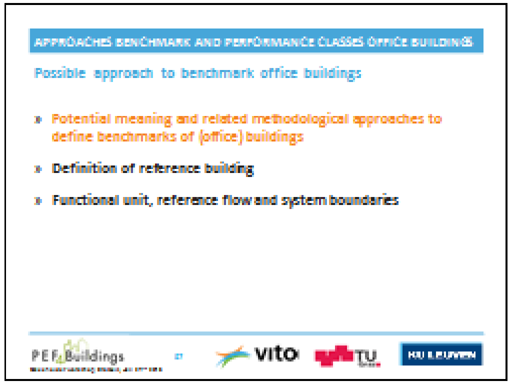
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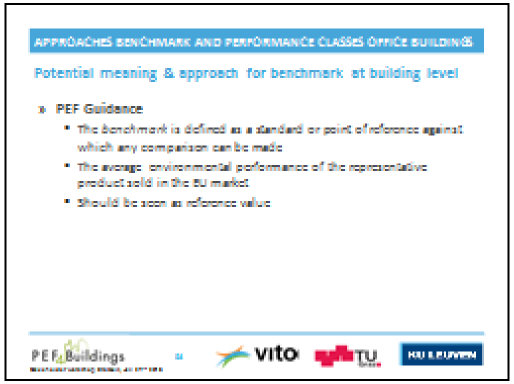
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
PEF Guidance
The benchmark is defined as a standard or point of reference against which any comparison can be made
The average environmental performance of the representative product sold in the EU market
Should be seen as reference value
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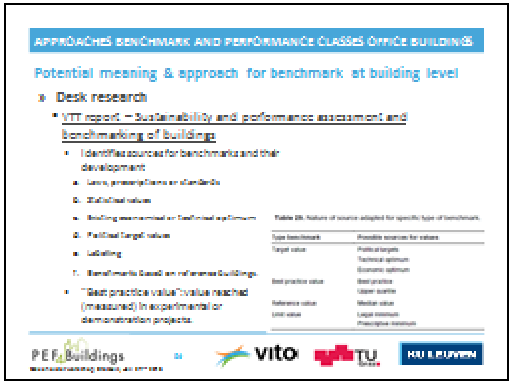
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
VTT report – Sustainability and performance assessment and benchmarking of buildings
Identifies sources for benchmarks and their development
"Best practice value": value reached (measured) in experimental or demonstration projects.
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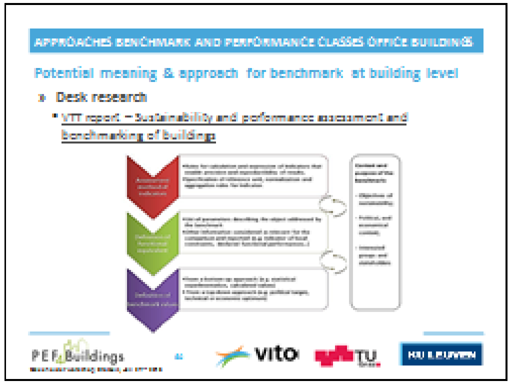
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
VTT report – Sustainability and performance assessment and benchmarking of buildings
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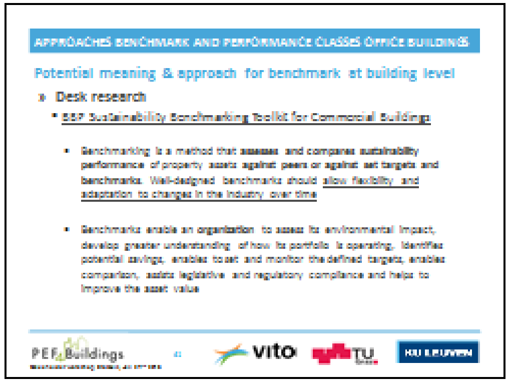
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
BBP Sustainability Benchmarking Toolkit for Commercial Buildings
Benchmarking is a method that assesses and compares sustainability performance of property assets against peers or against set targets and benchmarks. Well-designed benchmarks should allow flexibility and adaptation to changes in the industry over time
Benchmarks enable an organization to assess its environmental impact, develop greater understanding of how its portfolio is operating, identifies potential savings, enables to set and monitor the defined targets, enables comparison, assists legislative and regulatory compliance and helps to improve the asset value
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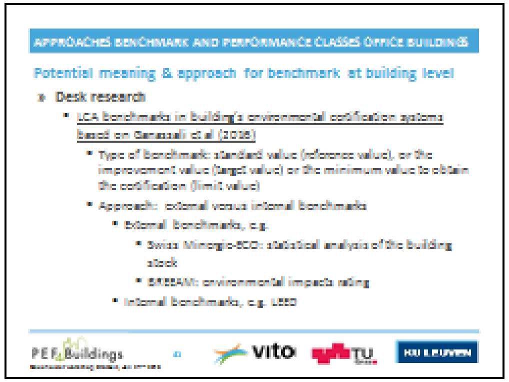
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
LCA Benchmarks in building's environmental certification systems based on Ganassali et al (2016)
Type of benchmark: standard value (reference value), or the improvement value (target value) or the minimum value to obtain the certification (limit value)
Approach: external versus internal benchmarks
External benchmarks, e.g.
Swiss Minergie-ECO: statistical analysis of the building stock
BREEAM: environmental impacts rating
Internal benchmarks, e.g. LEED
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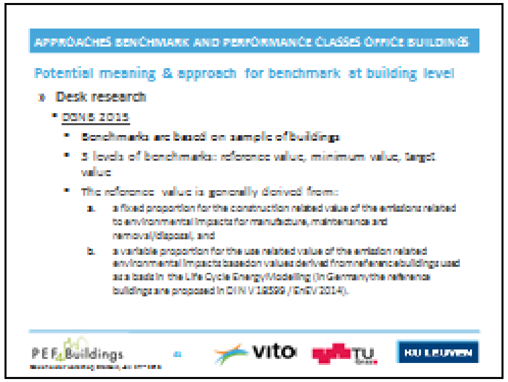
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
DGNB 2015
Benchmarks are based on sample of buildings
3 levels of benchmarks: reference value, minimum value, target value
The reference value is generally derived from:
a. a fixed proportion for the construction related value of the emissions related to environmental impacts for manufacture, maintenance and removal/disposal, and
b. a variable proportion for the use related value of the emission related environmental impacts based on values derived from reference buildings used as a basis in the Life Cycle Energy Modelling (in Germany the reference buildings are proposed in DIN V 18599 / EnEV 2014).
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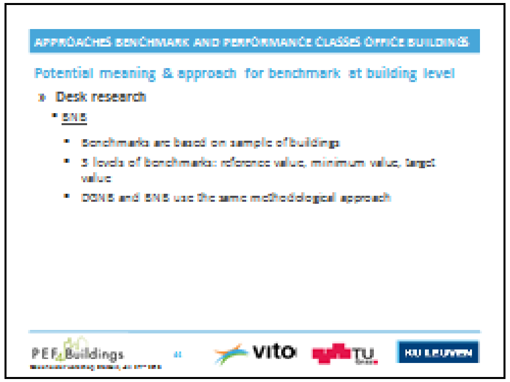
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
BNB
Benchmarks are based on sample of buildings
3 levels of benchmarks: reference value, minimum value, target value
DGNB and BNB use the same methodological approach
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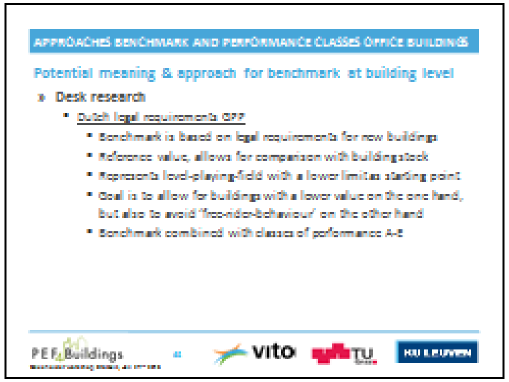
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
Dutch legal requirements GPP
Benchmark is based on legal requirements for new buildings
Reference value, allows for comparison with building stock
Represents level-playing-field with a lower limit as starting point
Goal is to allow for buildings with a lower value on the one hand, but also to avoid 'free-rider-behaviour' on the other hand
Benchmark combined with classes of performance A-E
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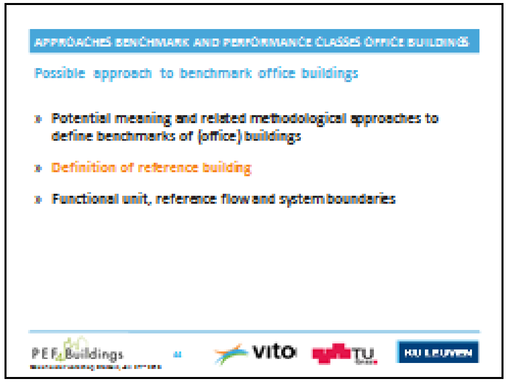
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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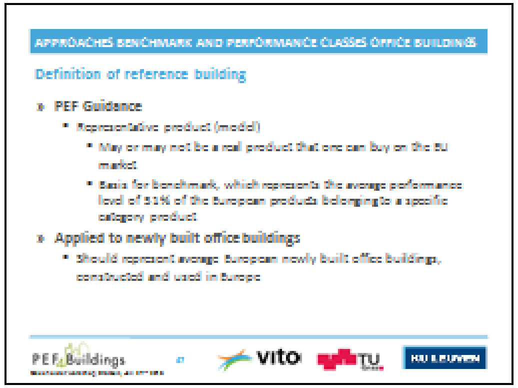
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
PEF Guidance
Representative product (model)
May or may not be a real product that one can buy on the EU market
Basis for benchmark, which represents the average performance level of 51% of the European products belonging to a specific category product
Applied to newly built office buildings
Should represent average European newly built office buildings, constructed and used in Europe
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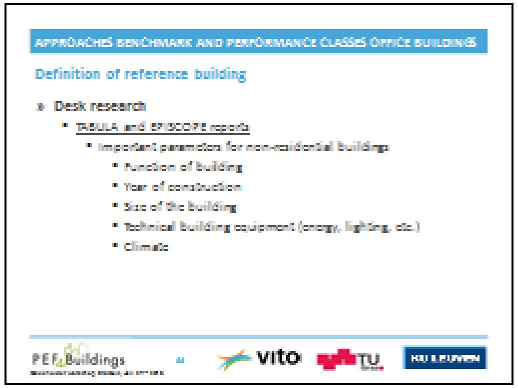
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
TABULA and EPISCOPE reports
Important parameters for non-residential buildings
Function of building
Year of construction
Size of the building
Technical building equipment (energy, lighting, etc.)
Climate
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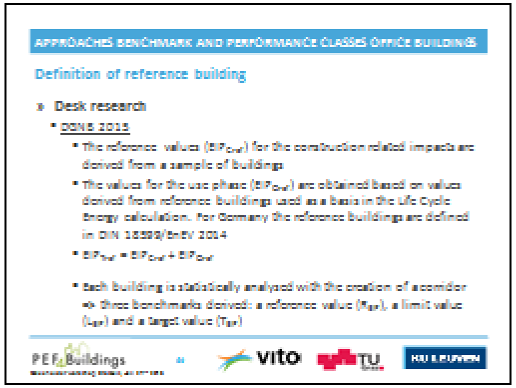
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
The reference values (EIP Cref) for the construction related impacts are derived from a sample of buildings
The values for the use phase (EIP Oref) are obtained based on values derived from reference buildings used as a basis in the Life Cycle Energy calculation. For Germany the reference buildings are defined in DIN 18599/EnEV 2014
EIP Tref = EIP Cref + EIP Oref
Each building is statistically analysed with the creation of a corridor => three benchmarks derived: a reference value (R), a limit value (L) and a target value (T)
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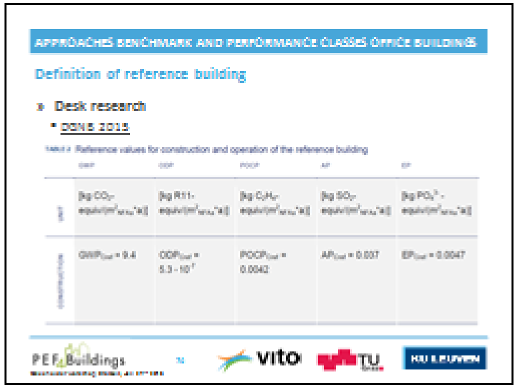
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Reference values for construction and operation of the reference building
GWP
ODP
POCP
AP
EP
[kg CO2-equiv/(m²NGF*a)]
[kg R11-equiv/(m²NGF*a)]
[kg C2H4-equiv/(m²NGF*a)]
[kg SO2-equiv/(m²NGF*a)]
[kg PO4³⁻-equiv/(m²NGF*a)]
GWPCref = 9.4
ODPCref = 5.3 · 10⁻⁷
POCPCref = 0.0042
APCref = 0.037
EPCref = 0.0047
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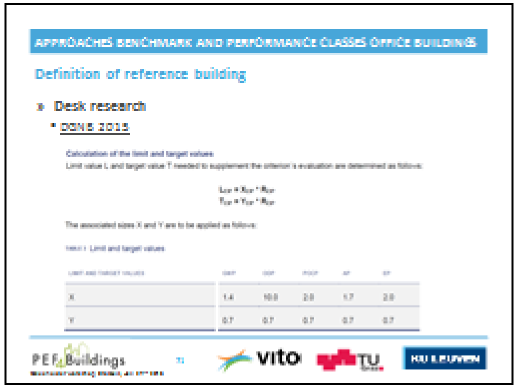
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Calculation of the limit and target values
Limit value L and target value T needed to supplement the criterion's evaluation are determined as follows:
The associated sizes X and Y are to be applied as follows:
Limit and target values
X
1.4
10.0
2.0
1.7
2.0
Y
0.7
0.7
0.7
0.7
0.7
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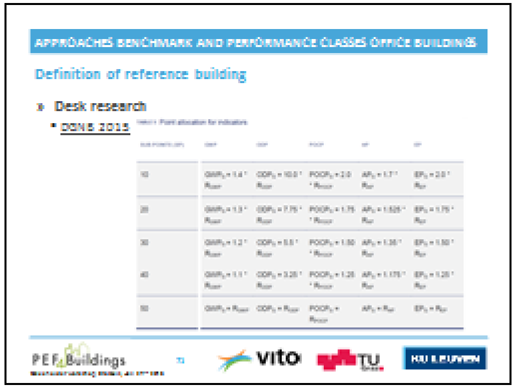
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
PEF4Buildings
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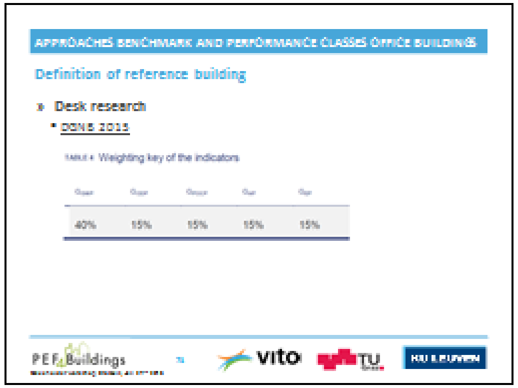
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Weighting key of the indicators
40% 15% 15% 15% 15%
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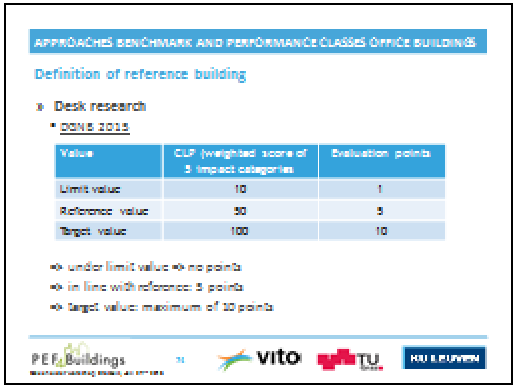
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
DGNB 2015
Value
CLP (weighted score of 5 impact categories
Evaluation points
Limit value 10 1
Reference value 50 5
Target value 100 10
under limit value => no points
in line with reference: 5 points
target value: maximum of 10 points
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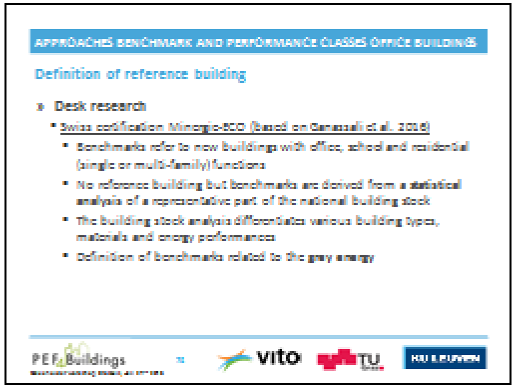
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO (based on Ganassali et al. 2016)
Benchmarks refer to new buildings with office, school and residential (single or multi-family) functions
No reference building but benchmarks are derived from a statistical analysis of a representative part of the national building stock
The building stock analysis differentiates various building types, materials and energy performances
Definition of benchmarks related to the gray energy
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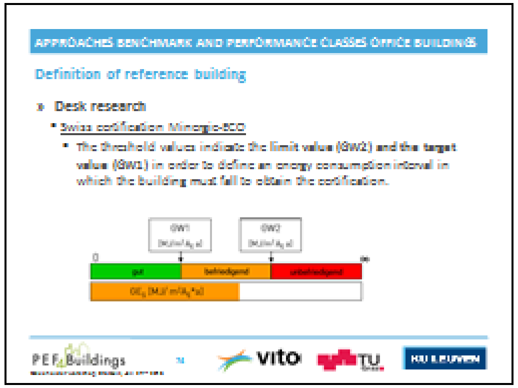
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO
The threshold values indicate the limit value (GW2) and the target value (GW1) in order to define an energy consumption interval in which the building must fall to obtain the certification.
GW1
GW2
0
gut
befriedigend
unbefriedigend
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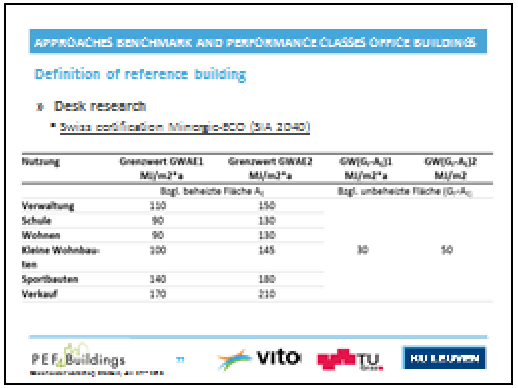
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Swiss certification Minergie-ECO (SIA 2040)
Nutzung
Grenzwert GWAE1 MJ/m2*a
Grenzwert GWAE2 MJ/m2*a
Bzgl. beheizte Fläche
Bzgl. unbeheizte Fläche
Verwaltung 110 150
Schule 90 130
Wohnen 90 130
Kleine Wohnbauten 100 145 30 50
Sportbauten 140 180
Verkauf 170 210
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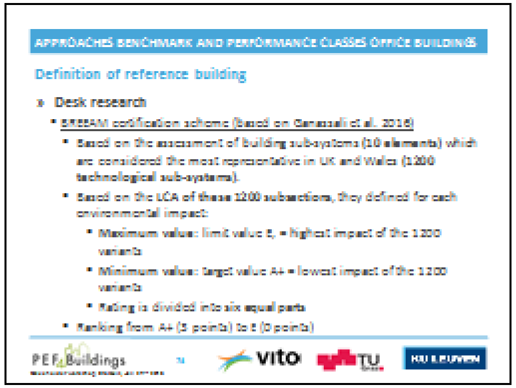
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
BREEAM certification scheme (based on Ganassali et al. 2016)
Based on the assessment of building sub-systems (10 elements) which are considered the most representative in UK and Wales (1200 technological sub-systems).
Based on the LCA of these 1200 subsections, they defined for each environmental impact:
Maximum value: limit value E, = highest impact of the 1200 variants
Minimum value: target value A+ = lowest impact of the 1200 variants
Rating is divided into six equal parts
Ranking from A+ (3 points) to E (0 points)
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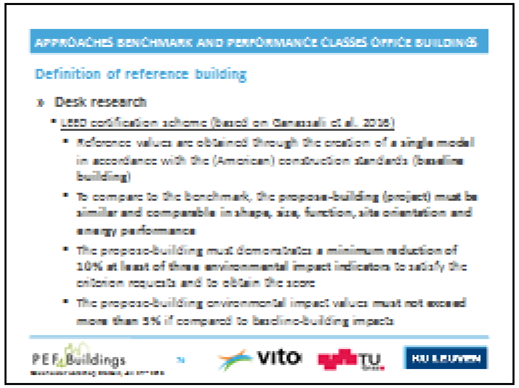
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
LEED certification scheme (based on Ganassali et al. 2016)
Reference values are obtained through the creation of a single model in accordance with the (American) construction standards (baseline building)
To compare to the benchmark, the propose-building (project) must be similar and comparable in shape, size, function, site orientation and energy performance
The propose-building must demonstrate a minimum reduction of 10% at least of three environmental impact indicators to satisfy the criterion requests and to obtain the score
The propose-building environmental impact values must not exceed more than 5% if compared to baseline-building impacts
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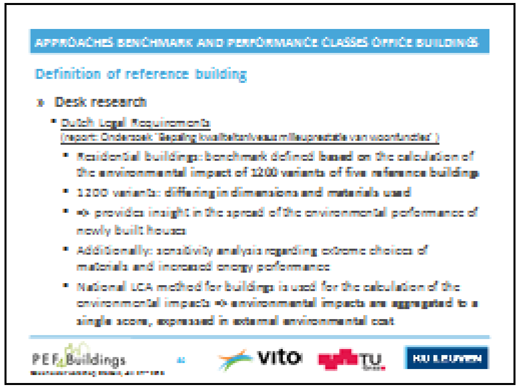
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Dutch Legal Requirements
(report: Onderzoek 'Bepaling kwaliteitsniveau milieuprestatie van woonfuncties')
Residential buildings: benchmark defined based on the calculation of the environmental impact of 1200 variants of five reference buildings
1200 variants: differing in dimensions and materials used
=> provides insight in the spread of the environmental performance of newly built houses
Additionally: sensitivity analysis regarding extreme choices of materials and increased energy performance
National LCA method for buildings is used for the calculation of the environmental impacts => environmental impacts are aggregated to a single score, expressed in external environmental cost
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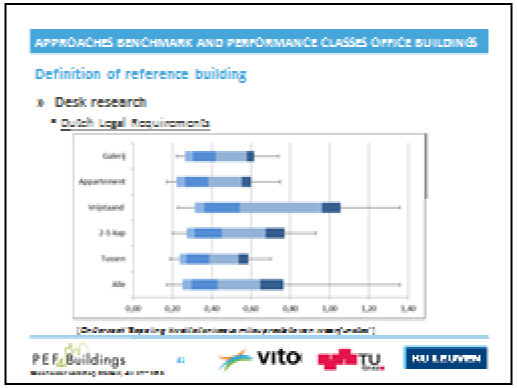
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Dutch Legal Requirements
Galerij
Appartement
Vrijstaand
2-1-kap
Tussen
Alle
0,00
0,20
0,40
0,60
0,80
1,00
1,20
1,40
(Onderzoek 'Bepaling kwaliteitsniveau milieuprestatie van woonfuncties')
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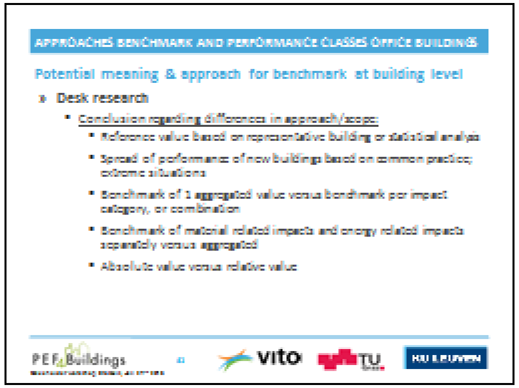
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Potential meaning & approach for benchmark at building level
Desk research
Conclusion regarding differences in approach/scope:
Reference value based on representative building or statistical analysis
Spread of performance of new buildings based on common practice; extreme situations
Benchmark of 1 aggregated value versus benchmark per impact category, or combination
Benchmark of material related impacts and energy related impacts separately versus aggregated
Absolute value versus relative value
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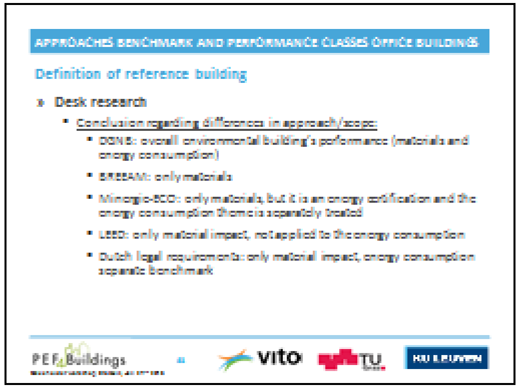
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Definition of reference building
Desk research
Conclusion regarding differences in approach/scope:
DGNB: overall environmental building's performance (materials and energy consumption)
BREEAM: only materials
Minergie-ECO: only materials, but it is an energy certification and the energy consumption theme is separately treated
LEED: only material impact, not applied to the energy consumption
Dutch legal requirements: only material impact, energy consumption separate benchmark
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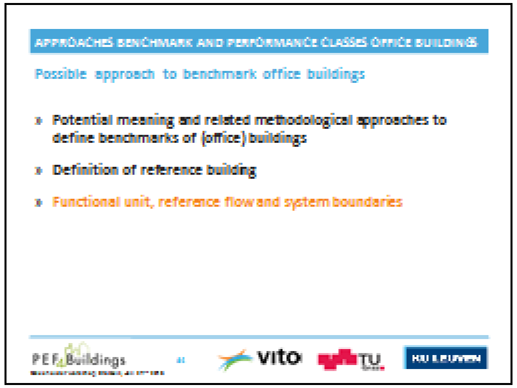
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to benchmark office buildings
Potential meaning and related methodological approaches to define benchmarks of (office) buildings
Definition of reference building
Functional unit, reference flow and system boundaries
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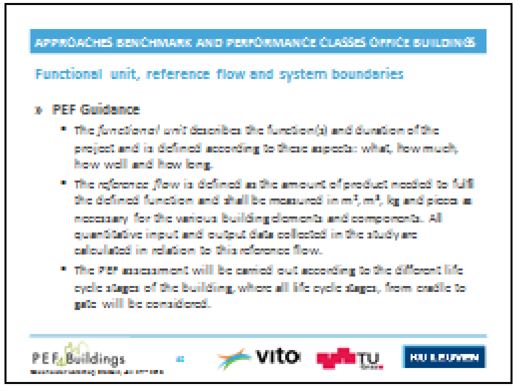
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
PEF Guidance
The functional unit describes the function(s) and duration of the project and is defined according to these aspects: what, how much, how well and how long.
The reference flow is defined as the amount of product needed to fulfil the defined function and shall be measured in m², m³, kg and pieces as necessary for the various building elements and components. All quantitative input and output data collected in the study are calculated in relation to this reference flow.
The PEF assessment will be carried out according to the different life cycle stages of the building, where all life cycle stages, from cradle to gate will be considered.
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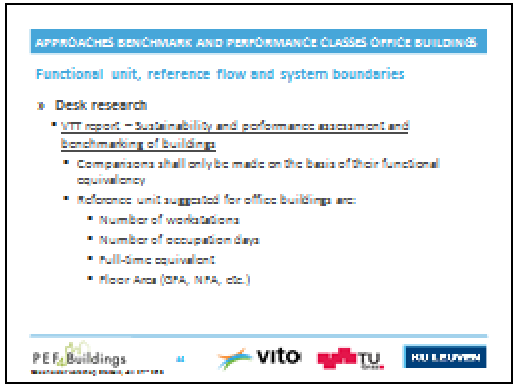
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
VTT report – Sustainability and performance assessment and benchmarking of buildings
Comparisons shall only be made on the basis of their functional equivalency
Reference unit suggested for office buildings are:
Number of workstations
Number of occupation days
Full-time equivalent
Floor Area (GFA, NFA, etc.)
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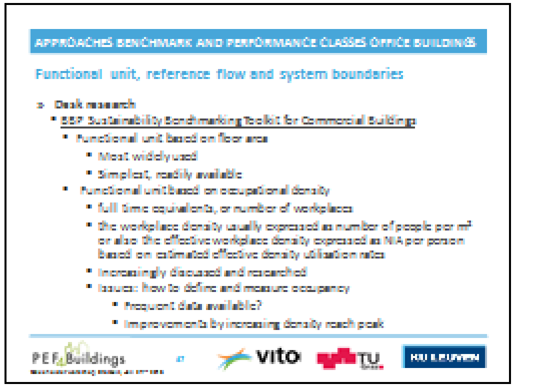
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
BBP Sustainability Benchmarking Toolkit for Commercial Buildings
Functional unit based on floor area
Most widely used
Simplest, readily available
Functional unit based on occupational density
full time equivalents, or number of workplaces
the workplace density usually expressed as number of people per m² or also the effective workplace density expressed as NIA per person based on estimated effective density utilisation rates
Increasingly discussed and researched
Issues: how to define and measure occupancy
Frequent data available?
Improvements by increasing density reach peak
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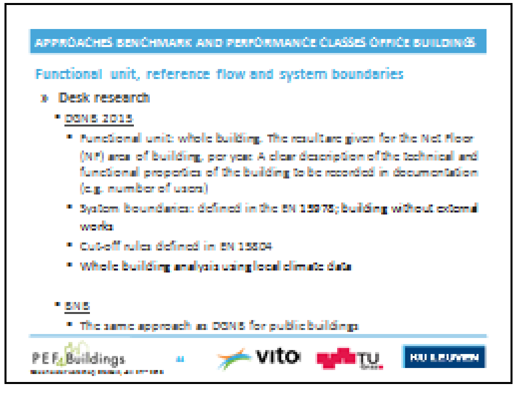
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
DGNB 2015
Functional unit: whole building. The results are given for the Net Floor (NF) area of building, per year. A clear description of the technical and functional properties of the building to be recorded in documentation (e.g. number of users)
System boundaries: defined in the EN 15978; building without external works
Cut-off rules defined in EN 15804
Whole building analysis using local climate data
BNB
The same approach as DGNB for public buildings
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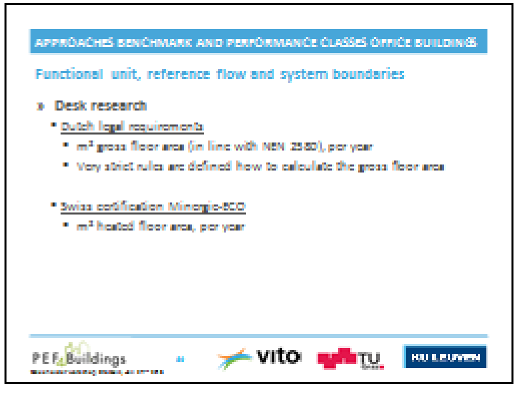
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
Dutch legal requirements
m² gross floor area (in line with NEN 2580), per year
Very strict rules are defined how to calculate the gross floor area
Swiss certification Minergie-ECO
m² heated floor area, per year
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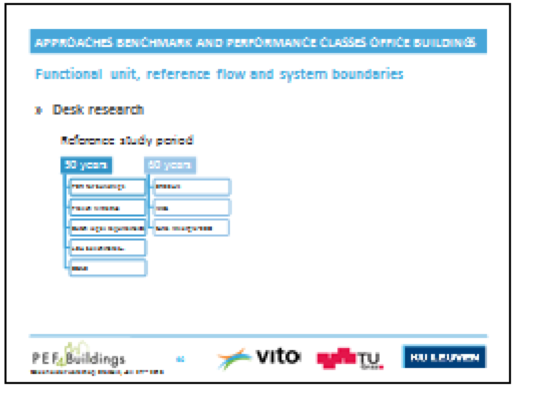
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Functional unit, reference flow and system boundaries
Desk research
Reference study period
50 years
60 years
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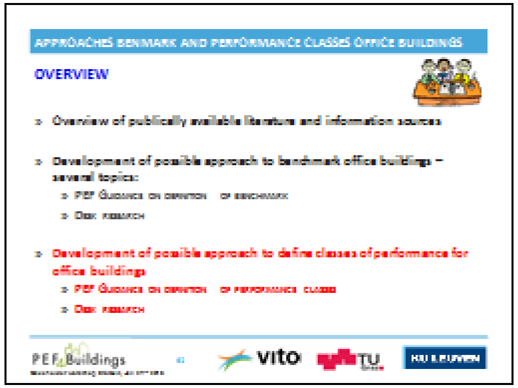
APPROACHES BENMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
OVERVIEW
Overview of publically available literature and information sources
Development of possible approach to benchmark office buildings – several topics:
Development of possible approach to define classes of performance for office buildings
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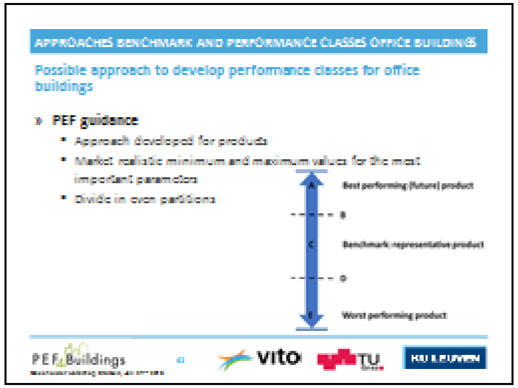
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
PEF guidance
Approach developed for products
Market realistic minimum and maximum values for the most important parameters
Divide in even partitions
Best performing (future) product
Benchmark representative product
Worst performing product
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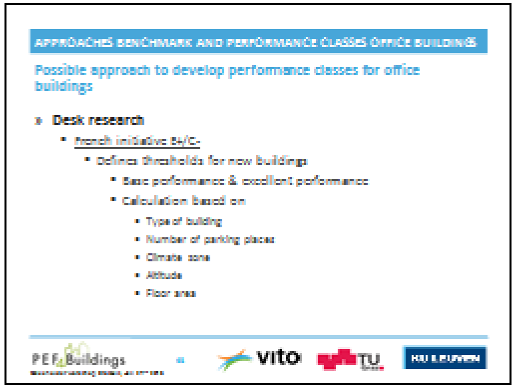
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
French initiative E+/C-
Defines thresholds for new buildings
Base performance & excellent performance
Calculation based on
Type of building
Number of parking places
Climate zone
Altitude
Floor area
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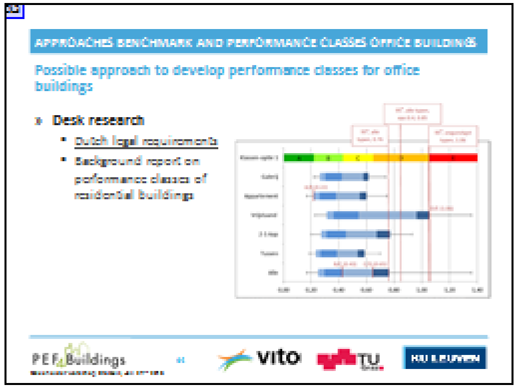
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
Dutch legal requirements
Background report on performance classes of residential buildings
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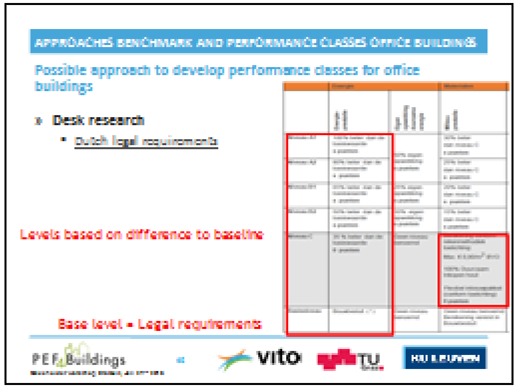
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
Dutch legal requirements
Levels based on difference to baseline
Base level = Legal requirements
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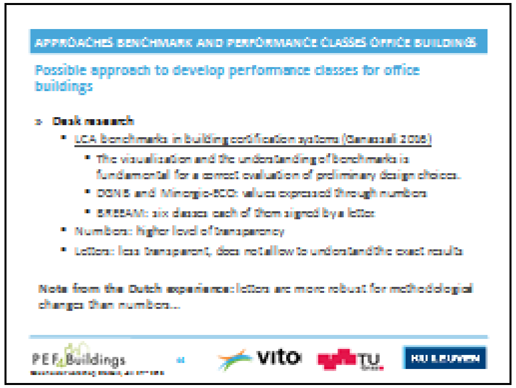
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
LCA benchmarks in building certification systems (Ganassali 2016)
The visualisation and the understanding of benchmarks is fundamental for a correct evaluation of preliminary design choices.
DGNB and Minergie-ECO: values expressed through numbers
BREEAM: six classes each of them signed by a letter
Numbers: higher level of transparency
Letters: less transparent, does not allow to understand the exact results
Note from the Dutch experience: letters are more robust for methodological changes than numbers...
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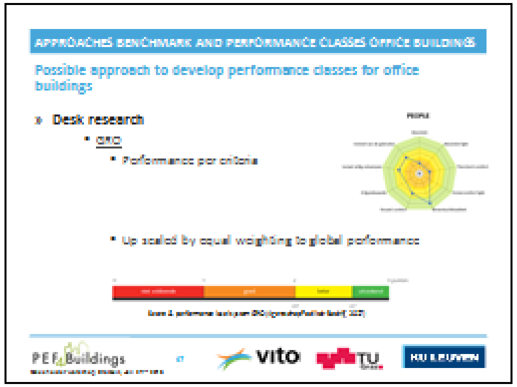
APPROACHES BENCHMARK AND PERFORMANCE CLASSES OFFICE BUILDINGS
Possible approach to develop performance classes for office buildings
Desk research
GRO
Performance per criteria
Up scaled by equal weighting to global performance
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AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 1: Reference building/benchmark
How to define reference buildings?
Question 1
Most projects are national, also the European/international projects we looked at differentiate buildings per country
Do we need (a) reference building(s)/benchmark per country, or per climate zone?
Could a geometry/layout be defined over Europe? Or do we need multiple geometries/layouts over Europe?
On which information should we base the definition of a reference building: statistical data?
How to deal with different construction techniques and different materials?
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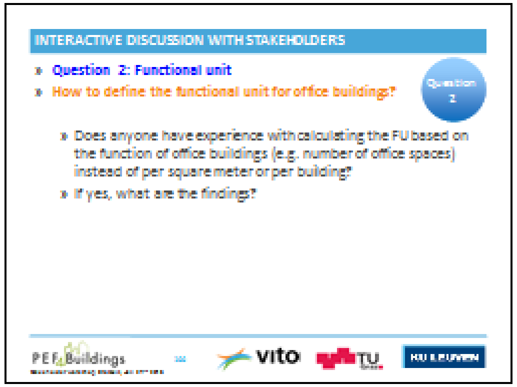
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 2: Functional unit
How to define the functional unit for office buildings?
Question 2
Does anyone have experience with calculating the FU based on the function of office buildings (e.g. number of office spaces) instead of per square meter or per building?
If yes, what are the findings?
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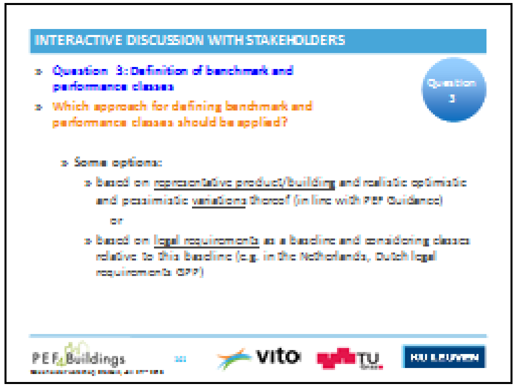
INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 3: Definition of benchmark and performance classes
Which approach for defining benchmark and performance classes should be applied?
Question 3
Some options:
based on representative product/building and realistic optimistic and pessimistic variations thereof (in line with PEF Guidance)
or
based on legal requirements as a baseline and considering classes relative to this baseline (e.g. in the Netherlands, Dutch legal requirements GPP)
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INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question 4: Reality check
How to perform reality check?
Question 4
The estimated environmental impacts as calculated in the design phase should be reflected by a reality check after the building is constructed and used.
How can this be achieved?
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AGENDA FOR STAKEHOLDER'S WORKSHOP
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15:30 – 16:30 - Closing of the meeting – Coffee – Networking
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LUNCH BREAK
TIME FOR LUNCH
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AGENDA FOR STAKEHOLDER'S WORKSHOP
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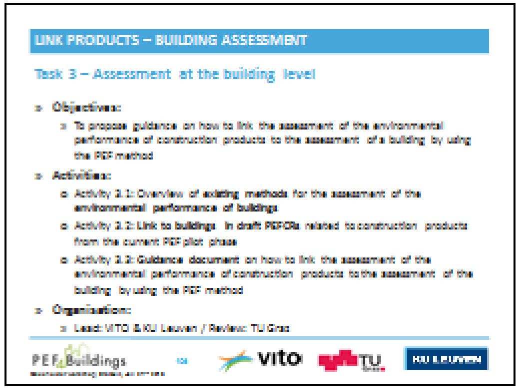
LINK PRODUCTS – BUILDING ASSESSMENT
Task 3 – Assessment at the building level
Objectives:
To propose guidance on how to link the assessment of the environmental performance of construction products to the assessment of a building by using the PEF method
Activities:
Activity 3.1: Overview of existing methods for the assessment of the environmental performance of buildings
Activity 3.2: Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Activity 3.3: Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Organisation:
Lead: VITO & KU Leuven / Review: TU Graz
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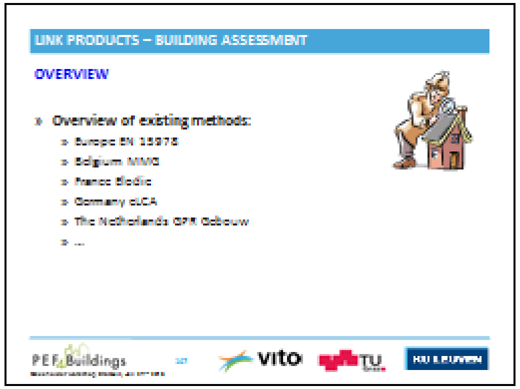
LINK PRODUCTS – BUILDING ASSESSMENT
OVERVIEW
Overview of existing methods:
Europe EN 15978
Belgium MMG
France Elodie
Germany eLCA
The Netherlands GPR Gebouw
...
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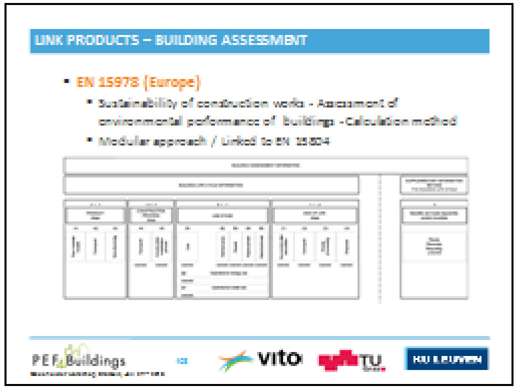
LINK PRODUCTS – BUILDING ASSESSMENT
EN 15978 (Europe)
Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method
Modular approach / Linked to EN 15804
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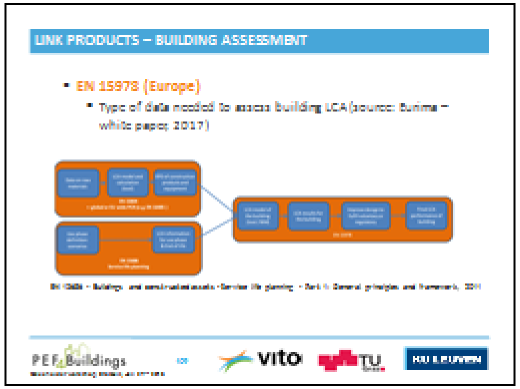
LINK PRODUCTS – BUILDING ASSESSMENT
EN 15978 (Europe)
Type of data needed to assess building LCA (source: Eurima – white paper, 2017)
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LINK PRODUCTS – BUILDING ASSESSMENT
MMG (Belgium)
Transparent methodology / assessment framework
Publications available on:
Broad environmental perspective
More than the 14 environmental impact categories
Based on existing frameworks
EN 15804, EN 15978, PEF Guide, ILCD Handbook
Applicable for the Belgian construction sector
Elements in line with the Belgian construction practices
In development (expected second half of 2018): inclusion of specific environmental profiles/ EPDs from the Belgian Federal EPD-database
To have an user-friendly tool
In development (expected in coming months): web based calculation tool
For architects (among others) to make them more aware of the environmental impact of their design choices
OVAM
PEF4Buildings
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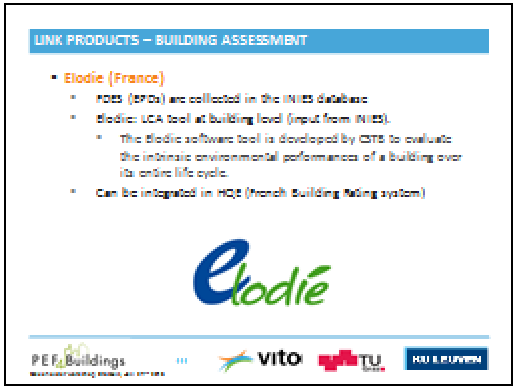
LINK PRODUCTS – BUILDING ASSESSMENT
Elodie (France)
FDES (EPDs) are collected in the INIES database
Elodie: LCA tool at building level (input from INIES).
The Elodie software tool is developed by CSTB to evaluate the intrinsic environmental performances of a building over its entire life cycle.
Can be integrated in HQE (French Building Rating system)
Elodie
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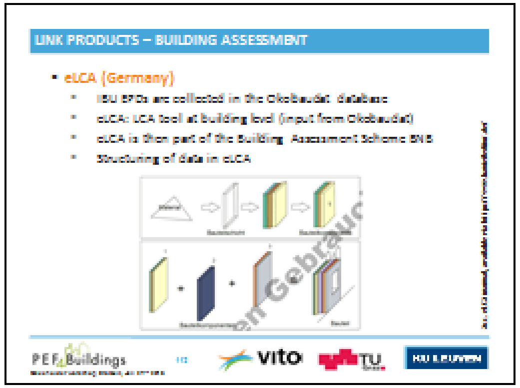
LINK PRODUCTS – BUILDING ASSESSMENT
eLCA (Germany)
IBU EPDs are collected in the Okobaudat database
eLCA: LCA tool at building level (input from Okobaudat)
eLCA is then part of the Building Assessment Scheme BNB
Structuring of data in eLCA
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LINK PRODUCTS – BUILDING ASSESSMENT
GPR Gebouw (the Netherlands)
Data are collected in the NMD database (Dutch National Environmental Database)
GPR Gebouw: LCA tool at building level (input from NMD)
GPR
GEBOUW
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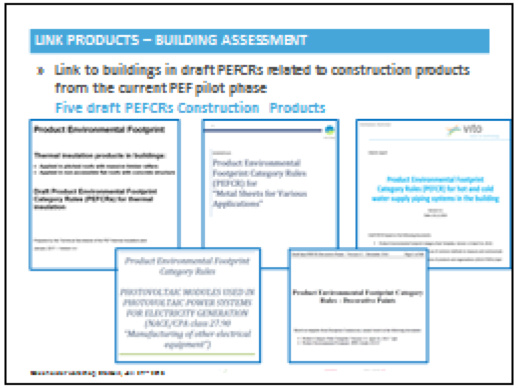
LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Five draft PEFCRs Construction Products
Product Environmental Footprint
Thermal insulation products in buildings
Draft Product Environmental Footprint Category Rules (PEFCRs) for thermal insulation
Product Environmental Footprint Category Rules (PEFCR) for "Metal Sheets for Various Applications"
Product Environmental Footprint Category Rules (PEFCR) for hot and cold water supply piping systems in the building
Product Environmental Footprint Category Rules
PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION (NACE/CPA class 27.90 "Manufacturing of other electrical equipment")
Product Environmental Footprint Category Rules : Decorative Paints

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LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Product level with clear link to building level:
Piping systems: for 5-storey apartment building for 50 years (can be adjusted)
Insulation materials: 1 m² for 50 years (building)
Paints: 1 m² for 50 years (building)
Metal sheets: 1 m² (upscalable to building level – scenarios use phase to be added)
To be included in use phase of building: equipment energy:
Photovoltaic module: 1 kWh
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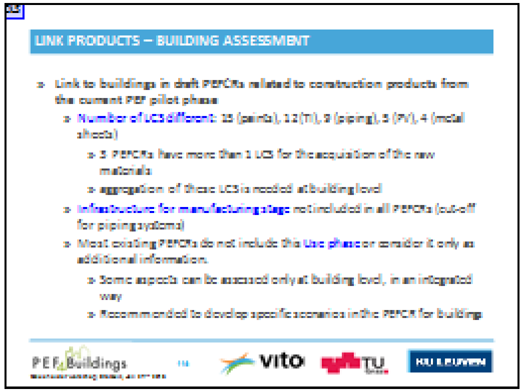
LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
Number of LCS different: 15 (paints), 12 (TI), 9 (piping), 5 (PV), 4 (metal sheets)
3 PEFCRs have more than 1 LCS for the acquisition of the raw materials
aggregation of these LCS is needed at building level
Infrastructure for manufacturing stage not included in all PEFCRs (cut-off for piping systems)
Most existing PEFCRs do not include the Use phase or consider it only as additional information.
Some aspects can be assessed only at building level, in an integrated way
Recommended to develop specific scenarios in the PEFCR for building
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LINK PRODUCTS – BUILDING ASSESSMENT
Link to buildings in draft PEFCRs related to construction products from the current PEF pilot phase
An overall scenario for dismantling/demolishing should be developed for the building level. At the moment for products only 2 PEFCRs include some basic scenarios
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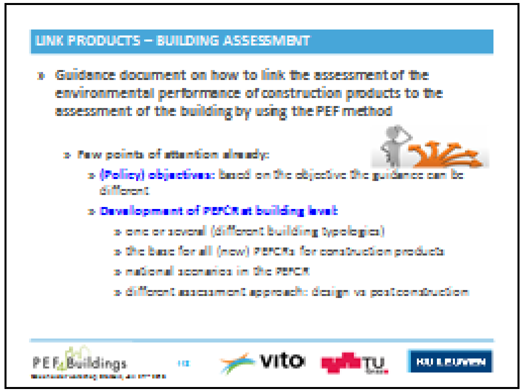
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
(Policy) objectives: based on the objective the guidance can be different
Development of PEFCR at building level:
one or several (different building typologies)
the basis for all (new) PEFCRs for construction products
national scenarios in the PEFCR
different assessment approach: design vs post construction
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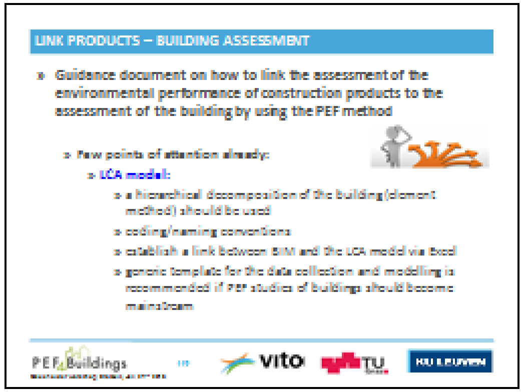
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
LCA model:
a hierarchical decomposition of the building (element method) should be used
coding/naming conventions
establish a link between BIM and the LCA model via Excel
generic template for the data collection and modelling is recommended if PEF studies of buildings should become mainstream
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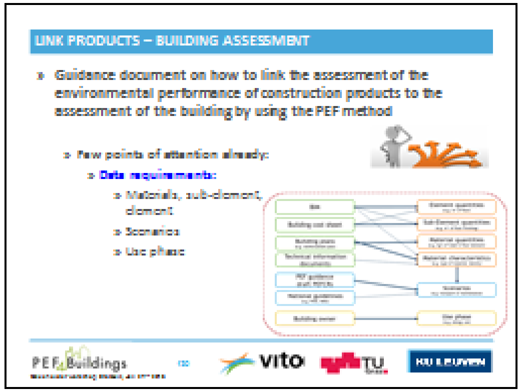
LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Data requirements:
Materials, sub-element, element
Scenarios
Use phase
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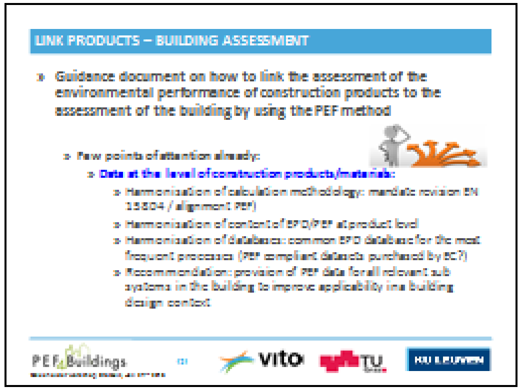
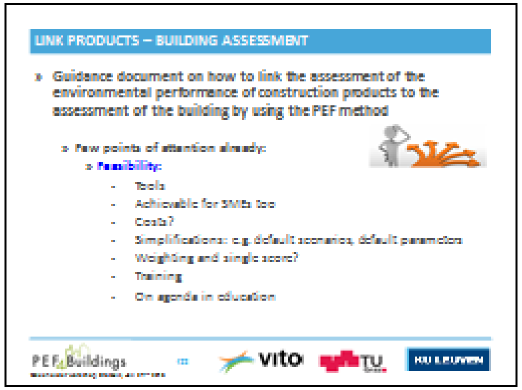
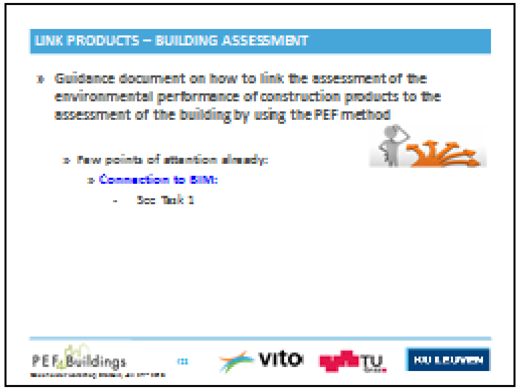
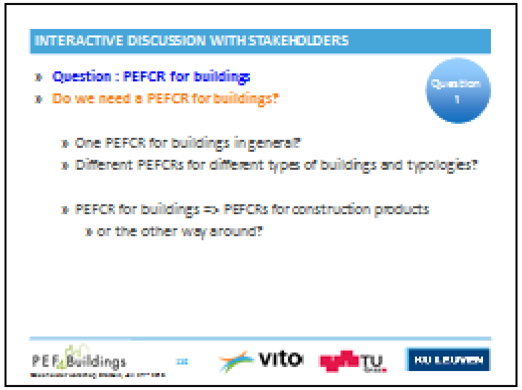
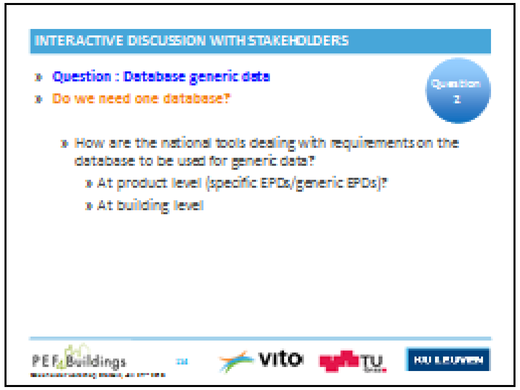

LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Data at the level of construction products/materials:
Harmonisation of calculation methodology: mandate revision EN 15804 / alignment PEF)
Harmonisation of content of EPD/PEF at product level
Harmonisation of databases: common EPD database for the most frequent processes (PEF compliant datasets purchased by EC?)
Recommendation: provision of PEF data for all relevant sub systems in the building to improve applicability in a building design context


LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Feasibility:
Tools
Achievable for SMEs too
Costs?
Simplifications: e.g. default scenarios, default parameters
Weighting and single score?
Training
On agenda in education


LINK PRODUCTS – BUILDING ASSESSMENT
Guidance document on how to link the assessment of the environmental performance of construction products to the assessment of the building by using the PEF method
Few points of attention already:
Connection to BIM:


AGENDA FOR STAKEHOLDER'S WORKSHOP
10:00 – 10:30 - Registration and welcome coffee
10:30 – 10:40 - Introduction by EC
10:40 – 10:50 - PEF4Buildings project in a nutshell
10:50 – 11:15 - Brief summary of the results of the PEF assessment of two office buildings
11:15 – 12:15 - Possible approaches for benchmark and classes of performance for office buildings
12:15 – 13:00 - Interactive discussion with stakeholders
13:00 – 14:00 - Lunch break / networking
14:00 – 14:45 - Link between the assessment of the environmental performance of construction products and the assessment of the environmental performance of buildings by using the PEF method
14:45 – 15:30 - Interactive discussion with stakeholders
15:30 – 16:30 - Closing of the meeting – Coffee – Networking


INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question : PEFCR for building
Do we need a PEFCR for buildings?
Question 1
One PEFCR for buildings in general?
Different PEFCRs for different types of buildings and typologies?
PEFCR for buildings => PEFCRs for construction products
or the other way around?


INTERACTIVE DISCUSSION WITH STAKEHOLDERS
Question : Database generic data
Do we need one database?
Question 2
How are the national tools dealing with requirements on the database to be used for generic data?
At product level (specific EPDs/generic EPDs)?
At building level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