FEBE EPD tool for precast concrete products: Methodological report

Tool for FEBE

November 2024

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Abbreviations and acronyms

EFCA	European Federation of Concrete Admixtures Association
EPD	Environmental Product Declaration
FU	Functional unit
GWP	Global Warming Potential
IEA	International Energy Agency
ISO	International Organization of Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Lower Heating Value
ODP	Ozone Depletion Potential
PCR	Product Category Rules
RSL	Reference service life
TNRPE	Total non-renewable primary energy

List of used references

Analysed document – used name in this document	Full name	Country
NBN EN 15804 + A2 (2019)	*Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*	*Europe*
Belgian Royal Decree of 22/05/2014	*Royal Decree establishing the minimum requirements for environmental displays on construction products for the registration of Environmental Product Declarations in the federal database*	*Belgium*
B-EPD PCR	*B-EPD – Construction Product Category Rules, Complementary to NBN EN 15804+A2 (version 18.02.2022)*	*Belgium*
"Bepalingsmethode" (version 2.0 -2014 + changes 2017)	*Environmental Performance Assessment Method for Construction Works (Calculation method to determine environmental performance of construction works throughout their service life, based on EN 15804)*	*Netherlands*
EN 16757:2017	*Sustainability of construction works — Environmental product declarations — Product Category Rules for concrete and concrete elements*	*Europe*
"MMG"	*Milieugerelateerde Materiaalprestaties van Gebouwelementen (MMG) (Environmental Performance of Materials used in Building Elements)* *"Environmental profile of building elements: towards an integrated environmental assessment of material use in buildings"*	*Belgium*

Glossary

Name	Source	Definition
Environmental declaration	ISO 14020	Claim which indicates the environmental aspects of a product or service
Type III environmental declaration	ISO 14025	environmental declaration providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information
PCR	ISO 14025	Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories PCR
Declared unit	EN 15804 +A2 (ISO 21930)	Quantity of a construction product for use as a reference unit in an EPD for an environmental declaration based on one or more information modules (example mass (kg), volume (m^3))
Functional unit	ISO 14040	Quantified performance of a product system for use as a reference unit
Product	/	In this document, a “product” shall refer to any kind of concrete product. The tool has as goal to have the widest range as possible concerning these products.
Co-product	EN 15804 +A2	Any of two or more marketable materials, products or fuels from the same unit process, but which is not the object of the assessment
Activity data	PEFCR Guidance v 6.3	Information which is associated with processes while modelling Life Cycle Inventories (LCI). The aggregated LCI results of the process chains that represent the activities of a process are each multiplied by the corresponding activity data and then combined to derive the environmental footprint associated with that process. Examples of activity data include quantity of kilowatt-hours of electricity used, quantity of fuel used, output of a process (e.g. waste), number of hours equipment is operated, distance travelled, floor area of a building, etc.
Primary data	Extract of PEFCR Guidance v 6.3	Primary data are site-specific, company-specific (if multiple sites for the same product) or supply chain specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods
Secondary, Inventory or generic data	Extract of PEFCR Guidance v 6.3	data that is not directly collected, measured, or estimated by the company, but sourced from a third party LCI database or other sources. Secondary data includes industry average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and may also be based on financial data, and contain proxy data, and other generic data.
Average EPD	B-EPD PCR (ISO 21930)	EPD based on average data. An average EPD can represent: a specific product from various manufacturing plants of one company; similar products from one manufacturing plant;

Name	Source	Definition
		similar products from several manufacturing plants of one or more companies. [SOURCE: ISO 21930:2015] For FEBE, the aim of average/generic EPD is to give average information on precast concrete products providing the performances described by the chosen functional unit. The data is mainly obtained from (public) databases, generic EPD and information gathered within the precast concrete industry. A set of average parameters is used in order to distinguish groups of products (types of concrete, ratios of reinforcement).
Collective EPD	B-EPD PCR	Average EPD representing similar products from various economic operators
Specific EPD	/	An EPD valid for a specific product in specific circumstances. The aim of this EPD is to take into account all specific parameters (e.g. specific manufacturing plant circumstances, specific raw materials, specific transport data…) as far as available.
Primary packaging	/	Any packaging designed so as to constitute at the point of sale a sales unit to the final user or consumer
Secondary packaging	/	Any packaging conceived so as to constitute at the point of sale a group of a certain amount of sales units, which is sold as such to the final user or consumer or whether it serves only to replenish the shelves at point of sale; these packages can be removed from the product without affecting its characteristics;
Tertiary packaging	/	Any packaging designed to facilitate the handling and transport of a number of sales units or combined package to avoid damage due to handling and transportation. The transport packaging does not include road transport containers, rail, sea and air;
REI	/	Fire resistance classification (R: load bearing capacity, E: integrity; I: insulation)
RSL	EN 15804 +A2 (ISO 21930)	Service life of a construction product which is known to be expected under a particular set, i.e., a reference set, of in-use conditions and which may form the basis of estimating the service life under other in-use conditions
Verifier	ISO 14025	Person or body that carries out verification, i.e. confirmation, through the provision of objective evidence, that specified requirements have been fulfilled
Critical review	ISO 14040-44	Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment

I. Introduction

I.1. Context

Environmental aspects are becoming more and more an essential part of the information to the market about the performances of building products. This information has entered the area of national and international standardisation and regulations. Environmental Product Declarations (EPD) have become the preferable way of communicating on the subject.

FEBE has an interest in the development of a software tool for the establishment of EPD to support the manufacturers of precast concrete products in this task on the one hand and to assure the quality and credibility of the EPD on the other hand.

	Owner and commissioner	Tool provider	LCA practitioner
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I.2. Goal of the study

The main objective of the study is to evaluate the "cradle-to-grave" environmental performances of precast concrete products manufactured by FEBE members in Belgium and installed in Belgium or in the Netherlands. For this purpose, a functional tool relying on an LCA model has been developed, making it possible to export EPDs for B2B and B2C communication.

The tool covers 54 predefined concrete products manufactured by the members of FEBE. An exhaustive list of these products is available in section II.1. The tool is designed for elaborating both average EPDs, based on representative or average values of parameters determined with the help of FEBE engineers (and provided as default values in the tool interface), and specific EPDs, based on producer's specific data.

The tool delivered in November 2024 complies with the following standards, programs and legislation:

- ISO 14040-44 standards and ISO 14025
- the European standard EN15804+A2:2019
- the European vertical PCR on concrete products, EN 16757:2017
- Belgian market: Belgian Royal Decree of 22 May 2014 and the B-EPD Construction Product Rules of 18.10.2022 (named "B-EPD PCR" in this document), established in complement to EN 15804+A2
- Dutch market: the Dutch program operated by MRPI, member of the ECO platform (with the aim of developing MRPI®-EPD certificate based on EN 15804 + A2); The guidelines of the "Environmental Performance Assessment Method for Construction Works" (Bepalingsmethode Milieuprestatie Bouwwerken in Dutch, hereafter called "*Bepalingsmethode*") are partially followed; it is referred to the integrated version 1.1 (March 2022), adapted to EN 15804+A2, and its Amendment 4 (June 2024).

Revision of the tool is required each time one of these reference documents is updated.

I.3. Purpose of this document

The present document aims at providing the user and project verifiers with the project documentation concerning the most important aspects of the tool and model:

- The methodological choices and assumptions made for the elaboration of the LCA model, in reference to the normative documents.
- The data sources that have been used (in particular for data that are not editable in the tool).
- The calculation methods and tools used for the LCA impact assessment.

This report is dedicated to verifiers, LCA practitioners and tool users. A user guide is further provided to the tool users to help them in using the tool.

This project report aims at fulfilling the requirements of chapter 8 of EN 15804+A2. In particular, the global structure and main titles follow the recommendations of section 8.2 of the standard. The annex VI.1 lists the information to be provided according to section 8.2 of EN 15804+A2 and, for each item, details which sections of this report deal with this subject.

Since this document supports the development of a calculation tool, it focuses on data and methodology rather than on results and their interpretation. Publication of results obtained with the tool will be the object of a further reporting process to be carried out by the tool users.

However, this report aims at serving as part of the project report for collective EPDs. Hence it includes the presentation and discussion of the results obtained from the sensitivity analysis, which is performed for assessing the homogeneity (in terms of environmental impacts) of the product group covered by the EPD (cf. V.2). This report can also be used as part of the project report for specific EPDs, in particular for modelling and background data.

I.4. Verification

The verification procedure aims at verifying that the EPDs generated with the help of the tool comply with the standards listed in section I.2. Two steps can be distinguished:[1]

1. the verification of the pre-integrated calculation LCA model and of the present methodological report regarding mainly scope, background data and methodology.[2]
2. the verification of the EPDs generated with the tool, including verification of data and parameter values selected by the tool user and the use of the results calculated by the tool in the EPD.

The present report focuses on the first verification step.

For the FEBE tool, the verifiers are different for step 1 (Solinnen) and for step 2.

I.5. Web tool

The tool described in this document is a web-tool.

The access to the tool and included confidential data is restricted to the members of FEBE and to verifiers for the time of the verification.

The tool is hosted on a secured server (https).

[1] In both steps, the verification includes the critical review, in the sense of ISO 14040 standard.

[2] In practice, the verification in step 1 carried out by the company Solinnen is dedicated to the compliance to the international standards, not to the Belgian or Dutch specific requirements.

I.6. Tool history

The first complete version of the tool was delivered in 2017. It was compliant to EN 15084+A1. Background data came from ecoinvent 2.2. Modelling of cement production was based on Cembureau EPDs published in 2015.

In March 2019, the tool was further made compliant to the Belgian technical document B-EPD PCR. Background data were extracted from ecoinvent 3.5.

In June 2021, the tool is adapted to EN 15804+A2:2019. Ecoinvent version is now 3.7.1 (2020) and modelling of cement production is based on Cembureau EPDs published in 2020.

In November 2024, both average and specific EPDs can be produced. Furthermore, the possibility to elaborate EPDs for the Dutch market according to EN 15804+A2 is made available.

II. Scope of the study

II.1. Functional unit

According to EN 15804+A2 (section 3.3.2.1), the functional unit of a construction product shall specify:

- the application of a product or product groups covered by the functional unit;
- the reference quantity for the functional unit when integrated in the construction works;
- the quantified key properties, when integrated into a building, for the functional use, quantified performance characteristics or minimum performance of the construction product, taking into account the functional equivalent of the building;
- the minimum performance characteristics under defined conditions shall be fulfilled over the defined time period of the functional unit;
- specified period of time under reference in-use conditions considering the RSL. If the functional unit uses a different time period than the RSL, the RSL shall be given as technical information in the EPD.

In terms of reference quantity, three main categories of functional unit can be defined:

- **Functional unit based on product area**: used for products with a function expressed in two dimensions (e.g. walls, panels, pre-walls or floor and roof coverings). The common unit is one m².
    - *E.g. Roof tiles: Ensure the waterproof covering of 1m² of roof*
- **Functional unit based on one product dimension (length/height)**: used for products with a function expressed in one dimension (e.g. curbs, gutters, columns, beams, etc.). The common unit is one m.
    - *E.g. Curb: Ensure the bordering of a sidewalk on a length of 1m.*
- **Other**: some products have a specific function, which may not be generalized or expressed by using one or two dimensions. This is the case for instance for products such as:
    - Stairways: allow to overcome one meter of height
    - Manholes: allow the inspection of conducts; in this example, the reference quantity corresponds to one item.

The functional units of all the products covered by the tool can be found in Table II-1 and in the tool.[3] Their definitions contain key properties and minimum performances such as, when relevant:

- Mechanical performances expressed as load or load descent supported or resistance to a defined force applied
- Fire resistance
- Acoustic or thermal insulation
- Air and water tightness

The Reference Service Life (RSL) varies in function of the studied product.

The standard EN 15804, in both versions +A1 (section 6.3.3) and +A2 (section 6.3.4.1), state that "*RSL information to be declared in an EPD covering the use stage shall be provided by the manufacturer. The RSL shall be specified under defined reference in-use conditions. The RSL shall refer to the declared technical and functional performance of the product within construction works. The RSL shall be established in accordance with any specific rules given in European product standards or, if not available, a PCR, and shall take into account ISO 15686-1, -2, -7 and -8. Where European product standards or a c-PCR provide guidance on deriving the RSL, such guidance shall have priority*."

The RSLs currently defined in the functional units are based on guidance provided by the PCR EN 16757 (Annex AA), which acts as a complement-PCR to EN 15804+A1. These RSLs are further confirmed by FEBE expert judgement, i.e. the manufacturer.

The Annex AA of EN 16757:2017 provides scenario guidance for concrete elements and defines nine types of scenarios. The column S in Table II-1 indicates the number of the scenario associated with each FU and Table II-2 provides, for each scenario number, the scenario and the associated RSL as described in Annex AA of EN 16757.

Table II-1: List of products covered by the tool and their FU

Name of the product	*RSL (years)*	*Functional unit*	*S*
Architectonic concrete façade elements - reinforced	*100*	*Ensure outerwear on one m² of building facade by helping to ensure air and water tightness and providing additive acoustic insulation Rw (C; Ctr) of 59 dB and a REI 180 for a reference service life of 100 years*	*1*
Architectonic concrete facade elements - white - reinforced	*100*		
Architectonic concrete facade elements - pigments - reinforced	*100*		

[3] FU definitions have namely been inspired by FU reported in EPDs established by the CERIB according to the French standard NF P 01-010 (CERIB stands for "« Centre d'étude et de recherche de l'industrie du béton », i.e. the Concrete Industry Research Centre in France ».

Name of the product	*RSL (years)*	*Functional unit*	*S*
Architectonic concrete facade elements - with insulation - reinforced	*100*	*Ensure outerwear on one m² of building facade by helping to ensure air and water tightness and providing additive acoustic insulation Rw (C; Ctr) of 59 dB, thermal insulation of 5 m².K/W and a REI 180, for a reference service life of 100 years*	*1*
Architectonic concrete facade elements - with insulation - pigments - reinforced	*100*		
Architectonic concrete facade elements - white - reinforced - insulation	*100*		
Architectonic concrete facade elements - white with pigments - reinforced - insulation	*100*		
Architectonic concrete facade elements - white with pigments - reinforced	*100*		
Beam - reinforced	*100*	*Ensure on one linear meter of beam of section 0,20 x 0,35 meters, load descents of 12 kN/m for the building considered while having a REI 60, for a reference service life of 100 years*	*5*
Beam - prestressed	*100*		
Beam for beam-and-block floor system - prestressed	*100*	*Ensure the structural part of one m² of flagstone made out of beams and interjoists, with a centre of 0.6 m and a payload of 4 kN/m² for the considered building, while having a REI 60, for a reference service life of 100 years*	*2*
Beam for beam-and-block floor system - reinforced	*100*		
Block for beam-and-block floor system	*100*	*Perform the function of formwork for one m² of flagstone made out of beams and interjoists, with a centre of 0.6 m and a payload of 4 kN/m² for the considered building, while having a REI 60, for a reference service life of 100 years*	*2*
Blocks - without pigments	*100*	*Perform the function of supporting wall (structure and nails) on one m² wall, while ensuring an acoustic insulation (Rw (C, Ctr) 54 dB additive to that of a dubbing) with a REI 60, for a reference service life of 100 years*	*2*
Blocks - with pigments	*100*		
Blocks (lightweight concrete) for thermal insulation (1 m³)	*100*	*Perform the function of supporting wall (structure and nails) of one m² wall, while ensuring acoustic insulation (Rw (C, Ctr) 49 dB additive to that of a dubbing) and a thermal insulation (thermal resistance of 0.31 m².K/W additive to that of a dubbing) with a REI 60, for a reference service life of 100 years*	
Column - reinforced	*100*	*Ensure on one linear meter of column of section 0,30 x 0,30 meter, load descents of 5 kN/m for the considered building while having a REI 60, for a reference service life of 100 years*	*5*
Curb	*50*		*6*

Name of the product	*RSL (years)*	*Functional unit*	*S*
Curb - with pigments	*50*	*Ensure the bordering of a sidewalk, street or a public space on one meter, for a reference service life of 50 years*	
Electric post	*100*	*Ensure one support of electric cables applying a force of 2 kN, at a height of 10 m, for a reference service life of 100 years*	*5*
Floor plate - prestressed	*100*	*Form the lower part (formwork and resistance) of one m² of floor that can support a normal load and having a REI 30, for a reference service life of 100 years*	*2*
Floor plate - reinforced	*100*		
Floor slats for livestock	*25*	*Ensure the sustainment of livestock on one m² while allowing the passage downwards of livestock dejecta, for a reference service life of 25 years*	9
Footing - reinforced	*100*	*Ensure the load transmission of a structure to one m² of foundation floor, for a reference service life of 50 years*	*2*
Gutter	*50*	*Ensure the collection of runoff water on one linear meter, for a reference service life of 50 years*	*6*
Gutter - with pigments	*50*		
Hollow core slab - reinforced	*100*	*Constitute one m² of flooring able to support a load of 4,5 kN/m² and having a REI 30, for a reference service life of 100 years*	*2*
Hollow core slab - reinforced concrete, with insulation	*100*	*Constitute one m² of flooring able to support a load of 4,5 kN/m², with a thermal insulation of 2,836 m².K/W (additive to that of a dubbing) and a REI 30, for a reference service life of 100 years*	
Hollow core slab - prestressed	*100*	*Constitute one m² of flooring able to support a load of 6 kN/m², and having a REI 60, for a reference service life of 100 years*	
Hollow core slab - prestressed concrete, with insulation	*100*	*Constitute one m² of flooring able to support a load of 6 kN/m², with a thermal insulation of 2,836 m².K/W (additive to that of a dubbing) and a REI 60, for a reference service life of 100 years*	
Manhole - base element	*100*	*Constitute one element of a manhole system, which ensures, in addition to ventilation, access by staff for cleaning and inspection of drain or sewer networks conveying wastewater, rainwater and surface water through gravity flow or occasionally under low pressure, installed in areas subject to road or pedestrian traffic, for a reference service life of 100 years*	*7*
Manhole - shaft elements	*100*		
Manhole - cover	*100*		
Manhole - fitting ring	*100*		
Panels - reinforced	*100*	*Perform the function of supporting wall (structure and nails) of one m² wall, while ensuring acoustic insulation (Rw (C, Ctr) of 59 dB additive to that of a dubbing) and a REI 180, for a reference service life of 100 years*	*1*
Panels - reinforced, with insulation, with connectors	*100*	*Perform the function of supporting wall (structure and nails) of one m² wall, while ensuring acoustic insulation (Rw (C, Ctr) of 59 dB additive to that of a dubbing) and a thermal insulation (thermal resistance 5 m²K/W additive to that of a dubbing) and a REI 180, for a reference service life of 100 years*	
Paving blocks	*50*	*Ensure the coating of one m² of road or public space. The coating is made to withstand pedestrian traffic loads and an occasional traffic, for a reference service life of 50 years*	*6*
Paving blocks - with white cement	*50*		

Name of the product	*RSL (years)*	*Functional unit*	*S*
Paving blocks - with white cement and pigments	*50*		
Paving blocks - with pigments	*50*		
Paving flags	*50*	*Ensure the coating of one m² of road or public space. The coating is made to withstand pedestrian traffic loads and an occasional traffic, for a reference service life of 50 years*	*6*
Paving flags - with white cement	*50*		
Paving flags - with white cement and pigments	*50*		
Paving flags - with pigments	*50*		
Pipe - reinforced - with seal	*100*	*Provide transportation on one linear meter of wastewater, stormwater or surface water by gravity flow or occasionally at low pressure, with a diameter of pipe of 1000 mm and with a thickness of 125mm, for a reference service life of 100 years*	*7*
Pipe - with seal	*100*	*Provide transportation on one linear meter of wastewater, stormwater or surface water by gravity flow or occasionally at low pressure, with a diameter of pipe of 1000 mm and with a thickness of 125mm, for a reference service life of 100 years*	
Pipe - fibered - with seal	*100*	*Provide transportation on one linear meter of wastewater, stormwater or surface water by gravity flow or occasionally at low pressure, with a diameter of pipe of 600 mm and with a thickness of 80mm, for a reference service life of 100 years*	
Pit (rainwater)	*100*	*Ensure the pretreatment of wastewater (from rainwater) in a system for up to 50 PT[4], for a reference service life of 100 years*	*7*
Pit (septic)	*100*	*Ensure the pretreatment of domestic wastewater in a system for up to 50 PT, for a reference service life of 100 years.*	
Pre-wall	*100*	*Perform the function of supporting wall (structure and nails) of one m² wall. with a REI 30, for a reference service life of 100 years*	*1*
Pre-wall - with insulation and connectors	*100*	*Perform the function of supporting wall (structure and nails) of one m² wall, while ensuring a thermal insulation (thermal resistance of 4.733 m².K/W additive to that of a dubbing) and a REI 30, for a reference service life of 100 years*	
Reinforced stairway (one piece)	*100*	*Allow to overcome a difference of height of one meter on a passing width of 120 cm with a REI 30, for a reference service life of 100 years*	*1*
Tile	*50*	*Provide the function of coverage and waterproofing for one m² of roof, for a reference service life of 50 years*	*3*
Tile - with pigments	*50*		

[4] PT stands for "Population total"; 50 PT means 50 inhabitants.

Table II-2 : List of scenarios and corresponding defaults RSLs associated with FU of the FEBE tool, as defined in Annex AA of EN 16757:2017

N	Scenario	RSL
1	Structural concrete or concrete elements for buildings (exterior) (Wall elements)	If known, equal to the ReqSL[5] of the construction work. If not, data assumed in some countries may be used as guidance, (normally 100 years)
2	Structural concrete or concrete elements for buildings (interior) (e.g. Floor elements)	If known, equal to the ReqSL of the construction work. If not, data assumed in some countries may be used as guidance, (usually 100 years)
3	Non-structural elements for buildings (exterior) (e.g. Non-load-bearing facade)	Data assumed in some countries may be used as guidance (usually 50 years)
5	Structural concrete or concrete elements for civil engineering works (e.g. Beam, column, box culverts)	If known, equal to the ReqSL of the construction work. If not, data assumed in some countries may be used as guidance, (usually 100 years)
6	Elements for street works (e.g. Sound barrier, kerb paving block)	Data assumed in some countries may be used as guidance (usually 50 years)
7	Elements for sewerage and draining systems (e.g. Pipe, manhole)	If known, equal to the ReqSL of the construction work. If not, data assumed in some countries may be used as guidance, (usually 100 years)
9	Non-structural elements for agricultural constructions (e.g. Floor slats for livestock)	Data assumed in some countries may be used as guidance (usually 25 years)

Annex A of EN 15804 further specifies: "*The reference service life of a product can be based upon empirical, probabilistic, statistical, deemed to satisfy or research (scientific) data and shall always taking into account the intended use (description of use), see ISO 15686-1, -2, -7 and -8. This basis shall be mentioned in the EPD.*"

The RSLs mentioned in Table II-1 can be considered as based on deemed to satisfy data (with reference to EN 16757) as well as on empirical data through FEBE manufacturers experience.

The same default values of RSL are proposed in the interface for Belgian and Dutch markets (cf. Table II-1). However, it is recommended to the tool user to check the value of the RSL, in particular its relevance with regard to the intended use of the product and specific in-use conditions. In the *Bepalingsmethode*, for use in buildings, the product reference service

[5] ReqSL stands for required service life, i.e. service life structural concrete elements are designed for.

life is considered to depend on the service life of the building (when product life is higher than building live):

- homes: 75 years;
- utilities: 50 years (including schools, shops, sports halls, etc.).

In practice, the user can modify the value of the RSL in the tool (and should then also adapt the description of the FU in the EPD accordingly).

II.2. Geographical scope

The tool is meant to be used by FEBE members, producing precast concrete products in Belgium, and selling these products in Belgium and/or in the Netherlands.

The geographical scope is the following:

- Raw materials come from Europe
- Production sites are located in Belgium
- Construction site, use stage and end-of-life of the product are either located either in Belgium or in the Netherlands.

II.3. System boundary according to the modular approach

The model has been made with the aim of generating EPDs that fulfil the requirements of the EN15804+A2 standard: it follows the same modular approach and allows to subdivide the stages according to each module mentioned in the standard.

Figure 1 indicates the various types of EPDs that can be produced according to EN15804+A2 and details which modules compose each one.

The LCA model supporting the tool covers all modules, enabling all types of EPDs to be generated, in particular the type "Cradle to grave and Module D".

The tool is hence compliant with the Belgian Royal Decree of 22 May 2014, which specifies that the EPD has to contain modules A1-A3, A4, C2-C3, C4, and D.

The model also complies with the modularity principle of the EN 15804 standard, i.e. "*Where processes influence the product's environmental performance during its life cycle, they shall be assigned to the module of the life cycle where they occur; all environmental aspects and impacts are declared in the life cycle stage where they appear*". It means that all impacts happening during a specific module are indeed accounted for in the given module.

According to EN 15804+A2 (section 7.2.2): "*Modules and indicators not declared shall be marked as "ND". If an indicator value has been calculated to be "zero" or if the value of "zero" is plausible for this indicator e.g. there is no activity in the scenario, then "0" is declared for this indicator.*".

As stated earlier in this section, all modules are covered by the model. However, as justified in sections III.2.7 and III.2.8, there is no relevant activity in the studied scenarios to be considered for modules B3 to B7. Therefore, zero values are reported for these modules for all prefab concrete products studied in the EPD tool. For module B2, the recommendation of the EPD program depends on the country. Maintenance activities are only modelled in the case of facades in architectural concrete installed in Belgium. For the Netherlands, module B2 is considered as not relevant in the *Bepalingsmethode,* as only functional maintenance can be considered and not aesthetic maintenance.

Apart from this difference in B2, the system boundaries are similar for EPDs for Belgium and for the Netherlands. Indeed, since alignment with EN 15804+A2, the *Bepalingsmethode* also consider module D reporting as mandatory.

	CONSTRUCTION WORKS ASSESMENT INFORMATION																
	CONSTRUCTION WORKS LIFE CYCLE INFORMATION																SUPPLEMENTARY INFORMATION BEYOND CONSTRUCTION WORKS LIFE CYCLE
	A1 - A3 PRODUCT STAGE			A4 - A5 CONSTRUCTION PROCESS STAGE		B1 - B7 USE STAGE							C1 - C4 END OF LIFE STAGE				D BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
	Raw material supply	Transport	Manufacturing	Transport	Construction - Installation process	Use	Maintenance	Repair	Replacement[1]	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse, recovery, recycling, potential
				scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario	scenario
Cradle to gate with modules C1-C4 and module D	Mand.	Mand.	Mand.										Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to gate with options, modules C1-C4 and module D	Mand.	Mand.	Mand.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to grave and module D	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mand.	Mandatory
Cradle to gate[2]	Mand.	Mand.	Mand.														
Cradle to gate with options[2]	Mand.	Mand.	Mand.	Opt.	Opt.												

Figure 1: Types of EPDs *(EN 15804+A2:2019)* and life cycle stages covered by the model

II.4. Average EPDs

For average EPDs, the tool is designed to elaborate EPDs for products having specific dimensions (and fulfilling one of the pre-defined functional units).

In the current development of average EPDs by FEBE, a typical or most representative product, with defined dimensions, has been associated with each functional unit. This product can be produced by several manufacturers and/or at different sites. Hence, the corresponding EPD is in most cases a collective EPD.[6]

Default values of activity data related to modules A1-A3 are provided in function of the functional unit in the tool and can be adapted by the tool user.

As required by the EN15804+A2 standard (8.2.1.c.ii) and B-EPD PCR (A19), the calculation rules used to determine the default average values to be associated with each product are described in Table II-3. These rules depend on the module and on how data are collected / made available. They have to be updated if the tool user replaces the default values by updated values.

The table also describes the way min and max values of parameters are determined for calculating the result variability (see section V.2).

The table focuses only on modules A1 to A3, i.e. the modules for which differences among sites/producers can be expected.[7]

Table II-3: Average default data and variability for collective EPDs

Module & Data	Rule for averaging data	Approach for min/max values
A1 - Concrete composition	Data source: FEBE has provided concrete compositions for the 10 types of recipes used in the studied prefab products (2015) Averaging rule: Each composition is obtained as unweighted average among all compositions reported by producers for the corresponding type of concrete	Min (max) values of impacts are calculated for min (max) values of cement percentage. Min (max) values of water percentage are counted simultaneously with the min (max) values of cement. The corresponding compositions of sand and aggregates are calculated so as to keep concrete volume constant: • For min values, additional amounts of sand and aggregates are counted for substituting the removed cement and water (on a volume-basis, taking densities into account). • For max values, amounts of sand and aggregates are reduced to compensate the additional volume occupied by cement and water.

[6] As defined in B-EPD PCR, collective EPD: average EPD representing similar products from various economic operators (e.g. EPD from trade associations)

[7] Module A4 is modelled using default values from the Belgian PCR. Hence, there is no difference in function of the producers/sites.

Module & Data	Rule for averaging data	Approach for min/max values
A1 - Amount of steel	Source: FEBE engineers (2019) Averaging rule: None. The amount of steel (for reinforcement, prestressed concrete or fibered steel) is calculated by engineers as the minimum amount allowing to fulfil the mechanical and safety requirements of the product (in some cases, expressed through the load to be supported). Due to economical constraints, producers will not use more steel than necessary.	It is assumed that the amount of steel will only slightly vary from one producer or site to another, as they all face the same mechanical and economical constraints. Hence, for the max value, a relative increase of 5% in the amount of steel is considered as compared to the nominal value. For the min value, 1% less steel (in relative amount) could be used instead of the nominal value). Furthermore, it is considered that the amount of steel does not depend on the variation of cement percentage around the mean value (e.g. the maximum value of steel can occur with the max value of cement percentage). To keep volume constant the variation in steel amount is compensated by the corresponding amount of concrete (taking densities into account).
A1 - Amount of pigments	Source: FEBE engineers (2019) Averaging rule: None. The amount of pigment is based on current typical practice, in function of the product (2% or 3% of the amount of cement).	For the sensitivity analysis, it is assumed that the amount of pigment can vary by +/- 10% around the value determined by the engineers for each pigmented product.
A2 - Transport from extraction to manufacturer	Source: FEBE experts (2016 Averaging rule: none. Typical distance and transport modes, representative of the raw material supply transport are used as reference values.	The sensitivity of the results to the parameters of A2 is only assessed for max values (min values are kept equal to default values): Max values: distances by truck are added (either in partial replacement of barge transport for cement and fillers; or in addition to default parameters for granulates and steel)
A3 – On-site manufacturing	Source in the current version of the tool: data collection from FEBE members through questionnaires (2015-2016); total amounts of electricity and fuels are divided by the total production in ton of the site. Averages per ton are then converted in average values per m3. The values are common to all families of products. Averaging rule: mass weighted averages of the amounts of energy per ton obtained per production site. Data from 12	It is assumed that for a same product, the electricity and fuel consumptions among sites will be at the minimum and at the maximum respectively 33% and 300% of the calculated average values.

Module & Data	Rule for averaging data	Approach for min/max values
	sites are used (3 sites with extreme values are excluded). *Remark: As recommended in section III.2.3.1, the data for on-site energy consumption for manufacturing should be updated as it is outdated.*	
A3 - Packaging	Source: FEBE experts with the help of producer surveys (2015-2016) Averaging rule: none. The most representative packaging sets are taken as default values.	No variability is modelled, except for some families of products for which a lower bound without pallet is investigated (e.g. paving flag).

Note that values for the min and max scenarios are not symmetric around the average. Indeed, for economic reasons, most producers tend to use the minimum amounts of cement and steel required for ensuring the technical and safety performances of the products. However, in some cases, higher values are used.

In a later stage, the average EPD obtained for a product of specific dimensions can also be used as representative of products of different dimensions that fulfil the same FU. In that case, the products covered by this average EPD and the resulting variability in the LCIA results should be further described in the EPD. Such use of the average EPD would be acceptable provided that the "*average EPD is reasonably descriptive of the product group represented by the EPD in view of the use of the EPD in a construction works assessment*" (B-EPD PCR, section A 19).

II.5. Cut-off criteria for initial inclusion of inputs and outputs

II.5.1. CUT-OFF CRITERIA

The study aims at fulfilling the rules mentioned in the EN15804+A2 standard concerning cut-off criteria (section 6.3.5):

"*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.*

The total of neglected input flows per module, e.g. per module A1-A3, A4-A5, B1-B5, B6-B7, C1-C4 and module D (see Figure 1) shall be a maximum of 5 % of energy usage and mass. Conservative assumptions in combination with plausibility considerations and expert judgement can be used to demonstrate compliance with these criteria;"

II.5.2. APPLICATION OF THE CUT-OFF CRITERIA

Conservative assumptions in combination with plausibility considerations and expert judgement have been used to demonstrate compliance with these criteria. The list of excluded processes is given in the table below:

Table II-4 : List of excluded processes and materials throughout the study

Excluded processes & materials	Justifications
Module A3	
Coating agents and acid product for the (surface) finishing of products	Insufficient data on consumption amounts. The used amounts are considered as low but depend on the product surface/weight ratio. Concerning mass usage, the coating is supposed to be applied on the light-exposed surface of the product. For the thinnest prefab concrete product, tiles, the total surface is of 0.2*0.5m = 0.1 m². The weight of one tile is 4.46 kg of concrete. The coating agent is used on a 2mm surface meaning that the volume used of coating for one tile is of 0.002*0.2*0.5 = 0.0002m³ The weight of coating used for one tile is of 0.0002m³*1100 kg/m³ = 0.22 kg The coating can represent 0.22/4.46 = 5% of the product mass. For some products, the exclusion of finishing constitutes an effective limit of the current version of the tool.
Labels on products	Low mass and energy demand compared to the overall product. If we consider a label of 3g per packaging of 5 tiles (22.5 kg), it corresponds to 0.013% of the mass of product. The mass criterion is respected.
Module A5	
Packaging of installation products used	The total mass of packaging for installation products is considered as limited since installation products such as mortar, sand, concrete, are rarely packed, but more often transported in gross by truck. Cement can be packed in paper bags. If we assume maximum 140 g of kraft paper for 50 kg of cement,[8] we get a ratio of less than 0.3% to the mass of cement. The mass criterion is respected.
Transport of packaging of installation products	It is considered that the transport of packaging of installation products has a low impact, because of the small amounts of packaging for this kind of products.

[8] Ma et al. (Sustainability 2019,11, 5554) mentions a paper weight for a bag of 50 kg cement of 65 g (area of 0.72 m2 multiplied by a grammage of 90 g/m2). As upper bound, we consider a 2-ply bag with a grammage of 100 g/m2, which gives a weight of 144 g (0.72 * 2 *100= 144 g; rounded to 140 g).

Excluded processes & materials	Justifications
(Pumping of ancillary materials)	(The consumption for this step can be included in vibration or compaction energy use.)
General	
Infrastructures for pumping stations, and water sanitary stations	Material and energy required for the manufacturing of this equipment are considered negligible due to its large number of uses.
Periods of stock of primary materials or (concrete) wastes	The only processes that may be accounted for during stock periods is the carbonation process of the concrete elements. It is assumed that this duration is <1% of total RSL.

If we except the coating agent for finishing, the excluded parts of all processes represent less than 1% of materials.

II.6. Allocation principles and procedures

II.6.1. ALLOCATION OF PLANT-LEVEL DATA TO THE PRODUCT

The tool allows the users to indicate the total energy consumption of the plant. Cases may occur in which various products are produced in the same plant. If consumption data specific to the product are available, a sub-plant producing only the declared product can be defined and there is no need for allocation. However, in most cases, product-specific consumptions cannot be determined at plant-level and total consumptions have to be allocated to the product. As illustrated in Figure 2, the allocation used in the model is based on the mass of products.

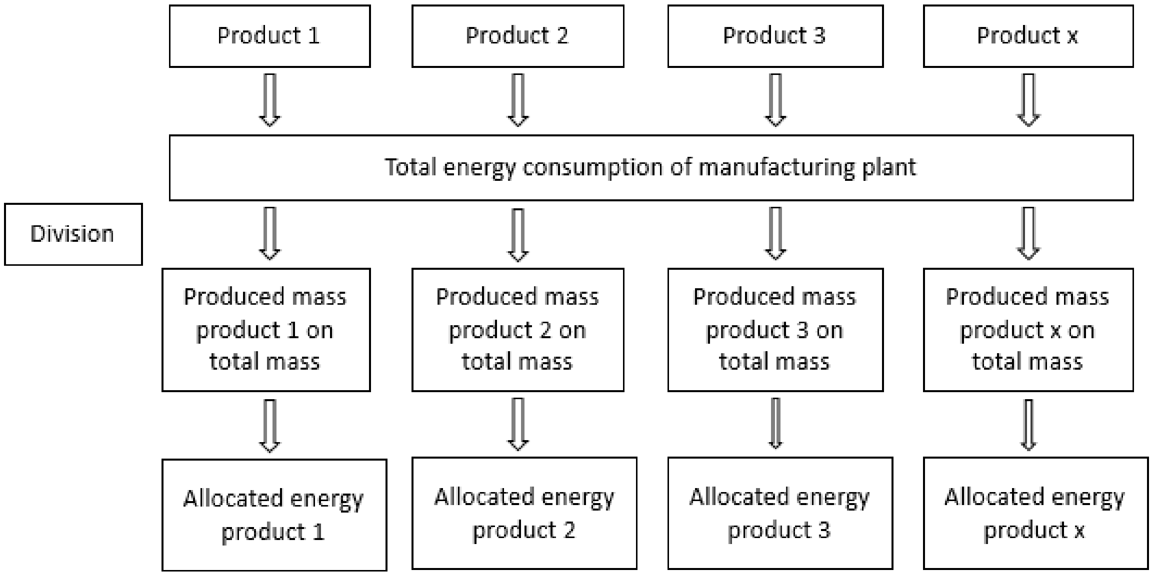

Figure 2 : Scheme of the used allocation method in case of various products within a same manufacturing plant

In practice, the tool user can report the production of a plant following three typologies:

1. Total production of the declared products can be expressed in concrete volume and is divided by the total volume of concrete produced at the plant.
2. The user can indicate the number of produced units of the various products and the weight of each type of units.
3. The user can indicate the surface produced of the various products and the weight per surface for each product.

Product mass allocation applies for typologies 2 and 3. For typology 1, the allocation of consumptions is based on the produced concrete volumes.

The mass

(or volume) allocation method has limits, since energy consumptions are higher for products containing steel parts (because of welding, cutting, etc. of steel). Taking this into account in the calculation method is currently not possible. Mass allocation method could be adapted if more precise data could be obtained from the producers.

Concerning material use and product characteristics in case the same product is made in various manufacturing sites, the tool users have to encode the average values in the tool. These values are based on a weighted average, as demonstrated in section II.4.

Note: *The allocation of water consumption at plant-level data has not yet been integrated in the tool and model. Prefab concrete products consume water mostly as an ingredient, and not much during the production process. If estimated as important, the allocation of water consumption will be added in the future version of the tool.*

II.6.2. CO-PRODUCT ALLOCATION

II.6.2.1. Use of co-product

The manufacturing of precast concrete products may be accompanied by the use of co-products from other production processes, in particular fly ashes (from hard coal power plants) and blast furnace slags (from steel production). The required allocation has to be applied in a consistent way for all co-products of the system, in particular if they are used in the same assessment.

EN 15804 advocates the modularity principle, where the environmental influence of processes is assigned to the module in the life cycle where they occur. Co-product specific LCIs are therefore required (if the associated impacts cannot be neglected).

According to EN 15804, § 6.4.3.2: "*Allocation shall be avoided as far as possible by dividing the unit process to be allocated into different sub-processes that can be allocated to the co-products and by collecting the input and output data related to these sub-processes.*

— If a process can be sub-divided but respective data are not available, the inputs and outputs of the system under study should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system;

In the case of joint co-production, where the processes cannot be sub-divided, allocation shall respect the main purpose of the processes studied, allocating all relevant products and functions appropriately. The purpose of a plant and therefore of the related processes is generally declared in its permit and should be taken into account. Processes generating a very low contribution to the overall revenue may be neglected. Joint co-product allocation shall be allocated as follows:

- *Allocation shall be based on physical properties (e.g. mass, volume) when the difference in revenue from the co-products is low;*
- *In all other cases allocation shall be based on economic values;*
- *Material flows carrying specific inherent properties, e.g. energy content, elementary composition (e.g. biogenic carbon content), shall always be allocated reflecting the physical flows, irrespective of the allocation chosen for the process.*"

Since the economic value of **fly ashes** is close to zero, impacts of its production are neglected (cf. EN 15804, § 6.4.3.2).

In the case of **blast furnace (BF) slag**, impacts of the blast furnace have to be consistently attributed between the main product, steel, and the co-product, BF slag. In a report entitled "A methodology to determine the LCI of steel industry co-products" (2014), Worldsteel proposes the range of price of 5-100 € per ton of BF slag and of 310-425 € per ton of hot metal/steel slab. The report further mentions "*This gives a range of % allocation of emissions to BFS of approximately 0.5% - 6.0%*". Hence, BF slag has an economic value and its production cannot be considered as burden-free.

There are three issues concerning the modelling of BF slag in our model:

- It should comply with the requirements of EN 15804 (and ISO 14040), which gives preference to, in decreasing order of priority:
  - Division into sub-processes that can be allocated to the co-products
  - Sub-division of processes with inputs and outputs partitioned between the products in a way which reflects the underlying physical relationships between them
  - If processes cannot be subdivided, economic allocation (when the difference in revenue from the co-products is higher than 25%)
- There should be a consistency between the modelling made by Cembureau in its EPDs for CEM II and CEM III published by Cembureau in 2020 (including BFS) and the modelling made in the FEBE model for adding BF slag as separate ingredient.
- It should be consistent with the way steel, as main product from blast furnace, is modelled, i.e. for fibered and prestressing steel, for which the production impacts are currently modelled using an LCI published by Worldsteel. The production of steel from electric furnace is not concerned by this issue (i.e. the LCIs taken from ecoinvent to model steel used as reinforcing steel and for stainless steel used for modelling anchors or bolts and nuts).

In terms of consistency, the main and most recent EPDs and LCIs published by international associations of producers for cement (Cembureau) and steel (Worldsteel) are not consistent from a methodological point of view:

- In the EPDs published by Cembureau (2020) for CEM II and CEM III and including BF slag as ingredient, economic allocation is used for modelling the impacts associated to the BF slag.[9] However, detailed modelling is not disclosed in the EPDs. Hence, the EPDs are used as such in the model for FEBE, although it might not correspond to a conservative approach.
- For steel production in blast furnace, Worldsteel provides inventory data based on system expansion (for avoiding allocation, cf. §4.3.4.2.a of ISO 14044). This means that credits are counted for the avoided production of a material substituted by the co-product, here BF slag. To our knowledge, there is no LCI dataset, nor EPD, already published and complying with EN 15804+A2, that address blast furnace co-product allocation in a way consistent with the assumptions made by Cembureau. This is a limit of the current modelling.

For the modelling of BF slag that can be used as additional binder in the tool,[10] the data selected is the LCI data (list of 45 elementary flows) published by Worldsteel in the already quoted report of 2014. This choice is justified as follows:

[9] Impacts associated with the production of BF slag were neglected in the EPDs published in 2015.

[10] There is no BF slag included as additional binder in the default recipes used for the 54 types of products covered in the tool.

- Worldsteel has established co-product LCIs with the use physical partitioning (cf. §4.3.4.2.b of ISO 14044) for allocating blast furnace impacts between steel and BF slag. This alternative methodology is in line with ISO 14044 and EN 15804 and corresponds to the second preference for modelling systems with co-products, before economic allocation. This is considered as a conservative approach for BF slag production. Indeed, the document mentions that the blast furnace energy partitioning ratio is 5.2% for the BF slag. This value lies in the upper bound of economic allocation range of 0.5%-6% quoted in the Worldsteel report.
- Since the EPDs from Cembureau do not provide detail about the economic allocation applied, it is not possible to adopt a modelling that ensures consistency with their approach.

Table II-5 summarizes how production impacts of the two co-products from other production systems are modelled in this study. This modelling needs to be improved. Therefore, a careful monitoring of upcoming data will be carried out.

Table II-5 : Allocation used for co-products

Co-product	Type of allocation	Source
Fly ashes	Economic allocation: co-product with very low economic value, near 0 (neglected impacts)	EN 16757:2017 and Cembureau EPD
Blast furnace slag in Cembureau EPDs	Economic allocation	Cembureau (2020) – no details provided
Blast furnace slag as separate ingredient	Physical partitioning	Worldsteel, February 2014: "A methodology to determine the LCI of steel industry co-products"

II.6.2.2. Production of co-product

No co-products are produced during concrete product production. Concrete losses are generally dried, stored and reintegrated into new concrete products used for less noble functions. This is also the reason why the production losses are estimated as being low (0.1%).

II.6.3. ALLOCATION PROCEDURE OF REUSE, RECYCLING AND RECOVERY

As required in the EN 15804+ A2 standard (section 6.4.3.3), "*the end-of-life system boundary of the construction product system is set where outputs of the system under study, e.g. materials, products or construction elements, have reached the end-of-waste* *state.*[11] *Therefore, waste processing of the material flows (e.g. undergoing recovery or recycling processes) during any module of the product system (e.g. during the production stage, use stage or end-of-life stage) are included up to the system boundary of the respective module as defined above*."

More explicit information on when the end-of-waste state is reached is given in annex 0.

According to section D.2.3 of EN 15804+A2, "*Significant choices relating to the emissions and resources should be described in the EPD, including:*

1. The point at which non-elementary inputs to modules A1-A3 are considered a waste, secondary material, secondary fuel or a co-product from another production process, and assigning of emissions;

2. The point at which non-elementary outputs from modules A5-C4 are considered a waste, secondary material, or secondary fuel, and assigning of emissions;"

The following sections detail the system boundaries in relation to end-of-waste state for the use of secondary materials and for recycling at end-of-life, successively for:

- concrete product components and product end-of-life
- packaging

Remark: There is no reuse of concrete products taken into account in the model. For packaging, pallets and wooden wedges and slats can be reused. Production (in A3) and end-of-life (in A5) are only counted for the amount of material equal to the packaging weight divided by the number of uses.

II.6.3.1. End-of-waste state for concrete products

For concrete prefab products, the input materials to the product system that have been recovered (here, recycled) from a previous system[12] are the following ingredients:

- coarse recycled granulates
- recycled part of steel

At end-of-life of the concrete prefab products, part of the following materials is recycled and corresponds to material exiting the system that will be recovered (here, recycled) in a subsequent system:[12]

- Steel
- Concrete (and inert installation materials)

Remark: insulants are not recycled and remain waste (as a reminder, insulants are used as layer and not in concrete bulk).

The point where end-of-waste (EOW) state is reached is fixed as follows in the model:

---

[11] The end-of-waste state is reached when certain waste ceases to be waste and becomes a product, or a secondary raw material.

[12] Cf. definitions in Annex D of EN 15804+A2 (section D.2.2)

- Granulates: EOW is reached at the exit of the sorting centre for demolition waste (where concrete is crushed), provided that the granulates fulfil the quality criteria, in conformity with for example the Walloon legislation.[13] Furthermore, FEBE confirms that no additional step is required for using ground concrete as granulates, except screening for the appropriate granulometry.
- Steel: EOW for steel scrap is fixed at the European level.[14] Accordingly, the point where scrap with satisfactory quality is obtained can be:
    - For pre-consumer waste: at the producer
    - For demolition waste: at the exit of the sorting centre
    - For post-consumer packaging waste: at the exit of the sorting centre

Figure 3 represents the processes included in the system boundaries when secondary material is used and at product end-of-life. Reference is made to the parameter definitions provided in section D.2.3 of EN 15804+A2.

[13] Order of the Walloon Government implementing the procedure for reaching end-of-waste state provided for in Article 4ter of the Decree of 27 June 1996 on waste and amending the Order of the Walloon Government of 14 June 2001 promoting the recovery of certain waste (M.B. 05.04.2019) http://environnement.wallonie.be/legis/dechets/degen040.htm (accessed 13/12/2021)

[14] Council Regulation (EU) No 333/2011 of 31 March 2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC of the European Parliament and of the Council;

https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32011R0333 (accessed 13/12/2021)

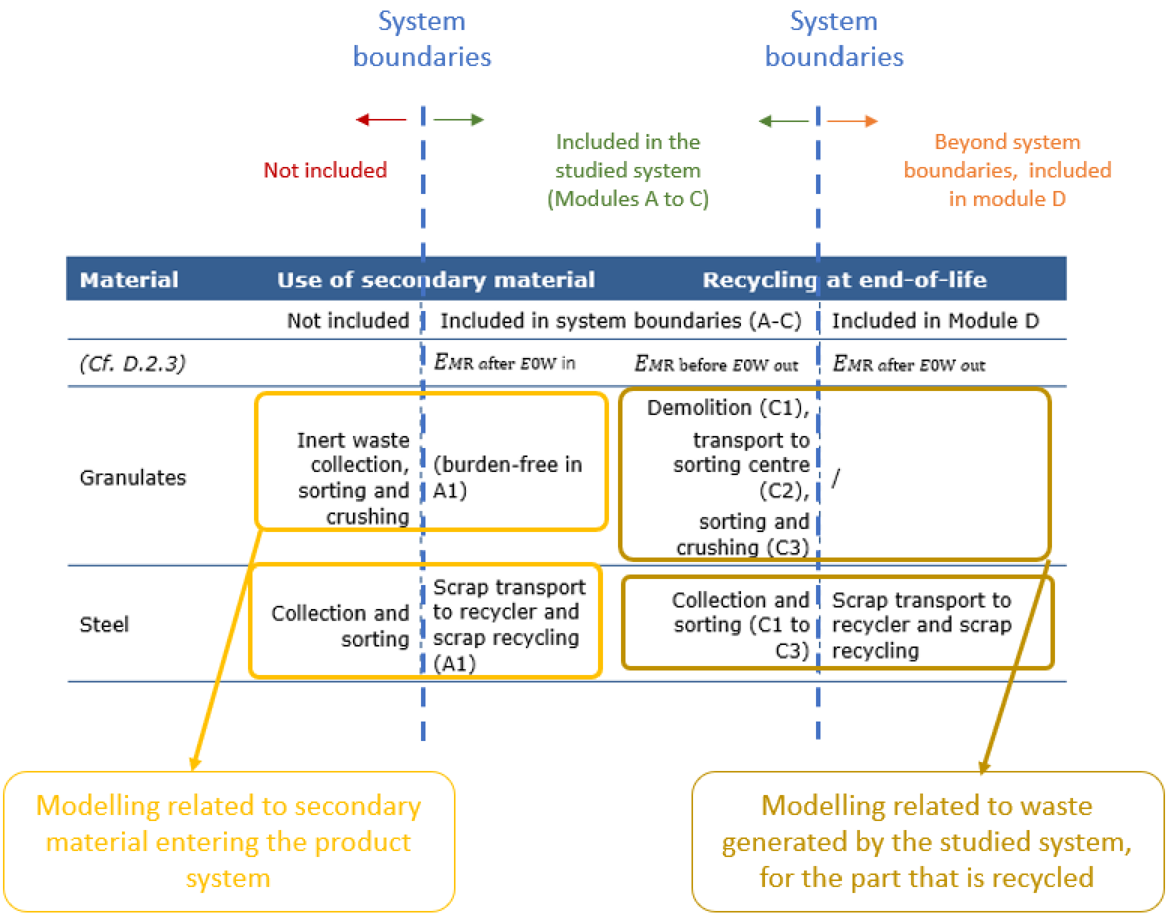

Figure 3: Processes included in system boundaries according to EOW of concrete product components

II.6.3.2. End-of-waste for packaging materials

For packaging, it is only for corrugated board that input material is modelled as recycled from a previous system.[12]

At end-of-life, recycling is modelled for the following types of packaging. Hence, there are materials exiting the system that will be recovered (here, recycled) in a subsequent system:[12]

- Corrugated board
- Plastic packaging
- Wooden pallet and wooden wedges and slats

The point where end-of-waste (EOW) state is reached is fixed as follows in the model:

- For corrugated board, there is no EOW before the pulping of the recovered material, hence in practice not before the exit of the papermill.
- For plastics, it is at the stage of pellets that recycled material reaches EOW.

- For wooden materials, wooden chips are considered in the model to have reached EOW state. It is determined here from a functional point of view and inspired by the EOW legislation in France, although, strictly speaking, there is currently no such agreement in Belgium (at least in Wallonia).

Figure 4 represents the processes included in the system boundaries when secondary material is used in packaging (only applicable for cardboard) and at packaging end-of-life.

Material	Use of secondary material		Recycling at end-of-life	
	Not included	Included in system boundaries (A-C)		Included in Module D
(Cf. D.2.3)		E_{MR} after EOW in	E_{MR} before EOW out	E_{MR} after EOW out
Corrugated board	Collection, sorting, pulping and paper machine	(burden-free in A3)	Collection, sorting, pulping and paper machine (A5)	/
Plastic packaging (PE films, foam, strapping bands)		N/A	Collection, sorting, regeneration, pelletisation (A5)	/
Wooden packaging (pallet, wedge, slat)		N/A	Wood chopping (A5)	/

Figure 4: Processes included in system boundaries according to EOW of packaging materials (same principles as in Figure 3)

III. Life cycle inventory analysis

III.1. Introduction

Various types of data are used in this study and can be defined as:

- **Primary data**: company-specific data describing the processes under the control of concrete product producers; here mainly activity data -potentially averaged among several producers - related to:
  - Concrete and product compositions
  - Energy and auxiliary consumptions at the manufacturing plants,
  - Installation auxiliaries (sectoral estimations from FEBE engineers)
- **Secondary data**: data sourced from a third-party life-cycle-inventory database or other sources
  - LCI datasets available in databases such as ecoinvent, Copert, European industry associations etc.
  - Published EPDs of raw materials
  - Activity data recommended as default values by standards or related technical documents.

Concerning these last standards or related technical documents, the study uses data from:

- the Belgian B-EPD PCR
- the document "Milieuprofiel van gebouwelementen: op weg naar een geïntegreerde milieubeoordeling van materiaalgebruik in gebouwen" (quoted below as "MMG") [15]
- the EN 16757:2017 standard
- (For the Netherlands) "Environmental Performance Assessment Method for Construction Works ", 2022, referred to as "*Bepalingsmethode*" in this report.

For modules A4, A5, B, C and D, besides the parameters determined by the references quoted for the Belgian context (or for the Netherlands), selected values aim at defining scenarios that are representative for one of the most likely scenario alternatives.

Another way to classify activity data is to indicate the parameters that can be adapted by the tool user in the tool interface or not, as described in Table III-1. The principle of the tool is to provide default values for all parameters, depending on the selected functional unit (out of the list in Table II-1). Sources of these default values are also presented in the

[15] Published in 2013, this document is not part of legislation. At the initiative of the Flemish Authorities, a methodology in line with EN 15804:2012 has been developed in order to move towards a transparent assessment of environmental performances of material use in buildings.

table. LCI datasets and LCIA results from EPDs are fixed in the model and cannot be chosen or adapted by the tool user.

Table III-1 : Activity data accessible in the tool interface or fixed in the model

Data	Status in the tool	Data source for default values
Dimensions of the product	Accessible (can be modified by the tool user)	FEBE engineers and manufacturers (typical dimensions of the product fulfilling each FU)
(A1) Concrete recipes and product compositions		Cf. Table II-3
(A2) Parameters of transport from extraction to manufacturer		
(A3) Energy use for on-site manufacturing		
(A3) Packaging		
(A4) Parameters of transport from factory to the construction site		Cf. III.2.5
(A5) Quantities of materials for installation		Cf. III.2.6.1
(A5) Energy use for installation		Cf. III.2.6.2
(A5) Parameters of packaging end-of-life	Fixed in the model	Cf. III.2.6.3
(C1-C4) End-of-life parameters	Fixed (cannot be modified by the tool user but are visible in the tool interface)	Cf. III.2.9

The next chapter will describe, per module, the modeling and the type of data used. The details about secondary LCI data sources are provided for all processes in Table III-33 and data quality is globally assessed in section III.4.

III.2. Qualitative/quantitative description of unit processes

Figure 5 represents the common scheme for modelling precast concrete products using the modular approach of EN 15804. Parts with an asterisk (*) designate processes that can differ among product families or are not relevant for some product types. Table III-2 details the corresponding modelling for the various product families.

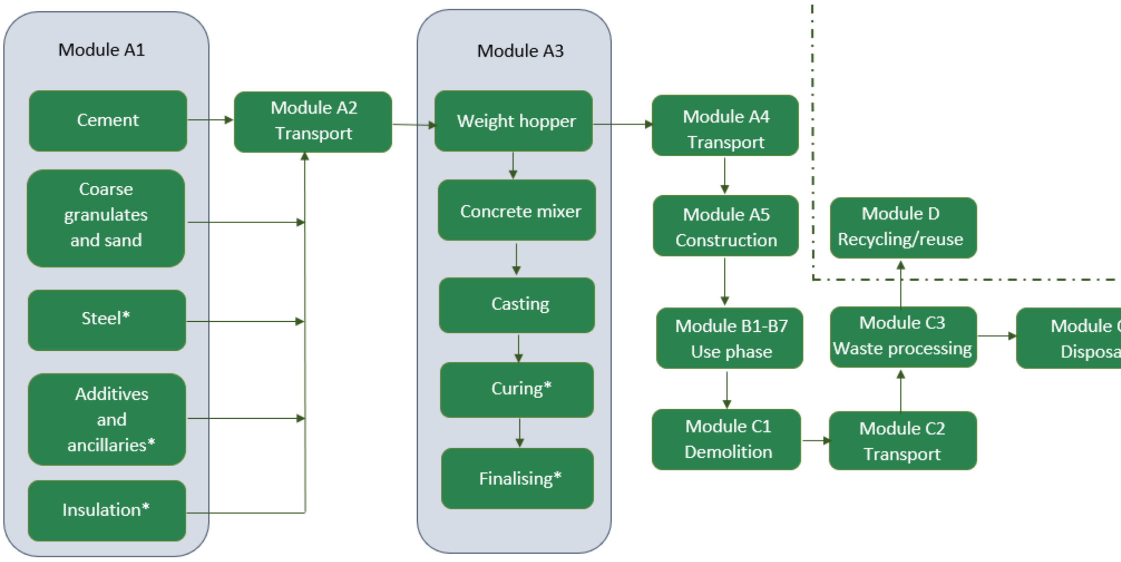

Figure 5: Global scheme describing the main steps studied (modular approach)

Table III-2 : Processes that differ within the precast concrete product families

Product family	Module A1			Module A3	
	Steel	**Additives and ancillaries**	**Insulation**	**Curing**	**Finalising**
Roof tile	-	For pigmented elements	-	Accelerated hardening	-
Block	-	For pigmented elements	-	Accelerated hardening	-
Stairway	Reinforced	-	-	Hardening	-
Hollow core slab	For reinforced and prestressed elements	For pigmented elements	For insulated elements	Accelerated hardening	-
Beam	For reinforced and prestressed elements	-	-	Hardening	-
Beam for beam-and-block floor system	For reinforced and prestressed elements	-	-	Accelerated hardening	-
Block for beam and block floor system	-	-	-	Accelerated hardening	-
Floor plate	For reinforced and	-	-	Hardening	-

Product family	Module A1			Module A3	
	Steel	Additives and ancillaries	Insulation	Curing	Finalising
	prestressed elements				
Panels	Reinforced	-	-	Hardening	-
Double wall	For reinforced element and connectors	-	For insulated element	Accelerated hardening	-
Column	For reinforced and prestressed elements	-	-	Hardening	-
Electric post	Prestressed	-	-	Hardening	-
Footing	Reinforced	-	-	Hardening	-
Manholes	For accessories	For elements with elastomer joint	-	Hardening	-
Paving flag	-	For pigmented elements	-	Hardening	-
Pipe	For the elements with joints	Elements with elastomer joint	-	Hardening	-
Pit	Reinforced elements with accessories	-	-	Hardening	-
Paving block	-	For pigmented elements	-	Hardening	-
Curb	-	For pigmented elements	-	Hardening	-
Gutter	-	For pigmented elements	-	Hardening	-
Façade elements of architectural concrete	Reinforced elements with accessories	For pigmented elements	For insulated elements	Hardening	Surface finishing
Floor slat for livestock	Reinforced element	-	-	Hardening	-

The following paragraphs explain the main assumptions, modelling and calculations made for each module, in line with EN15804+A2 and ISO 14044 standards. Data sources associated with all processes are summarized in Table III-33.

III.2.1. MODULE A1: EXTRACTION

Module A1 refers to all materials extracted in order to produce the studied product. The whole recipe is accessible in the tool (i.e. can be adapted through the tool interface), through the weights of the various components.

The module also contains the impacts of necessary materials for the manufacturing of the product, such as the formwork, lubricating oil, etc. The associated values are fixed (i.e. not accessible to the tool user).

III.2.1.1. Concrete ingredients

All materials entering in the composition of concrete are integrated in the model and the tool. They are listed in Table II-3.

Table III-3 : Concrete ingredients for precast concrete products

Concrete components	Materials available per category
Cement	CEM I, II, III, V
Other binders	Limestone fillers - Fly ashes (hard coal ash) – Blast furnace slag
Coarse granulates	Artificial – Natural – Recycled
Sand	Sea/River – Quarry & Crushed
Water	'Tap water' – No distinction is made
Admixtures	Air entraining admixtures - Waterproofing admixtures - Accelerating admixtures - Retarding admixtures - Superplastifiers - Plastifiers

Table III-4 presents the sources of data for the **cement types** as well as the associated clinker content and GHG impact per kg. The CO_2 eq emissions include the emissions from the incineration of fossil and biogenic waste used as fuel in cement kiln. Cembureau states that these wastes have not reached the end-of-waste state and that, according to the polluter pays principle, the system that generates the waste is responsible for declaring the emissions of waste combustion. In the FEBE tool, waste-related emissions are attributed to the cement since there is a still growing demand for this type of waste with energetic value. If not used in cement kiln, this waste would be used as refuse derived fuel in substitution to fossil fuels in another application.

When the FU description contains white cement, data for white cement is used in the model (cf. Table III-4).

Table III-4: Data for cement

CEM type	% clinker	kg eq CO2/ kg cement	Source
CEM I	92.2%	0.93	EPD Cembureau 2020, including emissions from fossil and biogenic waste combustion + ecoinvent (for data gap filling)
CEM II	77%	0.788	EPD Cembureau 2020, including emissions from fossil and biogenic waste combustion + ecoinvent (for data gap filling)
CEM III	44%	0.502*	EPD Cembureau 2020, including emissions from fossil and biogenic waste combustion + ecoinvent (for data gap filling)
CEM V	49%	0.519 +0.133	Ecoinvent v3.7.1 "cement production, blast furnace slag 18-30% and 18-30% other alternative constituents" + Worldsteel 2014 for impacts associated with blast furnace slag production (cf. allocation of co-products, section II.6.2)
White CEM I	95.3%	1.04	EPD published by Aalborg in 2021 for white cement produced in Denmark (elaborated following EN 15804+A2)[16]

*A sensitivity analysis can be performed on the allocation of BF slag impacts, for example for CEM III. Let us assume that Cembureau, through economic allocation, has allocated 1% of the blast furnace system to BF slag (in the EPD published in 2015, it is stated "*For the co-products given above, the contribution to the overall revenue of steel or electricity production is very low (<1%)*"). According to Worldsteel 2014 (cf. allocation of co-products, section II.6.2), the inventory they provide for BF slag is based on allocating 5% of the energetic-related impacts of the blast furnace to BF slag. For using this BF slag inventory, it is considered that 1% out of the 5% is already taken into account by economic allocation by Cembureau. The remaining 80% of the BF slag inventory can be added. It would bring a contribution of 0.214 kg eq. CO2/kg CEM III (with a total of 0.716 instead of 0.502 kg CO2 eq./kg).

Concerning the **binders** that can be added in addition to cement, limestone fillers are considered as a product, not as a co- or by-product. Fly ashes (hard coal ash) and blast

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[16] https://cer.rts.fi/wp-content/uploads/rts-epd_105-21_aalborg-white-cement-cem-i-525-r-sr-5.pdf. For increasing the internal consistency of results, the EPD value for the indicator "Total use of non-renewable primary energy resources (PENRT)" (2540 MJ/t) is adapted to be equal to "Abiotic depletion potential for fossil resources (ADP-fossil fuels)" (7660 MJ/t). Caution is recommended with the value associated with water deprivation potential since it seems very high.

furnace slag are co-products, for which allocation of impacts has been discussed in section II.6.2.

Among the materials entering in the concrete composition, only the recycled coarse granulates are **secondary materials** (according EN 15804, a secondary material is a material recovered from previous use or from waste, which substitutes primary materials).

Water, as ingredient, is considered as a raw material fully incorporated into the product. The tool makes no distinction between the origin of water consumed and considers in all cases water consumed as 'tap water' (taken from the distribution network).

III.2.1.2. Non-concrete ingredients

In order to cover all the ingredients of concrete prefab products, a wide range of other, non-concrete components, has also been integrated into the model. These ingredients are (associated LCI sources are provided in Table III-33):

- Steel used as
  - Reinforcement (low-alloyed steel)
  - Prestressing (steel wire rod)
  - Fibres (modelled as steel wire rod)
  - Anchors of lifting loops for the handling of products (stainless steel)
- Insulation material (synthetic: polyisocyanurate - PIR, polyurethane - PUR, etc.; glass wool)
- Pigments for various colours
- Rubber joints for pipes and manholes

For non-concrete ingredients, **secondary materials** are only found in steel components, proportionally to their corresponding recycled content (cf. Table III-26).

III.2.1.3. Manufacturing materials

During the production of precast concrete products, various materials that are not related to concrete are needed. These are either used during the manufacture stage of the concrete product or more specifically during the finishing phase of the product.

For the manufacturing stage, various materials such as formwork (in wood, steel or plastic) and lubricating oil) are taken into account in this model. The average values for the needed materials for formworks, lubricating oil, etc. have been discussed with FEBE experts.

III.2.2. MODULE A2: TRANSPORT FROM THE EXTRACTION SITE TO THE MANUFACTURING PLANT

The tool covers the transport of raw materials by truck, by train or by boat. The distances between the extraction site and the manufacturing plant can vary according to the transported material and are indicated by the user in the tool. Maximum payload for trucks can be further selected by the user.

The modelling of the various transport modes is explained in Annex VI.1. Transport modes are in each case considered to be fully loaded.

III.2.3. MODULE A3: MANUFACTURING STAGE

III.2.3.1. Manufacturing

During manufacturing of precast concrete products, various types of energy sources are used. In order to approximate realistic values for the purpose of generic EPDs, the necessary energy per m³ of concrete has been calculated, based upon data collected in 2015-2016 through a survey of 15 precast concrete producers.

The average values were obtained by calculating mean energy consumptions per ton of product (all products combined). Weighted averages were based on total tonnage per manufacturing plant. Extreme values of consumptions were excluded. The averages were calculated from 12 sites, covering an annual production of 1.01 million of tons. Consumptions per ton were converted in consumption per m^3 of concrete, using the common value of density of 2.35 t/m^3. Fuel densities and lower calorific values of Table III-6 were used to calculate energetic consumptions expressed in MJ/m^3. The used data and calculations can be made available on demand in a complementary Excel file.

Warning: EN 15804+A2 (section 6.3.8.2) requires producer-specific data to be less than 5-year-old. Therefore, it is recommended to the tool user to update the data collection for on-site energy consumption for manufacturing.

Table III-5 : Mean energy demands calculated through survey data

Energy type	Mean value (survey with FEBE members, 2015)				
Unit	Amount of electricity or fuel/t		Amount of electricity or fuel /m^3 *		MJ/m^3
Electricity	kWh/t	14.01	MWh/m^3	0.033	118.5
Natural gas	Nm^3/t	0.25	Nm^3/m^3	0.59	96.6
Diesel	l/t	1.06	l/m^3	2.48	22.6
Light fuel oil	l/t	0.47	l/m^3	1.10	42.7
LPG	l/t	0	l/m^3	0	0
Petrol	l/t	0	l/m^3	0	0

* By simplification, the density is assumed to be 2350 kg/m^3 in all cases.

Table III-6 : Density and LHV of used fuels in the tool

Fuels	Density	LHV (ecoinvent)
Diesel	0.85 kg/l	45.8 MJ/kg
Gasoline	0.75 kg/l	
Heavy fuel oil	1.00 kg/l	
Light fuel oil	0.86 kg/l	
Natural gas	0.08 kg/ m^3	38.3 MJ/Nm^3

The list of corresponding datasets used is available in Table III-33.

Electricity production can be modelled as from renewable modes if the following conditions are fulfilled, according to BE-EPD-PCR:

- In case of on-site generation: "*For the part that is consumed on-site, the life cycle data for that electricity shall be used if no contractual instruments have been sold to a third part.*" (cf. B-EPD PCR, A 12)
- For renewable electricity purchase with guarantee of origin certificate, from a production facility in Belgium (a country with a reliable tracking system in place for electricity), following guidelines from EN 15941: "*Supplier specific data shall be used if all of following conditions are met:*
  - *GoO (guarantee of origin certificate) have been valid and cancelled on behalf of the reporting entity for the period of production used for raw data collection of the EPD, or for the period from data collection to the publication of the EPD.*
  - *GoO will continue to be cancelled for the period of validity of the EPD (5 years).*" (cf. B-EPD PCR A 18)

If the conditions are not met, the B-EPD PCR of 2022 requires the Belgian residual mix to be used. In the FEBE model, the consumption mix is used in A3 (as in the other modules) because the residual mix dataset is not available in the version 3.7.1 of ecoinvent. It is a current limit of the tool.

The following renewable production modes can be selected in the interface:

- Hydropower
- Wind power
- Solar power
- Co-generation using biomass

The associated datasets are described in Table III-33.

There is no use of secondary fuel modelled at the manufacturing stage (fuel recovered from previous use or from waste which substitutes primary fuels).

Warning: for products requiring surface finishing (i.e. façade elements, cf. Table III-2), attention has to be paid to the specific energy use associated to this step as well as to the impacts of the finishing agents (coating and acid), that are not included in the model, to assess whether cut-off criteria are met (cf. section II.5.1) or whether additional processes should be modelled separately.

III.2.3.2. Transport inside the manufacturing plant

Transport inside the manufacturing plant (through cranes, moving carpets, trucks, bulldozers, and other modalities) has been accounted for through the global energy consumption of the plant, which is communicated by the producer in the tool. If various products are produced inside the manufacturing plant, the allocation is based on the weight of the studied product.

III.2.3.3. Losses during the life cycle of the product

During the life cycle of precast concrete products, the creation of wastes/losses occurs. In the tool, the impact of the production losses is accounted for in modules A1-A2-A3, and in A5. The losses of products due to transport occurring in A4 are accounted for in module A5 (such as in the *MMG*). This constitutes a limit to the compliance to the modularity principle of EN 15804+A2 (cf. II.3).

Table III-7: Summary of the losses considered for the modelling

Module	Type of losses	Belgian model losses (%)	Source	Dutch model losses (%)	Source
Module A3	Production	0.1%	*Expert judgement (FEBE)*	0.1%	*Expert judgement (FEBE)*
Module A4	cf. module A5	0.5% *Expert judgement (FEBE)* or 3% (CERIB)[17] Cf. Table III-8		3% for prefab products	*Bepalings-methode*
Module A5	Transport and installation				

The amount of losses has been estimated through expert judgement (FEBE) for the Belgian model. The reason for the very low production losses in modules A1-A3 is that the assumption is made that concrete losses during manufacturing are dried, temporarily stocked and incorporated as "aggregates" in new concrete products, thus never leaving the manufacturing plant, and never being considered as waste.

Table III-8: Losses considered for the modelling in function of the product type (in Belgium)

% Losses (A4-A5)	Products
0.5%	Large products or with tailored dimensions: Floor plate, hollow core slab, panel, double wall, manhole, pipe, pit, beam, column, façade, electric post, floor slat, footing, stairway
3%	Small products or cut/damaged at installation: tile, block, paving flag, paving block, curb, gutter, beam-and-block system,

[17] Fiche de Déclaration Environnementale et Sanitaire : Bloc en Béton (pose maçonnée à joints épais), CERIB, 2017

III.2.3.4. Packaging

Packaging used for the transport of precast concrete products to the construction site has been taken into account in the model and tool. Various packaging uses exist. These uses depend on the product type that has to be packed. The tool refers to primary, secondary and tertiary packaging.[18] Although in this project, it is not important to strictly define if a packaging is primary, secondary or tertiary since at end-of-life, all are managed at the construction site.

Table III-9 : Types of packaging available in the tool

Packaging type	Primary packaging	Secondary packaging	Tertiary packaging	No packaging
LDPE sheet	x			
Carton box		x		
Strapping band		x		
Stretch film (PE)		x		
Foam (PE)		x		
Wooden pallet			x	
Metal pallets			x	
Stacking plate			x	
Wooden wedges and slats				x

The used weight of packaging per FU is calculated in the model by using the weight of the packaging, number of units per packaging and number of uses of the packaging indicated by the user in the tool. For the generic EPDs, default values of these parameters available in the tool have been discussed with producers and with FEBE experts.

The content in recycled material is zero for these packaging materials except for the corrugated carton box for which the recycled content is fixed at 88% (source: PEF guidelines, Annex C v3.0).

III.2.4. MODULES A1-A3: FORMULA OF ANNEX D OF EN 15804+A2

According to Annex D of the EN 15804+A2 standard, the applicable formula for the calculation of the emissions and resources consumed related to material resources and energy per unit of analysis for module A is the following (equation D.2):

$$e_{module\ A} = e_{PE} + M_{VM\ in} \cdot E_{VM\ in} + M_{MR\ in} \cdot E_{MR\ after\ EoW\ in} + M_{ER\ in} \cdot E_{ER\ after\ EoW\ in}$$

[18] For definitions, see Glossary at the beginning of the document

The life cycle stages contributing to the various terms of this formula are mentioned in Table III-10.

Table III-10 : Terms of the formula for module A

Term of the formula	Associated with	Contributing to	
		Module A1	Module A3
e_{PE}	Energy consumption coming from primary sources	/	Production of electricity and supply and combustion of fuels
$M_{VM\ in} * E_{VM\ in}$	Acquisition and pre-processing of primary material	Production of primary materials entering in the prefab product composition	Production of primary materials for packaging
$M_{MR\ in} * E_{MR\ after\ EOW\ in}$	Material recovery (recycling and reusing) processes of the previous system after the end of waste state Production of secondary materials	Production of secondary materials entering in the prefab product composition: • Secondary steel • Recycled coarse granulates	Production of secondary materials for carboard packaging
$M_{ER\ in} * E_{ER\ after\ EOW\ in}$	Combustion of secondary fuel entering from a previous system	/	Not applicable for the studied products

Table III-11 : Application of the formula in the model

<table>
<tr><th colspan="2">Term of the formula</th><th colspan="2">Details about data and calculations</th></tr>
<tr><td colspan="2">e_{PE}</td><td colspan="2">Sum, for the different energy types (listed in Table III-5), of the amount of energy consumed per functional unit multiplied by the corresponding LCIA result per unit of energy use.
The amounts of energy consumed per product are specified in the tab “A3 - Product manufacturing” of the tool interface (and further linked to the functional unit in the model).</td></tr>
<tr><td rowspan="2">Ingredients of the prefab products</td><td>$M_{VM\ in} * E_{VM\ in}$</td><td>For primary materials listed in sections III.2.1.1 and III.2.1.2:
$M_{VM\ in}$ = weights specified per product in the tab “A1 - Ingredients” of the tool interface (and further linked to the functional unit in the model)
$E_{VM\ in}$ = corresponding LCIA result per kg of material</td><td rowspan="2">For steel, a single LCI dataset is available for the production of steel with the specific recycled content (the contributions of the virgin and the recovered materials cannot be separated).</td></tr>
<tr><td>$M_{MR\ in} * E_{MR\ after\ EOW\ in}$</td><td>$M_{MR\ in}$ = weight of “coarse recycled granulates”
$E_{MR\ after\ EOW\ in}$ = 0 (burden-free cf. Figure 3)</td></tr>
<tr><td rowspan="2">Packaging</td><td>$M_{VM\ in} * E_{VM\ in}$</td><td colspan="2">For packaging materials listed in Table III-9:
$M_{VM\ in}$ = weights specified per packaging in the tab “A3 - Packaging” of the tool interface (and further linked to the functional unit in the model)
Except for cardboard: $M_{VM\ in}$ = weight of carton box multiplied by ‘1- recycled content’ (i.e. multiplied by ‘100%-88%’ = 12%)
$E_{VM\ in}$ = corresponding LCIA result per kg of primary material</td></tr>
<tr><td>$M_{MR\ in} * E_{MR\ after\ EOW\ in}$</td><td colspan="2">For cardboard:
$M_{MR\ in}$ = weight of carton box multiplied by the recycled content (88%)
$E_{MR\ after\ EOW\ in}$ = 0 (burden-free cf. Figure 4)</td></tr>
</table>

The impacts arising from production and end-of-life of product losses occurring at the manufacturing stage are modelled in module A3, in a similar way as the production in A1 and end-of-life of the products after use in modules C (cf. Table III-11 and section III.2.9.5 respectively).

III.2.5. MODULE A4: TRANSPORT TO THE CONSTRUCTION SITE

The transport of the manufacturing plant to the construction site concerns the finalized products. It takes place by truck (truck with a maximum payload of 24t). The explanations on the used truck model are available in section VI.2.1.

In case the construction site is located in Belgium, the fixed default distance to the construction site is 100 km (mean travel distance to Brussels). If the construction site is in the Netherlands, the travel distance is of 170 km (default distance from Brussels to Utrecht, as demanded in the *Bepalingsmethode*).

The parameter available in the tool is the loading rate, to be encoded either through the number of pallets or through the number of products per truck.

The use of lashing straps can further be modelled by the tool user, with access to the following modelling parameters:

- Weight of polyester and of the steel for strap tensioner
- Number of uses of the lashing strap and tensioner over their life cycle
- Number of straps per product

Production and end-of-life of the lashing strap system are accounted for in module A4 and, for steel recycling and energy recovery at polyester incineration, in module D. The percentages of end-of-life treatments are assumed to be:

- Steel: 5% to landfill and 95% recycling (similarly to other steel parts in the study, cf. Table III-22 and Table III-23)
- Polyester: 5% to landfill (as for steel) and the remaining part to incineration (assuming there is no material recycling route).

III.2.6. MODULE A5: INSTALLATION ON CONSTRUCTION SITE

This module contains all energy and material consumptions necessary for the installation of the product inside the building.

III.2.6.1. Necessary material for the installation of the product

The various materials that are necessary for the installation of the covered products have been accounted for in the tool. The materials are for instance mortar, fixing sand and neoprene. The necessary amounts of material for each type of product were calculated based on expert judgement and converted to kg/FU. The list of covered materials is available in Table III-33 (Part "Module A5: Ancillary materials").

The packaging of these products has, as already mentioned in the cut-off criteria, not been taken into account for this study, nor the end-of-life of this packaging.

It is assumed that the transport of ancillary material is done by truck, with fully charged trucks having a maximum payload of 24t. The mean distance equals to 35 km except for cement, for which the distance is 100 km.

The loss rates that are applied and presented in Table III-7 only apply to the product itself, and not to the installation products.

III.2.6.2. Energy consumption for the installation of the product

The installation of products requires energy inputs for:

- Transport of products on the construction site
- Preparation of ancillary materials
- Vibration and compression of the installation materials before installation of the product

Various default values have been calculated and are used in the tool and model. Further explanations on these assumptions are available in section VI.3.

Transport on the construction site

The assumption has been made that ancillary materials and products are transported using a crane. The calculations for necessary energy for the crane are calculated based on a commercial document (see section VI.3). The average value for the electric consumption per kg is of 1E-04 kWh/kg.

Preparation of ancillary materials

Ancillary materials such as mortar might be prepared on the construction site. The necessary energy for the mixing of for instance mortar has been taken into account in the model. For casting concrete, the energy consumption at producer's plant is included in the modelling. The used LCI datasets are indicated in Table III-33.

Vibration and compression of ancillary materials

A number of prefab concrete products need ancillary materials for the stabilisation of the laying grounds. The vibration and compression of the ancillary materials is then required. The energy needs for these operations are taken into account and modelled as dependent of the volume of ancillary materials that has to be treated. The value of electricity consumption for vibration and compaction is 0.233 kWh/m3 of ancillary materials.

Pumping of ancillary materials

For various ancillary materials (mortar, concrete, etc.) it is sometimes necessary to pump the material for the concrete or mortar mixer to the placing surface. The energy necessary for this pumping has not been taken into account in the model (cf. II.5.2).

III.2.6.3. Specific material and energy for pipes and manholes

The following specific modelling applies to pipes and manholes.

Energy

Default values for energy use for installing pipes and manholes come from the PCR for pipes (2023), cf. Table III-12.

Table III-12 : Default values of energy consumption for pipe and manhole installation

Name of field on interface	Consumption of diesel per m of pipe	Expressed in kWh/FU	What is included?
Pipes			
Transport on site	0.95	9.473	Excavation, transporting the pipe to the site and laying the pipe in the hole
Vibration	1.4	13.960	Sand installation
Compaction	0.5	4.986	Compaction of sand
Manhole – base element			
Transport on site	6.8	67.806	Excavation, transporting all manhole elements on site and putting them in place
Vibration	13.7	136.610	Sand installation
Compaction	0.5	4.986	Compaction of sand

Remarks:

- Pipes: These values apply to all three types of pipes that can be studied in the tool.
- Manholes: As for sand, the whole energy consumption is allocated to the manhole base element (consumption of energy for installation is at zero for shaft, ring and cover parts).

Treatment of excavated soil

The volume to be excavated is calculated per functional unit for pipes and manhole_base element as:

2.4 * (2 *0.5 + inner_diameter_pipe_manhole_base + 2 * thickness_pipe_manhole_base)

Other assumptions are:

- Transport of excavated soil: over a distance of 35 km (same type of truck as for supply of raw materials for installation)
- Treatment of excavated soil: it is considered as stockpiled. The only impact considered is the use of land surface. The land occupation included amounts to 0.001883 m2*year per kg of soil (approximated from the ecoinvent dataset "treatment of drilling waste, residual material landfill, RoW"), i.e. 2000* 0.001883 = 3.766 m2*year per m3 of soil.
- There is no soil excavation allocated to manhole shaft, ring or cover.

Amount of sand

The volume of sand required for installation, per functional unit, is automatically calculated in the model as:

Excavated_volume – π * (inner_diameter_pipe_manhole_base/2 + thickness_pipe_manhole_base)^2

There is by default no use of sand allocated to manhole shaft, ring or cover.

Sand for pipes and manhole elements is non-stabilized sand (no water nor cement included, only sand).

III.2.6.4. End-of-life of packaging

The end-of-life of packaging materials listed in Table III-9 covers incineration, landfilling and recycling. The used percentages for each treatment follow the values of Belgian PCR (B-EPD PCR), also for the Netherlands.[19]

Table III-13 : Average packaging end-of-life values (B-EPD PCR)

Packaging material	Recycling	Incineration	Landfilling
Pallets (Wood or plastic) and stacking plate	50%	50%	0%
Plastic film (LDPE) + strapping bands	35%	60%	5%
Plastic foam	60%	30%	10%
Paper and cardboard	95%	5%	0%
Steel pallet (source: Val-I-Pac annual report, 2014)	100%	0%	0%
Wooden wedge	75%	25%	0%

Remark: For reused packaging (pallets, stacking plates and wooden wedges), the table indicates the share of end-of-life treatment at the end of reuse cycles.

The following distances are used for the transport from the sorting centre to the recycler for both Belgium and the Netherlands.

Table III-14 : Distances to recycler for packaging at end-of-life

Packaging material	Distance to recycler(km)	Source
Plastic packaging	250	Approximation RDC
Cardboard	150	
Wood	150	

[19] The document "Forfaitaire waarden" van mei 2024 and associated with the *Bepalingsmethode* does not contain end-of-life scenarios for packaging.

Impacts of end-of-life are calculated according to the following equation (equation D.4 of Annex D of EN 15804+A2, considered as also applicable to Module A5):

$$e_{module\ C} = M_{MR\ out} \cdot E_{MR\ before\ EoW\ out} + M_{ER\ out} \cdot E_{ER\ before\ EoW\ out} + M_{INC\ out} \cdot E_{INC} + M_{LF} \cdot E_{LF}$$

Table III-15: Application of the formula to packaging end-of-life (Module A5)

Term of the formula	Details about data and calculations
$M_{MR\ out}$ * $E_{MR\ before\ EOW\ out}$	$M_{MR\ out}$ = weights of packaging per FU multiplied by the recycling rate (cf. Table III-13) $E_{MR\ before\ EOW\ out}$ = LCIA result per kg of recycled material, corresponding to the processes included in the system boundaries cf. Figure 4. (The benefits of avoided production are integrated in module D for Belgium).
$M_{ER\ out}$ * $EE_{MR\ before\ EOW\ out}$	Not applicable
$M_{INC\ out}$ * E_{INC}	$M_{INC\ out}$ = weights of packaging per FU multiplied by the incineration rate (cf. Table III-13) E_{INC} = impacts of incineration per kg of incinerated material. (The benefits related to energy recovery are counted in module D)
M_{LF} * E_{LF}	M_{LF} = weights of packaging per FU multiplied by the landfilling rate (cf. Table III-13) E_{LF} = impacts of landfilling per kg of landfilled material

III.2.6.5. Production and end-of-life of losses

According to EN 15084+A2 (section 6.2.3), Modules A4-A5 "*also include all impacts and aspects related to any losses during this construction process stage (i.e. production, transport, and waste processing and disposal of the lost products and materials)*"

Table III-16 lists the impacts associated with the losses of concrete products occurring during transport and installation (loss percentages are given in Table III-7). As indicated in the first column, these impacts are counted in module A5, except the benefits and loads related to recovery and recycling that are included in module D. The way the modelling is performed for the losses at each of these steps is already described elsewhere in the report, in the corresponding modules of the product life cycle stages (modules indicated in the third column).

Table III-16 : Impacts and aspects related to losses occurring at the construction process stage

Module where impacts related to losses are counted	Steps related to losses occurring at the construction stage	Corresponding module for the main product life cycle
A5	Material extraction	A1
A5	Product manufacturing	A3
A5	Transport from construction site to sorting centre	C2
A5	Operations at the sorting centre	C3
A5	Landfilling of concrete (including carbonation) and of steel	C4
A5	Incineration and landfilling of insulants	C4
D	Loads and benefits of concrete, ancillary materials and steel recycling	D
D	Energy recovery at insulant incineration	D

III.2.7. MODULES B1 – B5: USE STAGE

According to the EN 16757:2017, the use phase for concrete precast products is rarely applicable. The standard considers modules B3 to B7 as having no associated activities in most of the cases (depending on the RSL of the product versus lifespan of the building) or as being not relevant. Following assumptions, in line with the PCR, have been made:

Table III-17 : Application of modules of the use stage in the model

Module	Module name	Model application
Module B1	Use phase	Carbonation process during the RSL
Module B2	Maintenance	Only taken into account for facades in architectural concrete. Assumptions are available in the EPD.
Module B3	Repair	Considered as not relevant
Module B4	Replacement	Considered as not relevant
Module B5	Refurbishment	Considered as not relevant

The modeling of module B2 is only taken into account in the Belgian version of the tool, and only for the maintenance of façade elements in architectural concrete. It is not considered when applying the Dutch legislation, as required by the "*Bepalingsmethode*" (only functional maintenance must be considered and not aesthetic maintenance).

Table III-18 presents the assumptions made when maintenance applies. It is considered that maintenance consists in cleaning with a pressure washer and clear cold water.

Table III-18 : Default values for module B2 (maintenance scenario), only applicable in Belgium for façade elements

Parameter	Unit	Value	Source
Frequency of the maintenance	times/yr	0.1	FEBE expert judgement
Total times during the RSL (RSL = 100 years)	times/RSL	10	10 = RSL*frequency
Machine Power	W	3000	Typical values from vendor technical specifications of a pressure washer[20]
Usage duration	min/m²	1	
Water consumption	l/h	600	
Total energy use per FU over the RSL (FU = 1 m^2)	kWh/FU.RSL	0.5	0.5= 3000/1000*(1/60)*10
Total water use	l/FU.RSL	100	100 = 600*(1/60)*10

III.2.8. MODULES B6 – B7: OPERATIONAL ENERGY & WATER USE

According to the PCR EN 16757:2017, the operational use phase for concrete precast products is rarely applicable.

The use of precast concrete products containing insulants can result in energy saving during the use phase at the building level. However, the associated benefits cannot be integrated in Module B6 of the EPD of concrete product. Indeed, integration in Module B6 could result in double-counting of benefits since they are already taken into account in the energy consumption of the building in the use phase. In the *Bepalingsmethode*, the reporting of modules B6 and B7 is not included.

Furthermore, for the studied precast concrete products, no additional technical information is provided in the EPD in relation to the use of energy or water during operation of building integrated technical systems.

[20] Source: https://www.kaercher.com/int/home-garden/pressure-washers/k-7-compact-14470500.html (accessed 29/12/2021)

III.2.9. MODULES C1 – C4: END-OF-LIFE

Parameters used for modules C1-4 cannot be modified by the tool user.

III.2.9.1. Module C1: Destruction and Deconstruction

The used scenario for de-construction and destruction of precast concrete products is based on the scenario available in the MMG-document (p. 22). These values are obtained from the activity "treatment of waste concrete gravel, recycling" in ecoinvent v3.5.

Table III-19 : Values for demolition of products (Source: MMG/ecoinvent v3.5)

Parameter	Unit	Value
Demolition scenario		
Diesel consumption for mechanical handling	MJ/kg	0.0437
Emission of particulate matter: PM < 2.5 µm	kg/kg material	$1.66*10^{-5}$
Emission of particulate matter: PM >2.5 µm & <10 µm	kg/kg material	$6.34*10^{-5}$
Emission of particulate matter: PM > 10 µm	kg/kg material	$8.35*10^{-5}$

Next to these values, the MMG-document assumes that impacts for dismantling (and reuse) are equal to nil.

The default scenario studied in the tool consists in demolition for all products.

In addition to the MMG-document, the consumption of water, in order to retain particulate matter during destruction, is taken into account. A conservative scenario has been used (see appendix section VI.3). The value is of 0.0164 l of water/kg of material.

There is no excavation impact taken in C1 for pipes and manholes, as recommended in the corresponding PCR.

III.2.9.2. Module C2: Transport to waste processing

This transport concerns exclusively the transport of wastes to the waste processing plants.

Table III-20 : Mean default distances for end-of-life

Parameter	Unit	Belgium B-EPD PCR	Netherlands (Bepalingsmethode)
Distance from the construction site to the sorting and breaking facility	km	30	50
Distance from the sorting and breaking facility to the landfill	km	50	50
Distance from sorting and breaking facility site to incinerator (for inflammable materials)	km	100	-

Distance from construction site to incinerator (for inflammable materials)	km	-	100

For the Belgian model, the modelling of the transport by truck is done by using the COPERT-model, which is explained in section VI.2.1 of the report. For the Dutch model, it is based on the LCI *"Transport, freight, lorry, unspecified, GLO"* recommended in the *Bepalingsmethode.*

III.2.9.3. Module C3: Waste processing for reuse, recovery and/or recycling

The processing of waste fractions follows the scenario described in the B-EPD PCR. Product wastes are either sorted on the construction/demolition site or at the sorting/waste processing plant. However, according to the PCR "*With the exception of soil, all construction and demolition waste, whether or not sorted on site, is transported from the construction/demolition site to a sorting facility/collection point*". In consequence, impacts of sorting plant are counted in module C3 for 100% of the waste and are modelled as follows.

Table III-21 : Values for waste processing (B-EPD PCR)

Parameter	Unit	Value
Electric consumption for sorting without crusher (for materials sorted prior to the crusher)	kWh/kg material	0.0022
Electric consumption for sorting with crusher (for concrete materials)	kWh/kg material	0.0037*
Diesel consumption for the loading and unloading	MJ diesel / m3 bulk volume of waste	5.9
Sorting plant for construction waste	Unit/kg material	10^{-10} *

* Cf. ecoinvent v3.5 "treatment of waste concrete gravel, sorting plant"

III.2.9.4. Module C4: Disposal

For Belgium, the recycling and the disposal of product wastes in landfill or incineration follow the scenarios defined in the Belgian PCR.

Table III-22 : End-of-life treatments of construction product waste in Belgium (B-EPD PCR)

Material in the product	Recycling	Incineration	Landfilling
Concrete and inert materials	95%	0%	5%
Metal (iron, steel, aluminium, non-ferrous)	95%	0%	5%
Synthetic insulation material (e.g. PUR, PIR, XPS, EPS)	0%	95%	5%
Glass wool (insulation)	0%	50%	50%

For the insulation material, it is assumed that it is not separated from the concrete prior to treatment of the concrete waste. As a consequence, the part of insulation material that accompanies the concrete to landfill is also landfilled (5%), while the part sent with concrete to be recycled is either incinerated or landfilled so as to reach the percentages in Table III-22.

Landfilling of concrete (5% of total concrete) takes into account the carbonation process (cf. section III.2.11.4).

In the Netherlands, modelling is similar to the Belgian case. The percentages of end-of-life treatments are presented in Table III-23. The source for the Netherlands, to be combined with the *Bepalingsmethode*, is the document "*Forfaitaire waarden*", version May 2024 ("Standard values", in English).

Table III-23 : End-of-life treatments of construction product waste in the Netherlands

Material in the product	Recycling	Incine-ration	Landfilling	Comment
Concrete and inert materials	99%	0%	1%	All concrete products are considered as the general product "beton" in "*Forfaitaire waarden*", i.e. the mentioned reuse percentage for paving, curbs and gutters is not considered
Metal (iron, steel, aluminium, non-ferrous)	95%	0%	5%	All steel parts are modelled with the percentages provided for "reinforcing steel"
Synthetic insulation material (e.g. PUR, PIR, XPS, EPS)	0%	95%	5%	The part of synthetic insulation material that accompanies the concrete to landfill is also landfilled (5%), while the part sent with concrete to be recycled is fully incinerated (the "*forfaitaire waarden*" indicate 100% of incineration for PUR but a mix of incineration and recycling for EPS; it is considered here that there is no recycling, as in Belgium)
Glass wool (insulation)	0%	15%	85%	It is considered here that there is no recycling, as in Belgium. The 15% of incineration corresponds to the sum of the incineration and recycling values in the "*forfaitaire waarden*"

III.2.9.5. Modules C1-C4: Formula of Annex D of EN 15804+A2

As detailed in Table III-24, the modelling of Modules C1 to C4 described in sections III.2.9.1 to III.2.9.4 follows the requirements of equation D.4 of Annex D of EN 15804+A2:

$$e_{module\ C} = M_{MR\ out} \cdot E_{MR\ before\ EoW\ out} + M_{ER\ out} \cdot E_{ER\ before\ EoW\ out} + M_{INC\ out} \cdot E_{INC} + M_{LF} \cdot E_{LF}$$

Table III-24: Application of the formula of Annex D to concrete product end-of-life (Modules C1-C4)

Term of the formula	Details about data and calculations
$M_{MR\ out}$ * $E_{MR\ before\ EOW\ out}$	For concrete and inert ancillary materials as well as for steel: $M_{MR\ out}$ = weights per FU multiplied by the recycling rate (cf. Table III-22) $E_{MR\ before\ EOW\ out}$ = LCIA result per kg of recycled material, corresponding to the processes included in the system boundaries (cf. Figure 3) in modules C1 to C3 as described in sections III.2.9.1 to III.2.9.3. (The benefits of avoided production are integrated in module D for Belgium).
$M_{ER\ out}$ * $EE_{MR\ before\ EOW\ out}$	Not applicable
$M_{INC\ out}$ * E_{INC}	For synthetic insulation material only: $M_{INC\ out}$ = weights of insulant per FU multiplied by the incineration rate (cf. Table III-13) E_{INC} = impacts of incineration per kg of incinerated material (C4, as described in section III.2.9.4) as well as the processes included in modules C1 to C3 (as described in sections III.2.9.1 to III.2.9.3), which are counted whatever the end-of-life treatment. (The benefits related to energy recovery are counted in module D)
M_{LF} * E_{LF}	For concrete, ancillary materials, steel and insulation materials: M_{LF} = weights of material per FU multiplied by the landfilling rate (cf. Table III-13) E_{LF} = impacts of landfilling per kg of landfilled material (C4, as described in section III.2.9.4) as well as the processes included in modules C1 to C3 (as described in sections III.2.9.1 to III.2.9.3), which are counted whatever the end-of-life treatment.

The LCI datasets used in Modules C1-C4 are specified in Table III-33.

III.2.10. MODULE D: LOADS AND BENEFITS BEYOND THE SYSTEM BOUNDARIES

The applicable formula for the calculation of the loads and benefits beyond the system boundary per unit of output for module D calculated for each output flow leaving the system boundary is the following (equation D.5 of Annex D of EN 15804+A2):

$$e_{module\ D} = e_{module\ D1} + e_{module\ D2} + e_{module\ D3} + e_{module\ D4}$$

With:

$e_{module\ D1}$	Being the benefits and loads related to the export of	Secondary materials	Applicable to this study
$e_{module\ D2}$		Secondary fuels	Not applicable
$e_{module\ D3}$		energy as a result of waste incineration (for R1 < 60 % and R1 > 60 %)	Applicable
$e_{module\ D4}$		energy as a result of landfilling	Not applicable

III.2.10.1. Benefits and loads associated with secondary materials

The term $e_{module\ D1}$ is calculated as follows (equation D.6 of Annex D):[21]

$$e_{module\ D1} = \sum_i \left(M_{MR\ out}\Big|_i - M_{MR\ in}\Big|_i\right) \cdot \left(E_{MR\ after\ EoW\ out}\Big|_i - E_{VMSub\ out}\Big|_i \cdot \frac{Q_{R\ out}}{Q_{Sub}}\Bigg|_i\right)$$

With

- $M_{MR\ out}$: amount of material exiting the system that will be recovered (recycled and reused) in a subsequent system.
- $M_{MR\ in}$: amount of input material to the product system that has been recovered (recycled or reused) from a previous system (determined at the system boundary)
- $E_{MR\ after\ EOW\ out}$: specific emissions and resources consumed per unit of analysis arising from material recovery (recycling and reusing) processes of a subsequent system after the end of waste status
- $E_{VMSub\ out}$: specific emissions and resources consumed per unit of analysis arising from acquisition and pre-processing of the primary material, or average input material if primary material is not used, from the cradle to the point of functional equivalence where it would substitute secondary material that would be used in a subsequent system
- $Q_{R\ out}/Q_{Sub}$: quality ratio between outgoing recovered material (recycled and reused) and the substituted material.

The subtraction in the term "$M_{MR\ out}$ - $M_{MR\ in}$" allows to calculate net effects of substitution as required in section 6.4.3.3 of EN 15804+A2: *"In module D substitution effects are calculated only for the resulting net output flow".*

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[21] Not included in the current version of the tool when following requirements in quoted reference document for the Netherlands

Table III-25 : Application of equation D.6 for calculating in Module D benefits and loads related to the export of secondary materials

Term of the formula	Details about data and calculations in Module D
Recycling of concrete and of inert ancillary materials	
Module where waste reaches EOW state: Module C3 + Modules A3 and A5 (for product losses)	
$M_{MR\ out}$	weights of concrete and ancillary materials per FU multiplied by the recycling rate (95%)
$M_{MR\ out}$	weights of concrete and ancillary materials per FU multiplied by the recycling rate (95%)
$M_{MR\ in}$	Weight per FU of coarse recycled granulates used as ingredients, if any
$E_{MR\ after\ EOW\ out}$	No further treatment (cf. Figure 3)
$E_{VMSub\ out}$	Avoided: extraction and transport of granulates (crushed concrete gravel is used as a substitute to gravel extracted from quarry) [22]
$Q_{R\ out}/Q_{Sub}$	Assumed to be 1
Recycling of steel	
Module where waste reaches EOW state: Module C3 + Modules A3 and A5 (for product losses)	
$M_{MR\ out}$	In function of the recycling rate (cf. Table III-22)
$M_{MR\ in}$	In function of the recycled content (cf. Table III-26)
$E_{MR\ after\ EOW\ out}$	Scrap transport to recycler and scrap recycling (cf. Figure 3) and avoided production of 100% virgin steel are modelled in a single average LCI called "value of steel scrap" by Worldsteel
$E_{VMSub\ out}$	
$Q_{R\ out}/Q_{Sub}$	1 (source: value of the parameter Qsout/Qp in Annex C of PEF Package 3.0)
Recycling of packaging	
Module where waste reaches EOW state: Module A5	
$M_{MR\ out}$	Cf. recycling rate (cf. Table III-13)
$M_{MR\ in}$	The recycled content is equal to zero, except for corrugated board (88%)
$E_{MR\ after\ EOW\ out}$	Cf. Figure 4
$E_{VMSub\ out}$	Production of the substituted virgin materials
$Q_{R\ out}/Q_{Sub}$	For plastics: =0.9 For cardboard = 0.85 Source: values of the parameter Qsout/Qp in Annex C of PEF Package 3.0, respectively for HDPE and for paper and cardboard when recycling does not consider fiber losses

[22] Round gravel production from quarry operation has globally lower environmental impacts than crushed gravel. In a conservative approach, it is assumed that crushed concrete waste substitutes gravel from quarry operation.

Table III-26 : Allocation principle for steel recycled content

Steel type	Source	Initial recycled content (%)	Recycling rate (%)	Source	Accounted recycling loads and benefits (%)
Reinforcing steel	Ecoinvent 3.7.1 (steel production, electric, low-alloyed)	100%	95%	cf. Table III-22 and Table III-23	-5%
Prestressing and fibered steel	Worldsteel (Wire rod steel)	2%	95%		93%
Steel for anchor, bolts and nuts	Ecoinvent 3.7.1 (steel production, chromium steel 18/8, hot rolled)	48.5%	95%		46.5%

Example: For prestressing steel, the actual recycling rate of steel is of 95 % and the recycled content within the used steel is 2 %. The benefits and loads of the recycling of 93% of the used steel are accounted for at end-of-life (=95-2%).

The LCI datasets used for modelling the treatment of secondary materials beyond the system boundaries and the production of substituted virgin materials are specified in Table III-33.

As described in section III.2.11.5, the benefits of carbonation occurring when concrete waste is used as secondary material is not accounted in module D (just provided as complementary information).

III.2.10.2. Benefits and loads associated with energy recovered at waste incineration

The term $e_{module\ D3}$ is calculated as follows (equation D.6 of Annex D), according to both Belgian and Dutch requirements:

$$e_{module\ D3} = -M_{INC\ out} \cdot \left(LHV \cdot X_{INC\ heat} \cdot E_{SE\ heat} + LHV \cdot X_{INC\ elec} \cdot E_{SE\ elec} \right)$$

As a reminder, incineration takes place at end-of-life of packaging (cf. III.2.6.3) and of insulants (cf. III.2.9.4).

The following values/modelling of parameters of equation D.6 are used.

Table III-27: Efficiencies of energy recovery at incineration

Parameters	Definition	Belgium	Netherlands
$X_{INC\ heat}$	efficiency of the incineration process for heat	20%	31%
$X_{INC\ elec}$	efficiency of the incineration process for electricity	10%	18%
Source		B-EPD PCR	*Bepalingsmethode*

Table III-28: Used LHV (Lower Heating Values) for the incinerated materials (Source: Ecoinvent v3.7.1, also quoted by *Bepalingsmethode*)

Materials	LHV (MJ/kg)
Cartons/ Cardboard	15.92
PE (and other plastic packaging)	42.47
Wood	13.99
polyurethane (and polyisocyanurate)	30.67
Expanded polystyrene	32.20
Extruded polystyrene	38.67
Polyester	28.67[23]
Neoprene (as rubber)	27.19

Furthermore, $E_{SE\ heat}$ represents specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted heat. It is modelled as (source: ecoinvent 3.7.1):

- "heat, district or industrial, natural gas - Europe without Switzerland" for end-of-life in Belgium or for fossil-based waste in the Netherlands.
- or "heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 – NL" (reference product: heat, district or industrial, other than natural gas), when incinerating waste based on renewable raw materials in Netherlands.

$E_{SE\ elec}$ represents specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted electricity. It is modelled as (source: ecoinvent 3.7.1):

- "market for electricity, low voltage – BE or NL" in Belgium or for fossil-based waste in the Netherlands (source: ecoinvent 3.7.1).

[23] Proxy value in https://milieudatabase.nl/nl/rapporten-tool/report/154/

- or “heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical – NL” (reference product: electricity, high voltage), when incinerating waste based on renewable raw materials in Netherlands.

III.2.11. CARBONATION PROCESS

The carbonation process is the process in which concrete parts exposed to air will reintegrate CO_2 from the atmosphere into their structure. The process speed depends mostly on the amount of surface exposed to air and the amount of clinker used in the concrete.

Carbonation has an impact on global warming potential, since part of the emitted CO_2 will be reintegrated into the concrete’s structure. Taking this process into account in the EPD thus has an unneglectable impact on the final results for this impact category.

The carbonation process occurs at various life cycle stages of the precast concrete products. Its modelling in the various modules is summarized here. Calculations performed in the tool are illustrated for two products, the prestressed hollow core slab and the reinforced beam (see The Reference Service Life (RSL) varies in function of the studied product.

The standard EN 15804, in both versions +A1 (section 6.3.3) and +A2 (section 6.3.4.1), state that “*RSL information to be declared in an EPD covering the use stage shall be provided by the manufacturer. The RSL shall be specified under defined reference in-use conditions. The RSL shall refer to the declared technical and functional performance of the product within construction works. The RSL shall be established in accordance with any specific rules given in European product standards or, if not available, a PCR, and shall take into account ISO 15686-1, -2, -7 and -8. Where European product standards or a c-PCR provide guidance on deriving the RSL, such guidance shall have priority*.”

The RSLs currently defined in the functional units are based on guidance provided by the PCR EN 16757 (Annex AA), which acts as a complement-PCR to EN 15804+A1. These RSLs are further confirmed by FEBE expert judgement, i.e. the manufacturer.

The Annex AA of EN 16757:2017 provides scenario guidance for concrete elements and defines nine types of scenarios. The column S in Table II-1 indicates the number of the scenario associated with each FU and Table II-2 provides, for each scenario number, the scenario and the associated RSL as described in Annex AA of EN 16757.

for the definition of the functional unit).

Modelling is based on the EN 16757 PCR (June 2017. - Annex BB, “CO2 uptake by carbonation — Guidance on calculation”).

III.2.11.1. Principles

Carbonation of concrete is a natural process by which CO_2 in the ambient air penetrates the concrete and reacts with $Ca(OH)_2$ to form $CaCO_3$:

$$Ca(OH)2 + CO2 \rightarrow CaCO3 + H2O$$

Carbonation reduces the CO_2 content in the atmosphere and is an important factor in the lifecycle of concrete. A major part of the CO_2 emissions from the production of concrete is related to the cement production where approximately 50 % of the released CO_2 is due to calcination of limestone and the other 50 % is from the combustion of fuel at the cement plant. This ratio is due to change when/if cement production is optimized regarding CO_2 emissions but the amount of CO_2 emitted in kg due to calcination will not change for a given type of cement. This means that concrete during its service life and, more important, after demolition is able to absorb up to 50 % of the CO_2 emissions from cement in the concrete. As the CO_2 from the atmosphere diffuses into the concrete via the surface most of the carbonation will occur after demolition and crushing of the concrete as these processes drastically increase the surface area.

III.2.11.2. Module A3

In the production stage, for precast concrete products, carbonation may occur during long term storage before delivery or may be enhanced on purpose.

The hypothesis is made that the storage period of products before installation is too short to be taken into account in the model. This means that the carbonation process during the manufacturing stage is not calculated in the model.

Carbonation associated with concrete losses occurring at the manufacturing site is treated in sections III.2.11.5 and III.2.11.6.

III.2.11.3. Module B1

In the use stage, the degree of carbonation depends on the strength of the concrete and the exposure condition. An indoors concrete with low strength will absorb more CO_2 during its use stage than a high-strength concrete exposed to outdoors climate. Surface treatments will most likely limit the carbonation.

Carbonation during the use stage is modelled according to the specifications in the PCR EN 16757:2017. The carbonation depth (in meter) reached during the RSL is calculated as equal to $k/1000 * (RSL)^{0.5}$ with k-factor obtained from Table BB1 of Annex BB, in function of concrete strength class and exposure conditions.

This calculated depth is compared to

- the product thickness
- a maximum depth of carbonation, justified by the asymptotic trend of the CO2 penetration depth in carbonated concrete. This limit is fixed here at a 3 cm.[24]

Carbonation during the use stage is modelled to occur on an effective depth equal to the minimum of these 3 dimensions.

The corresponding CO_2 uptake per m^2 is calculated as

[24] This value of 3 cm is taken from the order of magnitude cited in the publication of Infociments, « Solutions béton », SB-OA 2012-3

$$CO_2\text{-uptake} = \text{eff. carb depth} * (\text{max } CO_2\text{-uptake}) * \text{cement content} * \text{degree of carb}$$

With

- CO_2-uptake expressed in kg CO_2/ m^2
- max CO_2-uptake (in kg CO_2/kg cement): the maximum theoretical uptake for totally carbonated concrete is correlated to the amount of reactive CaO in the binders. It is determined by the formula BB.3 of Annex BB of EN 16757.
    - Portland cement includes at least 95 % clinker and a typical value for reactive CaO is 65 %. For one kg Portland cement (CEM I), the maximum theoretical CO_2 uptake is (65/100)*0.95*(44/56) = 0.49 kg CO_2/kg cement.
    - For other cement type, the value of 0.95 is replaced by the clinker content of the cement.
- Cement content: cement content in kg / m^3 of concrete (cf. concrete recipe)
- Degree of carb: degree of carbonation obtained from Table BB1 of Annex BB of EN 16757, in function of exposure conditions.

It is difficult to define for each product whether one or two surfaces is accessible for carbonation. Hence, in a conservative approach, it is considered here that only one surface of the product participates to carbonation.

Table III-29: Example of calculations for carbonation counted in Module B1[25]

Module B1	Prestressed hollow core concrete slabs	Reinforced concrete beam
Exposure conditions and strength class	Buildings Indoor in dry climate without cover Concrete strength > 35 MPa	Buildings Indoor in dry climate with cover Concrete strength class C25/30
k-factor	3.8	4.6
Degree of carbonation	40 %	
Service life	100 years	
Max CO_2 uptake	0.49 kg CO_2/kg cement (CEM I)	
Cement content	300 kg/m3 (cement content according to recipes of both products)	
Surface/UF	1.00 m^2	0.35 m^2
The carbonation depth	Minimum between: -k/1000*(RSL)^{0,5} = 0.038 m -Product thickness = 0.2 m -The limit for the depth of carbonation = 0.03 m → Eff. Carb depth = 0.03 m	Minimum between: -k/1000*(RSL)$^{0.5}$ = 0.046 m -Product thickness = 0.2 m -The limit for the depth of carbonation = 0.03 m → Eff. Carb depth = 0.03 m
Application of the formula above for CO_2-uptake during the use stage		
CO_2-uptake in B1	0.03*0.49*300*0.4 = 1.764 kg CO_2 /m^2 = 1.764 kg CO_2/FU	0.03*0.49*300*0.4 = 1.764 kg CO_2 /m^2 Per UF = 1.764*0.35 = 0.617 kg CO_2/FU

III.2.11.4. Module C4

In the end-of-life stage, the carbonation will depend on the actions taken. Most effective is a crushing of the concrete and here the particle size is important, the smaller the better. The time exposed to atmospheric air is important as well, and positive results have been seen with periodically "stirring" of the pile of crushed concrete.

The carbonation of the landfilled concrete (5% of total concrete, source: B-EPD PCR) is taken into account in the tool, as stipulated in section BB4 of EN 16757:2017. It is considered that the concrete waste is not crushed and that there is no limit of time. Hence, carbonation will occur up to the maximum depth of 3 cm (or to the product thickness if smaller), and with a max carbonation degree of 0.75, corresponding to a long-term

[25] The main purpose of these examples is to highlight the steps of the calculations. Due to rounding of numbers at each step, the results presented in the table can be slightly different from the results extracted from the tool, where calculations are performed with a large number of digits.

perspective (cf. section BB6 of EN 16757:2017).[26] Only the delta between this calculated uptake and what has already been taken in the use phase is counted.

In a long-term perspective, the CO_2 uptake per m^3 of concrete is calculated as (cf. section BB6 of EN 16757:2017):

CO_2 uptake	=	max CO_2-uptake	*	cement content	*	0.75
kg CO_2/m^3		kg CO_2/kg cement		kg cement /m^3 concrete		

Table III-30 : Example of calculations for carbonation counted in Module C4[25]

Module C4	Prestressed hollow core concrete slabs	Reinforced concrete beam
Max theoretical CO_2 uptake	0.49 kg CO_2/kg cement (CEM I)	
Maximum degree of carbonation	0.75 (for a long-term perspective)	
Cement content	300 kg/m3	
Uptake in C4	$0.49 \times 300 \times 0.75 = 110.25$ kg CO_2/m^3	
Surface concerned by carbonation in C4	Considering a landfill rate of 5%	
	0.05 m^2 per FU	0.05 * 0.35 = 0.0175 m^2 per FU
Volume concerned in C4	0.05 m^2 * 0.03 m = 0.0015 m^3	0.0175 m^2 * 0.03 m = 5.25 E-04 m^3
Maximum uptake in C4	110.25 * 0.0015 = 0.165 kg CO_2 per FU	110.25 * 5.25 E-04 = 5.79 E-02 kg CO_2 per FU
Part already carbonated in B1 (for the landfilled product) cf. Table III-29	0.05*1.764 = 0.088 kg CO_2 per FU	0.05 * 0.617 = 3.09 E-02 kg CO_2 per FU
Net CO_2 uptake in C4	0.165-0.088 = 0.077 kg CO_2 per FU	5.78E-02 – 3.09E-02 = 0.027 kg CO_2 per FU

III.2.11.5. Carbonation of losses occurring in Module A3 and Module A5

Carbonation occurs for the landfilled part of concrete losses arising in A3 and A5.

The same approach as for C4 is adopted except that the carbonation of the use phase does not have to be subtracted.

[26] As stated in EN 16757, the value of 75% of the potential maximum uptake can be used as a mean practical maximum uptake for long-term perspective.

Table III-31 : Example of calculations for carbonation counted in Module A3 and Module A5[25]

	Prestressed hollow core concrete slabs	Reinforced concrete beam
Max theoretical CO_2 uptake	0.49 kg CO2/kg cement (CEM I)	
Maximum degree of carbonation	0.75 (for a long-term perspective)	
Cement content / m3 concrete	300 kg/m3	
Uptake in C4	0.49 × 300 × 0.75 = 110 kg CO2/m^3	
Volume concerned in A3 per m2	Considering a loss rate of 0.1005% and a landfill rate of 5%	
	0.001005 *0.05 * 0.03 = 1.5 E-06 m^3/m^2	
CO2-uptake per m^2	1.5 E-06 * 110 = 1.65 E-04 kg CO_2/m^2	
CO2-uptake per FU in A3	1.65 E-04 kg CO_2 per FU	0.000165 * 0.35 = 5.8E-05 kg CO_2 per FU
Volume concerned in A5 per m2	Considering a loss rate of 0.5% and a landfill rate of 5%	
	0.005 *0.05 * 0.03 = 7.5 E-06 m^3/m^2	
CO2-uptake per m^2	7.5 E-06 * 110 = 8.3 E-04 kg CO_2/m^2	
CO2-uptake per FU in A5	8.3 E-04 kg CO_2 / FU	8.3 E-04 *0.35 = 2.9E-04 kg CO_2 / FU

III.2.11.6. Module D

The standard EN 16757:2017 states that: "*CO2 uptake in module D can be considered up to the point of functional equivalence. (EN 15804 applies)*"

It is assumed that crushing and further use of crushed concrete take place in a too limited period of time for allowing carbonation to be accounted for "up to the point of equivalence". Furthermore, carbonation occurring during the potential applications of secondary crushed concrete should not be reported in module D. An estimation of this contribution beyond the system boundaries can however be provided as additional information and is calculated using the long-term perspective formula described in section III.2.11.4.

Table III-32 : Example of calculations for carbonation counted in Module D[25]

	Prestressed hollow core concrete slabs	Reinforced concrete beam
Max theoretical CO_2 uptake	0.49 kg CO_2/kg cement (CEM I)	
Maximum degree of carbonation	0.75 (for a long-term perspective)	
Cement content/m3 concrete	300 kg/m3	
Uptake per m3 beyond system boundaries	0.49 × 300 × 0.75 = 110.25 kg CO_2/m^3	
Weight of concrete per product (kg/product)	2784.7 kg	167.4 kg
Density of concrete (in function of the recipe)	2445 kg/m^3 concrete	2440 kg/m^3 concrete
Volume of concrete per FU	2784.7 / 2445 * 0.098 = 0.1116 m^3	167.4 / 2440 * 1 = 0.0686 m^3
Uptake for the product recycled after C3		
Volume of concrete beyond system boundaries	Considering a recycling rate of 95%	
	0.1116 * 0.95 = 0.1060 m^3	0.0691 * 0.95 = 0.0652 m^3
Max CO_2 uptake	0.1060 * 110.25 = 11.687 kg CO_2 per FU	0.0652 * 110.25 = 7.188 kg CO_2 per FU
Part already carbonated in B1 (for the recycled product)	0.95*1.764 = 1.676 kg CO_2 per FU	0.95*0.617 = 0.586 kg CO_2 per FU
Net CO_2 uptake beyond system boundaries for the recycled product in C3	=11.687 – 1.676 =10.011 kg CO_2 per FU	7.188 – 0.586 = 6.602 kg CO_2 per FU
Uptake for the product recycled after A3		
Net CO_2 uptake beyond system boundaries for the recycled product in A3	110.25 * 0.1116 *0.95 * 0.001= 0.012 kg CO_2/FU	110.25 * 0.0686 *0.95 * 0.001 = 0.007 kg CO_2/FU
Uptake for the product recycled after A5		
Net CO_2 uptake beyond system boundaries for the recycled product in A5	110.25 * 0.1116 *0.95 * 0.005= 0.058 kg CO_2/FU	110.25 * 0.0686 *0.95 * 0.005 = 0.036 kg CO_2/FU
Total CO_2 uptake beyond system boundaries		
Total CO_2 uptake	10.011 + 0.012 + 0.058 = 10.081 kg CO_2/FU	6.602 + 0.007 + 0.0361 = 6.645 kg CO_2/FU

This is the potential CO_2 uptake due to carbonation during the possible applications of secondary crushed concrete (beyond the system boundaries).

III.2.12. ELECTRICITY MIXES USED IN THE MODEL

Electricity production is modelled by using the ecoinvent data "market for electricity, low voltage" of the country where electricity is used. The ecoinvent datasets represent consumption mixes. Data are based on IEA World Energy Statistics and Balances for the year 2017.

III.2.13. CARBON CYCLE AND BIOGENIC CARBON CONTENT

The term "biogenic carbon" refers to CO_2 uptake during biomass growth and release of CO2, CH4 and CO along with combustion or degradation of biomass-based product (such as cardboard and wood).

The studied concrete products do not contain biogenic carbon.

The following packaging contain biogenic carbon: corrugated board box, wooden pallet and wooden wedges. According to EN 15804+A2 (section 7.2.5), the biogenic carbon content at the gate has to be reported in the EPD. [27]

The biogenic carbon content at the gate is calculated as the sum of the weights per FU of the carboard and wooden elements of packaging (not divided by its number of uses), each multiplied by the specific biogenic carbon content of each packaging material:

- 0.42 kg C/kg corrugated board; This number is obtained as the carbon content of dry cardboard (0.46 according to ecoinvent), multiplied by 0.92 (i.e. considering a moisture content of the corrugated board of 8%; source FEFCO 2018)
- or 0.43 kg C/kg wooden packaging. This number is obtained as the carbon content of dry pallet (0.518 according to ecoinvent), multiplied by 0.833 (i.e. considering a moisture content of 16.7%%; source ecoinvent, activity "EUR flat pallet").

Carbon cycles are balanced along the life cycle for the biobased packaging. It means that carbon content is used consistently to model

- carbon uptake in biomass (for the virgin part of the supply)
- emissions of biogenic CO_2 at incineration.

[27] The standard also indicates that "If the mass of biogenic carbon containing materials in the packaging is less than 5 % of the total mass of the packaging, the declaration of the biogenic carbon content of the packaging may be omitted." However, when carboard or wood is used as packaging in the studied systems, it represents usually much more than 5% of the packaging weight.

III.3. Data sources

All ecoinvent datasets correspond to the "cut-off by classification" system model (as required by B-EPD PCR, section A23 and by the *Bepalingsmethode*).

Table III-33 : List of used datasets with source, dataset name, year of data, year of publication

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
Module A1					
Cement – CEM I	CEMBUREAU EPD	"Portland Cement (CEM I) produced in Europe – CEMBUREAU"	2016	2020	
Cement – CEM II	CEMBUREAU EPD	"Portland-composite cement (CEM II) produced in Europe – CEMBUREAU"	2016	2020	
Cement – CEM III	CEMBUREAU EPD	"Blast furnace cement (CEM III) produced in Europe – CEMBUREAU"	2016	2020	
Cement – CEM V	EI 3.7.1	"Cement production, blast furnace slag 18-30% and 18-30% other alternative constituents, Europe without Switzerland"	2001-2020	2020	
White cement	EPD Aalborg	"Aalborg White® Cement". EPD published by Aalborg in 2021 for white cement produced in Denmark	2020	2021	
Fly ashes		No dataset associated since according to the allocation method, these products are considered as co-products from other processes, with no economic values (cf. II.6.2.1)			
Blast furnace slags	Worldsteel + EI 3.7.1	Data from Worldsteel 2014 + Impacts of granulation and grinding: "ground granulated blast furnace slag production – RoW"	2007 + 2001-2020	2014+2020	
Limestone fillers	EI 3.7.1	Limestone production, crushed, washed - RoW	2000-2020	2020	
Artificial aggregates (coarse granulates)	EI 3.7.1	Expanded clay production - DE	1995 - 2020	2020	
Natural aggregates	EI 3.7.1	Gravel production, crushed – CH (with electricity mix of CH replaced by Europe without Switzerland)	2013-2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
(coarse granulates)					
Recycled aggregates (coarse granulates)	EI 3.7.1	"Treatment of waste concrete gravel, sorting plant – RoW" (without 'inert waste' processes) after subtraction of "treatment of waste concrete gravel, recycling"	1997 - 2020	2020	x
River/sea sand	EI 3.7.1	Sand quarry operation, extraction from river bed - RoW	2015-2020	2020	
Quarry sand	EI 3.7.1	Gravel and sand quarry operation – sand – CH (with electricity mix of CH replaced by Europe without Switzerland)	1997 - 2001	2020	
Crushed sand (temporarily "Quarry sand" in the tool interface)	EI 3.7.1	Gravel production, crushed – CH (with electricity mix of CH replaced by Europe without Switzerland)	2013 - 2020	2020	
Pigment – carbon black	EI 3.7.1	Carbon black production - GLO	2000-2020	2020	
Pigment – cobalt	EI 3.7.1	Cobalt production - GLO	2011-2020	2020	
Pigment – chromium oxide	EI 3.7.1	Chromium oxide production, flakes - RER	2000-2020	2020	
Pigment – titanium dioxide	EI 3.7.1	Market for titanium dioxide - RER	1997 - 2020	2020	
Insulation – extruded polystyrene	EI 3.7.1	Polystyrene production, extruded, CO2 blown - RER	1994 - 2020	2020	
Insulation – expanded polystyrene	EI 3.7.1	Polystyrene production, expandable - RER	2001-2020	2020	
PUR	EI 3.7.1	Polyurethane production, rigid foam - RER	1997 - 2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
PIR	EI 3.7.1	Polyurethane production, rigid foam - RER	1997 - 2020	2020	x
Glass wool	EI 3.7.1	(55%) glass wool mat production, with phenolic binder, uncoated, Saint-Gobain ISOVER SA - CH (45%) glass wool mat production, with plant-based binder, uncoated, Saint-Gobain ISOVER SA - CH (proportions according to the dataset "market for glass wool mat, uncoated, Saint-Gobain ISOVER SA - CH") Electricity for CH replaced by electricity for BE	2018-2020	2020	
Reinforcing steel	EI 3.7.1	Steel production, electric, low-alloyed – Europe without CH & AT+ hot rolling, steel – Europe without AT	2013/ 1997-2020	2020	
Steel for prestressing and steel fibres	Worldsteel	Steel wire rod	2012-2015	2019	
Steel for anchors	EI 3.7.1	Steel production, chromium steel 18/8, hot rolled	2000	2020	x
Manufacturing anchors	EI 3.7.1	Market for metal working, average for chromium steel product manufacturing	2011	2020	
Entraining admixtures	EI 3.7.1	Plasticiser production, for concrete, based on sulfonated melamine formaldehyde	2014	2020	x
Waterproofing admixtures					x
Set accelerators					x
Set retarders					x
Plastifiers and superplastifiers					
Hardening accelerators					x

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
Synthetic rubber	EI 3.7.1	Synthetic rubber production - RER	1997-2020	2020	
Release agent	EI 3.7.1	Lubricating oil production - RER	2000-2020	2020	
Transport by truck – Modules A2, A4, A5, C2, C4, D; Train & barge: Module A2					
Truck transport operation	Copert 5 tool (v5.2.2)	Fuel consumption and on road emissions of truck (in function of euro standards and maximum payload)	2007-2016	2018	
Truck transport infrastructure	EI 3.7.1	Lorry production, 40 metric ton - RER	1998 - 2020	2020	
		Maintenance, lorry 40 metric ton - GLO	2011 - 2020	2020	
		market for road - GLO	2011 - 2020	2020	
		Road maintenance – Europe w/o CH	1990 - 2020	2020	
Truck transport: diesel supply	EI 3.7.1	Market for diesel, low-sulfur – Europe without Switzerland	2000 - 2020	2020	
Truck transport for EPD for Netherlands	EI 3.7.1	Transport, freight, lorry, unspecified - GLO	2012-2020	2020	
Train transport operation	EcoTransIT & LRTAP-EEA	Electricity or diesel consumption calculated according to formula from EcoTransIT & Emissions per kg diesel	2010 2005	2019 2016	
Train transport	EI 3.7.1	Market for diesel, low-sulfur – Europe without Switzerland	2000 - 2020	2020	
	EI 3.7.1	Locomotive production - RER	1993 - 2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
Train transport infrastructure		Goods wagon production - RER	1993 - 2020	2020	
		Maintenance, goods wagon - RER	1993 - 2020	2020	
		Maintenance, locomotive - RER	1993 - 2020	2020	
		Railway track construction - RoW	1990 - 2020	2020	
Barge transport	EI 3.7.1	Operation, barge, RER (including infrastructure)	1990 - 2020	2020	
Module A2, A3, A5, B2, C1, C3, D					
Electricity mix	EI 3.7.1	Market for electricity, low voltage – BE or NL (For waste based on renewable materials incinerated in the Netherlands: heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical – NL)	2014-2020	2020	
Module A3 – Manufacturing					
Infrastructures	EI 3.7.1	Concrete mixing factory construction - CH	1997 - 2020	2020	
Diesel	EI 3.7.1	Diesel, burned in building machine - GLO	1996 - 2020	2020	
Natural gas	EI 3.7.1	Heat production, natural gas, at industrial furnace >100kW – Europe without Switzerland	2000 - 2020	2020	
Light fuel oil	EI 3.7.1	Heat production, light fuel oil, at industrial furnace 1MW – Europe without Switzerland	1991 - 2020	2020	
Heavy fuel oil	EI 3.7.1	Heat production, heavy fuel oil, at industrial furnace 1MW – Europe without Switzerland	2001-2020	2020	
LPG	EI 3.7.1	Propane, burned in building machine - GLO	2013 - 2020	2020	X
Hydropower	EI 3.7.1	electricity, high voltage - electricity production, hydro, pumped storage – RoW (6%) (percentages are based on ecoinvent 3.4 data for the dataset "market group for electricity, high voltage – Europe without Switzerland")	1945	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
	EI 3.7.1	electricity, high voltage - electricity production, hydro, reservoir, alpine region – RoW (36%)	1945	2020	
	EI 3.7.1	electricity, high voltage - electricity production, hydro, reservoir, non-alpine region – RoW (7%)	1945	2020	
	EI 3.7.1	electricity, high voltage - electricity production, hydro, run-of-river – RoW (51%)	1945	2020	
Wind power	EI 3.7.1	electricity, high voltage - electricity production, wind, 1-3MW turbine, offshore – RoW (4%) (percentages are based on ecoinvent 3.4 data for the dataset "market group for electricity, high voltage – Europe without Switzerland")	2000	2020	
	EI 3.7.1	electricity, high voltage - electricity production, wind, 1-3MW turbine, onshore – RoW(70%)	2005	2020	
	EI 3.7.1	electricity, high voltage - electricity production, wind, <1MW turbine, onshore – RoW (20%)	2000	2020	
	EI 3.7.1	electricity, high voltage - electricity production, wind, >3MW turbine, onshore – RoW (6%)	2012	2020	
Solar	EI 3.7.1	electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted (50%) (percentages are based on ecoinvent 3.10 data for the dataset "market for electricity, low voltage - BE")	2005	2020	
	EI 3.7.1	electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted (25%)	2005	2020	
	EI 3.7.1	electricity production, photovoltaic, 570kWp open ground installation, multi-Si (25%)	2008	2020	
Biomass	EI 3.7.1	electricity, high voltage - heat and power co-generation, wood chips, 6667 kW – RoW (6%) (percentages are based on ecoinvent 3.4 data for the dataset "market group for electricity, high voltage – Europe without Switzerland")	2010	2020	
	EI 3.7.1	electricity, high voltage - heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 – RoW (94%)	2010	2020	
Module A3 - Packaging					
LDPE film	EI 3.7.1	Packaging film production, low density polyethylene - RER	1993 - 2020	2020	
Cardboard	EI 3.7.1	Containerboard production, linerboard, kraftliner - RER	2012-2020	2020	
Strapping bands	EI 3.7.1	Polyester resin production, unsaturated - RER	1995 - 2020	2020	
	EI 3.7.1	Extrusion production, plastic film - RER	1993 - 2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
PE foam	EI 3.7.1	Polyethylene production, high density, granulate - RER	2011 - 2020	2020	
	EI 3.7.1	Polymer foaming - RER	1995-2020	2020	
Wooden pallets	EI 3.7.1	EUR-flat pallet production - RER	2000 - 2020	2020	
Metal pallets	EI 3.7.1	steel production, electric, low-alloyed – Europe without CH & AT+ hot rolling, steel – Europe without AT	2013/ 1997-2020	2020	
Stacking plate PE	EI 3.7.1	Injection moulding - RER	1993 - 2020	2020	
	EI 3.7.1	Polyethylene production, high density, granulate - RER	2011 - 2020	2020	
Wooden wedges and slats	EI 3.7.1	market for particleboard, uncoated - RER	2012 - 2020	2020	x
	EI 3.7.1	Market for sawnwood, softwood, raw, dried (u=20%) - RER	2011 - 2020	2020	x
Module A4					
Lashing strap - Polyester	EI 3.7.1	polyester fibre production, finished - RoW	2007	2020	
	EI 3.7.1	treatment of waste polyethylene terephthalate, municipal incineration - RoW	2006-2020	2020	x
	EI 3.7.1	treatment of waste polyethylene terephthalate, sanitary landfill - RoW	1994-2020	2020	x
Lashing strap – stainless steel tensioner	EI 3.7.1	steel production, chromium steel 18/8, hot rolled, RoW + market for metal working, average for chromium steel product manufacturing	2000 – 2020 2011-2020	2020	
	EI 3.7.1	treatment of scrap steel, inert material landfill	1995-2020	2020	
Module A5					

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
Bolts and nuts + manufacturing	EI 3.7.1	steel production, chromium steel 18/8, hot rolled - RER	2000	2020	x
	EI 3.7.1	Market for metal working, average for chromium steel product manufacturing - GLO	2011	2020	
Classic & casting mortar	EI 3.7.1	Silica sand production - DE	1998 - 2001	2020	
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
	EI 3.7.1	Cement production, Portland – Europe without Switzerland	1997 - 2001	2020	
	EI 3.7.1	Plaster mixing – CH (with electricity mix of the installation country Belgium or NL)	2001 - 1017	2020	
Casting concrete	EI 3.7.1	Silica sand production - DE	1998 - 2001	2020	
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
	EI 3.7.1	gravel and sand quarry operation – gravel round - RoW	1997-2020	2020	
	EI 3.7.1	(Electricity BE and heat consumption cf. unreinforced concrete production, with cement CEM II/A – CH)			
Water	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
Neoprene	EI 3.7.1	Synthetic rubber production - RER	2003	2020	x
Glue	EI 3.7.1	polyurethane adhesive production - GLO	2015-2020	2020	x
Reinforcing steel	EI 3.7.1	steel production, electric, low-alloyed – Europe without CH & AT+ hot rolling, steel – Europe without AT	2013/1997-2020	2016	
Fixing sand	EI 3.7.1	Gravel and sand quarry operation, sand - RoW	1997 - 2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
	EI 3.7.1	Market for cement, unspecified – Europe without Switzerland	2013 - 2001	2020	
Module B2					
Water	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
Module C1					
Water use for demolition of products	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	
Diesel consumption for demolition of products	EI 3.7.1	Diesel, burned in building machine - GLO	1996 - 2020	2020	
Transport to recycling/treatment centre by truck		List of LCI for truck transport (see above)	/		
Module C3					
Sorting plant infrastructure	EI 3.7.1	Sorting facility construction, for construction waste - CH	1996 - 2020	2020	
Module C4					
Concrete landfill disposal	EI 3.7.1	Treatment of waste concrete, inert material landfill – Europe without Switzerland	1995-2017	2020	
Steel landfill disposal	EI 3.7.1	Treatment of scrap steel, inert material landfill	1995-2020	2020	
PS landfill disposal	EI 3.7.1	Treatment of waste polystyrene, sanitary landfill– Europe without Switzerland	1994-2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
XPS landfill disposal					
PUR landfill disposal	EI 3.7.1	Treatment of waste polyurethane, inert material landfill – Europe without Switzerland	1995-2020	2020	
PIR landfill disposal				2020	X
Glass wool disposal	EI 3.7.1	treatment of waste glass, sanitary landfill	2010-2020	2020	
Neoprene landfill disposal	EI 3.7.1	Treatment of waste polyvinylchloride, sanitary landfill – Europe without Switzerland	1994-2020	2020	X
PS incineration	EI 3.7.1	Treatment of waste polystyrene, municipal incineration – Europe without Switzerland	2006-2020	2020	
XPS incineration	EI 3.7.1	Treatment of waste expanded polystyrene, municipal incineration – Europe without Switzerland	2006-2020	2020	
PUR and PIR incineration	EI 3.7.1	Treatment of waste polyurethane, municipal incineration – Europe without Switzerland	2006-2020	2020	(x)
Glass wool incineration	EI 3.7.1	treatment of waste glass, municipal incineration	2006-2020	2020	(x)
Neoprene incineration	EI 3.7.1	Treatment of waste rubber, unspecified, municipal incineration – Europe without Switzerland	2006-2020	2020	X
Module D					
Part of modelling of wood recycling process	EI 3.7.1	wood chipping, industrial residual wood, stationary electric chipper - RER	1996 - 2020	2020	
Operations for valorising secondary crushed	EI 3.7.1	"Treatment of waste concrete gravel, sorting plant – RoW" (without 'inert waste' processes) after subtraction of "treatment of waste concrete gravel, recycling"	1997 - 2020	2020	

Use	Source	Dataset	Reference year	Publi-cation year	Proxy
concrete material					
Replacement scenario of gravel by crushed concrete	EI 3.7.1	Gravel and sand quarry operation – Gravel, round – CH (with electricity mix of CH replaced by Europe without Switzerland)	1997 - 2001	2020	x
All steel except reinforcing steel (and metal pallet)	Worldsteel	Value of scrap	2011	2019	
Reinforcing steel and metal pallet	EI 3.7.1	Recycling: steel production, electric, low-alloyed – Europe without CH & AT Avoided virgin production: steel production, converter, low-alloyed – RER	2013-2020	2020	
Cardboard recycling	EI 3.7.1	Treatment of recovered paper to linerboard, testliner - RER	2012-2020	2020	
Recycling of PE films, foam, strapping band	EI 3.7.1	polyethylene production, high density, granulate, recycled	2010	2020	(x)
Heat recovery	EI 3.7.1	Heat production, natural gas, at industrial furnace >100kW (For waste based on renewable materials incinerated in the Netherlands: heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014)	2000-2020	2020	

Remark: Through losses at production (A3) and during transport and installation (reported in A5), the processes involved in A1, A2 and A3 also contribute to A5.

III.4. Data quality assessment

III.4.1. PRINCIPLES OF DATA QUALITY ASSESSMENT

The EN 15804+A2 standard uses mostly the same criteria as ISO 14044 for data quality assessment (DQA) and describes these criteria as follows:

- Geographical representativeness: the geographical coverage shall reflect the physical reality for the declared product or product group by as far as possible taking into account:
  - technology representativeness for the region/country;
  - input materials representativeness for the region/country;
  - input energies representativeness for the region/country.
- Technological representativeness: the technological coverage shall reflect the physical reality for the declared product or product group by as far as possible taking into account:
  - representativeness for the technology mix and location type stated in the documentation;
- Time-related representativeness:
  - data shall be as current as possible. Data sets used for calculations shall be valid for the current year and represent a reference year within 10 years for generic data and 5 years for producer specific data;
  - the reference year refers to the year which the overall inventory best represents, considering the age/representativeness of the various specific and background data included, i.e. not automatically the year of modelling, calculation or publication year. Validity of data sets refers to the date to which the inventory is still judged sufficiently valid with the documented technological and geographical representativeness;
  - data sets shall be based on 1 year averaged data; deviations shall be justified;
- Completeness: data sets shall be complete according to the system boundary within the limits set by the criteria for the exclusion of inputs and outputs. (According to PEF guidelines v6.3, the completeness check aims at assessing the inclusion of the most important elementary flows contributing to each impact category.)
- Methodological consistency: degree to which the study methodology is applied uniformly to the various components of the analysis and methods and methodological choices (e.g. allocation, substitution, etc.) are in line with the goal and scope of the study, especially its intended applications as support to decisions.

For assessing the first three criteria in this study, the quality levels defined in the "UN Environment Global Guidance on LCA database development" are used.[28] They are presented in Table III-34.

Table III-34: Definitions of data quality levels used in this study

Value	Geographical representativeness	Technological representativeness	Time-related representativeness
1 - Very good	Data from area under study	Data from processes and products under study. Same state of technology applied as defined in goal and scope (i.e. identical technology)	Less than 3 years difference between the reference year according to the documentation, and the time period for which data are representative
2 - Good	Average data from larger area in which the area under study is included	Data from processes and products under study (with similar technology). Evidence of deviations in state of technology, e.g. different by-product.	Less than 6 years of difference between the reference year according to the documentation, and the time period for which data are representative
3 - Fair	Data from area with similar production conditions	Data from processes and products under study but from different technology. This score is also applied when not technology is specified; e.g. wheat (no further specification)	Less than 10 years of difference between the reference year according to the documentation, and the time period for which data are representative
4 - Poor	Data from area with slightly similar production conditions	Data on related processes or products; organic wheat under study, data for organic rye provided.	Less than 15 years of difference between the reference year according to the documentation, and the time period for which data are representative
5 - Very poor	Data from unknown or distinctly different area (North America instead of Middle East, OECD Europe instead of Russia)	Data on related processes on but with a different scale or from different technology; organic wheat under study, data for conventional wheat provided.	Age of data unknown or more than 15 years of difference between the reference year according to the documentation, and the time period for which data are representative

[28] As quoted in EN 15804+A2:2019

Remark: For time-related representativeness, it is very difficult to obtain a level defined as "very good" for LCI datasets. Indeed, the process of LCI publication takes often at least two or three years between the year of reference considered for data collection and the release of the peer-reviewed dataset.

Further specific requirements of the EN15804+A2 standard are:

- the documentation format and data sets for the LC inventory data used in the LCA modelling shall use the current ILCD format and nomenclature as defined in the document, "International Reference Life Cycle Data System (ILCD) Handbook - Nomenclature and other provisions"; this requirement is fulfilled since the database associated with RangeLCA, the software supporting the tool, is developed with the ILCD format (and EF nomenclature)
- generic data shall be checked for plausibility; LCIA results for important components production or of results found in other EPDs were compared to data and results of the tool.
- the time period over which inputs to and outputs from the system shall be accounted for is 100 years from the year for which the data set is deemed representative. However, for solid waste disposal of products containing biogenic carbon declared as GWP-biogenic, see 6.3.5.5 of the standard; this aspect is discussed in section IV.2.1.

III.4.2. DISCUSSION OF DATA QUALITY

For the secondary datasets (presented in Table III-33), the systematic data quality assessment (DQA) is reported in Appendix 5 (section VI.5). This analysis allows the global comments of sections III.4.2.1 to III.4.2.3 to be written concerning geographical, technological and time-related representativeness.

These sections also include the DQA discussion of primary data provided by FEBE. Strictly speaking, it is the purpose of the second verification step to assess the data quality for activity data accessible in the tool (cf. I.4). However, data quality of default values can be discussed (and discussion shall be updated if the tool user replaces values).

III.4.2.1. Temporal representativeness

Firstly, time-representativeness can be discussed for default activity data (listed in Table III-1):

- Average producer data for module A3 (energy and packaging) have been collected during the period 2015-2016 (cf. II.4). Hence, they are more than 5 years-old. It is recommended to update this data collection. However, in the absence of update, the current default values are expected to be conservative, as the trend is expected to be a reduction of energy use due to process optimisation.

- For concrete recipes, composition data has been averaged over a longer period, starting before 2015. However, there is little change occurring with time for such data (which can also be adapted in the tool interface).
- Quantities of steel and pigments in products as well as materials for installation have been revalidated in 2019 by FEBE engineers and, hence, are considered as representative of the current scenarios.

Secondly, the time horizon of secondary data is detailed in section VI.5 for LCIs. Periods of data collection for ecoinvent v3.7.1 datasets span from 1990's to 2018, depending on the activity. For data coming from other generic sources, i.e. CEMBUREAU EPDs and Worldsteel LCI data, the release years is 2020 and 2019 and data was collected for the representative year 2016.

As described above, the EN 15804 requires the reference year of generic data to be within 10 years (quality levels from 1 to 3). Based on section VI.5, the temporal representativeness of secondary datasets contributing most to the impacts ('+++' in last column of the table, i.e. datasets for cement production and steel production and recycling) can be considered satisfactory. The reference year for the LCI of stainless steel production is however older than 10 years.

Data presenting a quality level of 4 or 5 for time-representativeness are mostly related to power plants, infrastructure, mineral extraction. These datasets are considered as still valid, although older, since limited evolutions have occurred in the related technologies since data collection.

Older reference years of data are also found for production of plastics used as insulation or packaging. Although ecoinvent does not propose more recent data for these materials, the ecoinvent data is used in the model for privileging homogeneity of data source, considering that these steps do not bring the largest contributions to the results.

Anyway, because of technological improvement with time, old datasets could overestimate impacts. Hence, their use corresponds to a conservative approach.

III.4.2.2. Geographical representativeness

For LCIs, the secondary datasets are well representative of the Belgian and Dutch situations since they mostly correspond to European average or to a larger scope comprising these countries (2 as quality level). Some inventories for "Switzerland" are used. The electric mix is then replaced by either the European mix (when the activity can take place in other European countries, e.g. gravel crushing) of by the Belgian (or NL) mix for example for activities related to installation. Furthermore, the EPD for white cement corresponds to the production in Denmark, which might not be representative of the average white cement consumed in Belgium.

Apart from electricity, which is well modelled in a country-specific way, there are no steps where big differences of technology are expected between Belgium and other countries.

Concerning primary data provided by FEBE and values coming from national documents specifying requirements complementing the EN 15804 standard, the geographical representativeness is high (level 1 of data quality).

III.4.2.3. Technological representativeness

The technological representativeness is globally satisfactory since proxy data are only used for a limited number of data and for data having low or medium influence on the results.

Ecoinvent data are used for modelling sand and gravel production, with a potential lack of diversity for representing the various types of sand used in the concrete industry. However, this aspect has improved because there exists a dataset for sand extraction from riverbed since ecoinvent version 3.7.1.

With the aim of consistency, only EPDs complying with EN 15804+A2 can be used as data source. The number of such EPDs is currently limited. This limits the technological representativeness for some data. For example, for concrete admixtures, updated EPDs are not published by EFCA yet. Therefore, the ecoinvent data "plasticiser, for concrete" has to be used as proxy for all types of admixtures.

III.4.2.4. Methodological consistency

The methodology behind the dataset provided by Worldsteel for wire rod steel corresponds to system expansion (cf. II.6.2.2). This is not consistent with the economic allocation applied in the Cembureau EPDs nor with the physical partitioning approach retained for separated modelling of blast furnace slag. There is a need for improving consistency. However, there was no other satisfactory data available when the model has been reviewed in 2021.

Because of the limits mentioned, comparison of concrete products with different sand types or with reinforcement steel and prestressing steel should be still further restricted.[29]

III.4.2.5. Data completeness

It is difficult to assess the completeness of the LCIs, in the sense of ensuring that they include the most important elementary flows contributing to each impact category, in particular for the new LCIA methods recommended by EN 15804+A2 (and by the PEF guidelines). It is observed that many elementary flows that have characterization factors are not included in the inventories so far, mainly for emissions contributing to human toxicity or ecotoxicity but also, to a lesser extent, to resource use.

More experience has to be gained by collecting data for these "new" elementary flows and analysing how much they contribute to the results.

III.4.3. TREATMENT OF MISSING DATA

III.4.3.1. Proxy datasets

The treatment of missing data is handled using proxies, which allow the inclusion of processes and materials for which no strictly related LCI or data has been found. The list of used proxies is included in Table III-33.

[29] This remark adds to the general restrictions on comparisons described in ISO 14044 and in EN 15804+A2 § 5.3.

III.4.3.2. Missing LCIA results

The European Cement Association, CEMBUREAU, does not provide environmental information about cement production under the form of LCI datasets but well as EPDs. Similarly, data for white cement production is also taken from an EPD.

Hence, the LCA practitioner is prevented from analysing contributions to the environmental indicators at the elementary flow level. However, these EPDs have been elaborated in reference to EN 15804+A2 and have been peer reviewed by an external expert. This is considered as a pre-verification in the meaning of CEN/TR 15941:2010. Therefore, results from these EPDs are used in this project.

As mentioned, the EPDs published by CEMBUREAU in 2020 cover the core environmental impact indicators recommended by the EN 15804+A2 standard. However, only two indicators out of the six additional indicators are reported in the EPDs. LCIA results were calculated from another source for:

- Human toxicity, cancer effects
- Human toxicity, non-cancer effects
- Eco-toxicity (freshwater) Potential
- Land use related impacts/ Soil quality

The following ecoinvent 3.7.1 datasets[30] have been used (UPR data of these datasets have been adapted to align to the same compositions as for Cembureau EPDs):

- CEM I: activity "cement production, Portland, Europe without Switzerland"
- CEM II: activity "cement production, alternative constituents 21-35%, Europe without Switzerland"
- CEM III: activity "cement, blast furnace slag 36-65%, Europe without Switzerland"

[30] Allocation, cut-off by classification

IV. Life cycle impact assessment

IV.1. Life Cycle Assessment

IV.1.1. DEFINITION

Life Cycle Assessment (LCA) is the investigation and evaluation of the environmental impacts caused directly or indirectly by a product, material or service during its whole life cycle. LCA addresses environmental impacts in the areas of ecological health, human health and resource depletion.

IV.1.2. RANGELCA SOFTWARE

Calculations are performed using the software Range LCA, developed by RDC Environment.

The modelling of the studied functional unit ends up in a process tree, conceived to make it possible to model different systems and to distinguish between the impacts of the different stages of the life cycle. Each process of the process tree is characterized by a unit of output (example: 1 kg of product) and by elementary flows associated with this unit of output. These elementary flows consist in resource consumptions and in emissions, as shown in Figure 6.

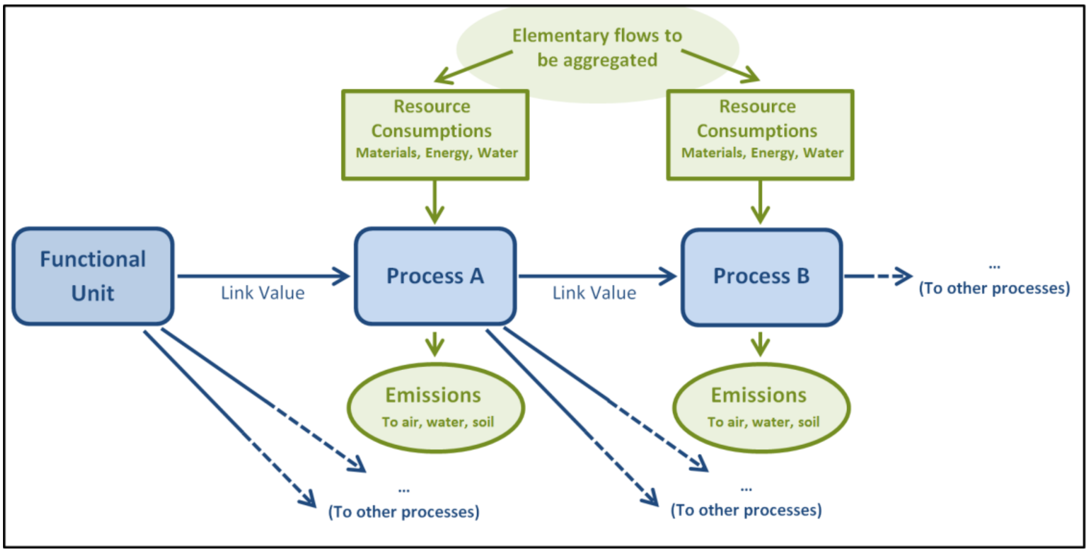

Figure 6 : Scheme of the elementary processes and of the process tree

Processes are linked directly to the functional unit or to other processes through a formula that expresses the number of process output required by the functional unit or by unit of output of the preceding process (in Figure 6, the link value expresses the number of times the process B has to be counted by unit of process A). The mentioned formula (defining the link value) can be:

- A number.
- A statistical distribution.
- Mathematical operations using numbers and/or statistical distributions.

The environmental balance is calculated by aggregating the elementary flows of the different processes. As a result, all elementary flows, the direct ones as well as the indirect ones, are automatically attributed to the functional unit.

The RangeLCA software is able to calculate multiple results for a same system to be assessed (e.g. several thousands). As explained, every link of the model can be a statistical distribution (a range of values). This way, at each calculation, the software selects a possible value (randomly chosen by the software) in the ranges encoded. The software is so able to produce:

- Range of results which can be used for the sensitive analysis.
- Unique average results which reflect all the possible values encoded in the links as activity data (see section III.1).

In this study, the "range" feature of the software has been used at the beginning, for the sensitivity analysis. This step allowed the most influential parameters to be identified and contributed to the selection of parameters that can be modified through the tool interface.

Results of the EPD tool are however based on a single calculation using a model without statistical distributions in the links.

IV.2. Impact Categories

IV.2.1. PARAMETERS DESCRIBING ENVIRONMENTAL IMPACTS

The impact categories used in the tool are the ones indicated by the EN 15804+A2 (in Table 3 and table 4 of the standard).

Table IV-1 : Set of impact categories covered by the tool (Source : EN 15804+A2)

Impact Category	Indicator	Unit	Name in the tool, EPD and Excel export[31]
Core environmental impact indicators			
Depletion of abiotic resources - mineral elements[1)]	Abiotic depletion potential (ADP-elements) for non-fossil resources	kg Sb eq	Abiotic Depletion Potential - Elements
Depletion of abiotic resources -fossil fuels[1)]	Abiotic depletion potential (ADP-fossil fuels) for fossil resources	MJ, net calorific value	Abiotic Depletion Potential - Fossil Fuels
Acidification Accumulated Exceedance	Acidification potential AP	mol H+ eq.	Acidification Potential - Soil and Water
Ozone Depletion	Depletion potential of the stratospheric ozone layer, ODP	kg CFC 11 eq.	Ozone Depletion Potential
Global Warming total	Global warming potential, GWP	kg CO2 eq.	Global Warming Potential - Total
GWP from fossil carbon emissions and removals	GWP fossil	kg CO2 eq.	Global Warming Potential - Fossil
GWP from biogenic carbon emissions and removals	GWP biogenic	kg CO2 eq.	Global Warming Potential - Biogenic
GWP from land use and land use transformation emissions and removals	GWP land use and land use transformation	kg CO2 eq.	Global Warming Potential - Land use change
Eutrophication terrestrial Accumulated Exceedance,	Eutrophication potential, EP terrestrial	mol N eq.	Eutrophication potential - Terrestrial

[31] Names are aligned to names used in the EPD template of the Belgian EPD program (version +A2 of March 2021)

Impact Category	Indicator	Unit	Name in the tool, EPD and Excel export[31]
Eutrophication aquatic freshwater Fraction of nutrients reaching freshwater end compartment	Fraction of nutrients reaching freshwater end compartment Eutrophication potential, EP freshwater	kg P eq.	Eutrophication potential - Freshwater
Eutrophication aquatic marine	Fraction of nutrients reaching freshwater end compartment Eutrophication potential, EP marine	kg N eq.	Eutrophication potential - Marine
Photochemical ozone creation	Formation potential of tropospheric ozone, POCP	kg Ethene eq.	Photochemical Ozone Creation
Water scarcity[1)]	User deprivation potential (deprivation-weighted water consumption)	m3world eq. deprived	Water use (Deprivation potential)
Additional environmental impact indicators			
Human toxicity, cancer effects [1)]	Potential Comparative Toxic Unit for humans	CTUh	Human Toxicity - Cancer effects
Human toxicity, non-cancer effects[1)]	Potential Comparative Toxic Unit for humans	CTUh	Human Toxicity - Non cancer effects
Eco-toxicity (freshwater) Potential[1)]	Comparative Toxic Unit for ecosystems	CTUe	Ecotoxicity - Freshwater
Land use related impacts/ Soil quality[1)]	Potential soil quality index	dimensionless	Land Use Related impacts
Particulate Matter emissions	Potential incidence of disease due to PM emissions	Incidence of disease	Particulate Matter (Potential incidence of disease due to PM emissions)
Ionizing radiation, human health Potential [2)]	Human exposure efficiency relative to U235	kBq U235 eq.	Ionizing Radiation - human health effects (Potential Human exposure efficiency relative to U235)

Disclaimer:

1) – The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experienced with the indicator.

2) – This impact category deals mainly with the eventual impact of low dose ionizing radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionizing radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

For all indicators mentioned in Table IV-1, the characterization factors from EC-JRC shall be applied, available at the following web-link: http://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml. They correspond to the EF 3.0 sets of methods.

Temporary remark (June 2021): *Ecoinvent datasets contain emissions to air and to water in the long-term sub-compartment. The list of characterization factors included in the "EN 15804" Excel file (cf. URL above) contains non-zero factors for these long-term elementary flows (except for human toxicity and ecotoxicity for which characterization factors are at zero for long-term emissions). Nevertheless, the EN 15804 (§ 6.3.8.2) specifies that "the time period over which inputs to and outputs from the system shall be accounted for is 100 years from the year for which the data set is deemed representative. A longer time period shall be used if relevant."*

There is potentially a lack of consistency between the list of characterization factors and this requirement of EN 15804, as it is a widespread practice to eliminate contributions from long-term emissions by setting the characterization factors to zero. Pending the answer from a CEN TC 350 expert (to be contacted by Dieter De Lathauwer) about the intention of the EN 15804 standard, and in a conservative approach, it is decided to strictly use the characterization factors of the provided Excel file and not to modify ecoinvent LCIs, i.e. to keep contributions of long-term emissions to the results.

Results for all core and additional indicators shall be provided in the project report, while in the EPD, results for some additional indicators may be marked as not declared (ND).

IV.2.2. PARAMETERS DESCRIBING RESOURCE USE

The parameters describing resource use are also taken into account in the tool and are in accordance with the EN15804+A2.

Table IV-2 : Parameters describing resource use covered by the tool (Source : EN 15804+A2)

Name	Unit
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ, net calorific value
Use of renewable primary energy resources used as raw materials	MJ, net calorific value
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	MJ, net calorific value
Use of non-renewable primary energy resources used as raw materials	MJ, net calorific value

Name	Unit
Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value
Use of secondary material	kg
Use of renewable secondary fuels	MJ, net calorific value
Use of non-renewable secondary fuels	MJ, net calorific value
Net use of fresh water	m^3

Remark: the resource use indicator "total use of non-renewable primary energy" gives the same results as the abiotic resource depletion (fossil fuels).

IV.2.3. OTHER ENVIRONMENTAL INFORMATION DESCRIBING WASTE CATEGORIES AND OUTPUT FLOWS

Table IV-3 : Parameters describing waste and output flows (Source : EN 15804+A2)

Name	Unit
Hazardous waste disposed	kg
Non-hazardous waste disposed	kg
Radioactive waste disposed	kg
Components for reuse	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	MJ

IV.3. Results

Indicator results are provided in the EPD for the whole RSL per information module.

In order to calculate the final results, the obtained values for the elementary flows per FU are multiplied by characterisation factors, such as indicated in the EN 15804+A2 standard. The results for each elementary flow inside an impact category are summed, in order to obtain a total impact for each impact category. The results of the LCA study are available for the various prefab concrete products in:

- The live results of the tool
- The EPD export
- The Excel export

"The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks."

As mentioned above (section I.3), the report is not intended to provide and discuss results.

V. Life cycle interpretation

V.1. Assumptions and limitation concerning the interpretation of the results

Several sources of limitations can be identified:

- Limitations related to methodology
- Limits related to life cycle impact assessment
- Limitations related to the model, LCI and data source that are not accessible through the tool interface
- Limitations related to the data accessible in the tool interface.

The limits related to this third category are not discussed here.

V.1.1. LIMITS RELATED TO METHODOLOGY

V.1.1.1. Consistency in allocation methods for steel and blast furnace slag

As already mentioned in II.6.2.1 and III.4.2.4, due to limited data availability, there is a difference in allocation method used for modelling the production of the various types of steel involved in the concrete precast products. Furthermore, there is no consistency with the methods used for determining the impacts to be allocated to blast furnace slag, a co-product of steel production in blast furnace.

V.1.1.2. End-of-life of products based on BE-PCR and MMG scenarios

The end-of-life of products is mostly based on scenarios available in the MMG document and horizontal Belgian PCR. Although compliant with the EN 15804+A2, these references have been elaborated in order to encompass an important range of production processes and construction products. This means that the used scenarios and used data are not specific for precast concrete products and may not reflect the reality for prefab concrete products.

V.1.1.3. Finishing of products

Due to a lack of information, finishing products and processes are not included in the tool. This can be a limit for the interpretation of the results for façade elements.

V.1.2. LIMITS RELATED TO LIFE CYCLE IMPACT ASSESSMENT

As underlined in the EN 15804+A2 standard, caution is recommended in the use of the results, in particular for the following environmental impact indicators (cf. IV.2.1):

- Depletion of abiotic resources -mineral elements
- Depletion of abiotic resources -fossil fuels
- Water scarcity
- Human toxicity, cancer effects

- Human toxicity, non-cancer effects
- Eco-toxicity (freshwater) Potential
- Land use related impacts/ Soil quality

Uncertainties arise from the robustness of the methods and from the potential lack of completeness of LCIs for these indicators (cf. III.4.2.5).

Furthermore, regionalized characterization factors are included for the following indicators:

- Acidification
- Eutrophication - terrestrial
- Water use
- Land use

The spatial differentiation can however not be taken into account in the EPD results since the ecoinvent database and other data sources do not include regionalized flows (only the datasets provided by Worldsteel contain regionalized elementary flows).

V.1.3. LIMITS RELATED TO DATA

In a general manner, the data quality assessments and data influence on results in section III.4 indicate the limitations concerning the interpretation of the results.

V.1.3.1. Problems of datasets with specific impact categories

Two points can be raised:

- The values of the elementary flow "Tellurium - Resources from ground" have increased in many ecoinvent 3.7.1 datasets by a factor of 1E5 or more compared to ecoinvent version 3.5. Consequently, tellurium becomes the most contributing flow to the category "Resource use, minerals and metals, EF". Its contribution is typically one order of magnitude higher than the contribution of the most contributing flow of the 3.5 dataset (e.g. gold or copper). In total, the LCIA results of the activity can increase by a factor 2 o 3 for example.
- In module D, the avoided production of aggregates thanks to waste concrete recycling is modelled using the ecoinvent data for "gravel and sand quarry operation" (reference product: gravel, round); which is not used in the A1 module. This data is used as conservative approach (limiting benefits in module D) for most impact categories but not for Water resource depletion. The benefits might be overestimated for this water scarcity indicator since, for some of the studied products, they make the total results negative for this category.

V.1.3.2. Use of data from EPDs

For cement production, peer reviewed EPDs are used for calculating the environmental impacts instead of LCI datasets.

V.1.3.3. Use of proxy data

The production or end-of-life treatment of some materials is modelled by approximating datasets (cf. Table III-33). In most cases, it has a very small influence on the results.

The choice of the type of steel for modelling anchors or bolts or nuts can however have a significant influence for the products including such elements.

V.1.3.4. Lubricating oil and pigments

The impact of some products may still be overestimated in this version of the tool. In following cases, the lack of data of higher quality is the cause.

The data used for the modelling of lubricating oil, which is used to remove the product form the formwork, is based on aged data (2000) (see Table III-33). The recent evolution in the sector of lubricating oil has made these products more organic-based, namely containing thus less CFC.

The use of organic pigments for precast concrete products is increasingly becoming common practice. The used LCI data still make use of aged LCI, which are specific to non-organic and fossil fuel-based pigments. This means that the current LCI data that is used is a conservative value for pigments.

V.1.3.5. Type of energy for installation

The tool does not give access to the type of energy used on the building site for vibration, compaction and transport on the site (crane). Only electricity consumption is modelled.

V.2. Variability of the results for collective EPDs

In the current development of average EPDs by FEBE, a typical or most representative product, with defined dimensions, has been associated with each functional unit. This product can be produced by several manufacturers and/or at different sites.

The corresponding collective EPDs have to follow the requirements described in EN 15804 (cf. 8.2.f.3)[32] and B-EPD PCR (A 32 for the EPD and A 46 for the project report). This section presents the results of the required sensitivity analysis.

V.2.1. GENERAL ASPECTS

The approaches for determining average data used in the collective EPDs have been described in II.4, as well as the way they are considered to vary among the producers involved in a collective EPD (cf. Table II-3). Three scenarios are defined:

- Default, with average data
- Max, with parameter values resulting in maximum impacts
- Min, with parameter values resulting in minimum impacts

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[32] *"the variance from the means of LCIA results should be described, if generic data are declared from several sources or for a range of similar products;"*

The analysis of variability has been performed on 13 products installed in Belgium, selected for covering all of the 10 concrete recipes as well as cases with or without steel reinforcement, prestressing, pigment, white cement or insulation.

The variability is communicated on the total results, in percentage. In practice, the results of all modules studied in the EPD (including module D) are summed for each of the 3 scenarios. The ratios of the min and max scenarios on the default are reported in %.

The amplitude of the interval between the min and max ratios depends mainly on:

- the relative contributions of modules A1-A3 to the total results, since variability is only modelled for these modules. For example, if module A5 has a high impact (independently of packaging end-of-life), it will reduce the variable part of the results
- the variability of cement composition in the concrete recipes.

V.2.2. MOST INFLUENCING PARAMETERS

According to B-EPD PCR (cf. A 29), the EPD has to include information on the most influencing parameters in the LCA.

The relative contributions of each module are first discussed for the environmental impact "climate change -total". For most products, the contribution of cement production in module A1 dominates the climate change results. Exceptions to this observation occur in cases where a large amount of materials is used in module A5 for installation (e.g. for the fibered pipe or the prestressed floorplate). For prestressed products, the climate change impacts associated with the production of virgin steel can be of the same order of magnitude as the cement production. Considering contributions in decreasing order of magnitude, reinforcing steel and/or insulating material come next, if present in the product. The other steps contribute less, with magnitudes depending on the product type.

Parameters contributing to other impact categories with a ranking very different from climate change results are pointed here:

- Particulate matter: the module C1 (demolition) dominates the results due to PM emissions modelled using ecoinvent data, recommended by the MMG document ("Milieuprofiel van gebouwelementen", OVAM, 2013).
- Stratospheric ozone depletion: dominating contributions are observed from energy consumption in module A3 and for A1-insulation. These impacts come namely from halon 1301. This elementary flow is still present in ecoinvent datasets, although this compound was completely phased-out by 2010. The relative contribution of cement to this environmental impact is very small.
- Abiotic resource depletion – elements: Steel production can become the most contributing step (in cases of reinforced or prestressed concrete and especially in the presence of anchors, modelled as stainless steel).
- Water depletion: sand and aggregate extractions bring major contributions to module A1 and module D (in absolute value).

- Land use: sand and aggregates as well as packaging can become the most contributing steps.
- Acidification: pigments contribute, in relative, much more to this impact category (due to SO2 emissions, when producing titanium oxide through the sulphate process).
- Eutrophication – freshwater: The relative contribution of cement to this environmental impact is very small.

V.2.3. CLIMATE CHANGE: VARIABILITY OF THE 13 PRODUCTS

The variability of the results for "climate change – Total" is studied among the scenarios default, max and min. Figure 7 shows the ratios of the default, max and min scenarios for the 13 products. For each product, the default scenario corresponds to 100%. Figure 8 is equivalent except that the variability of module A3 (the manufacturing part) is suppressed, by taking the average values of energy use for the min and max scenarios. The variability of the results including module A3 is likely between the situations of Figure 7 and Figure 8 since for one product, the variability among producers is probably lower than among the different products.

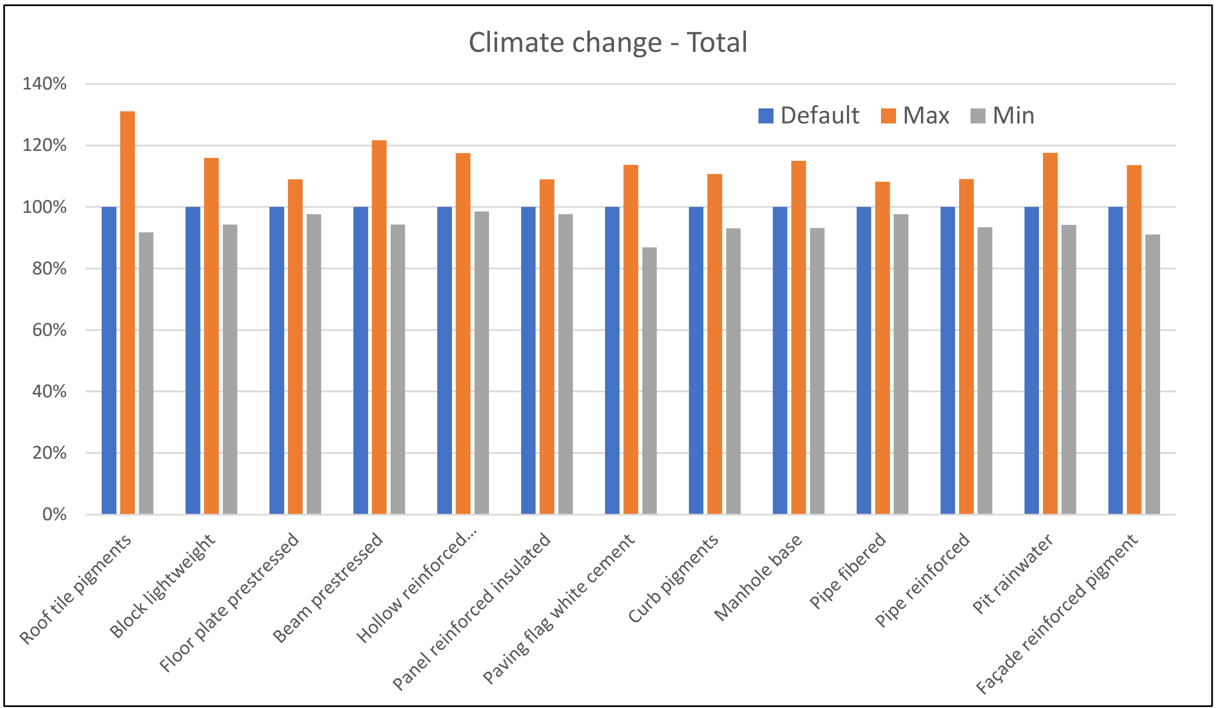


Figure 7 : Climate change - Total: Min-max results for 13 products

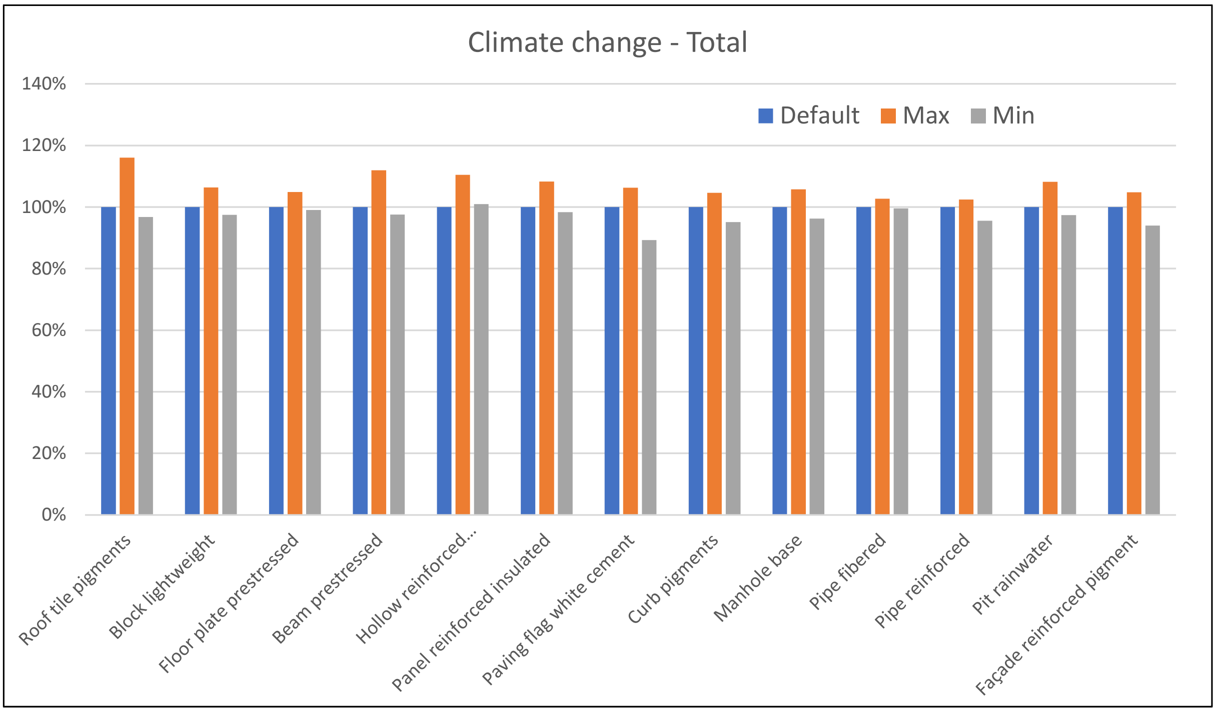


Figure 8 : Climate change - Total: Min-max results for 13 products without variability of module A3 (manufacturing energy)

Table V-1 describes for each product the modules that contribute most to the total impacts as well as the modules that contribute most to the variability of the results (among the parameters taken variable).

Table V-1: Contributions of the modules to climate change - total, by decreasing order of magnitude

Product	Absolute contribution	Contribution to variability	Comments
Roof tile pigments	A1_Cement > A5 > A3_Packaging > B1	A3_energy > A1_Cement > A2 >> A1_pigments, A5	In the max scenario, there is 125% of cement in the recipe versus the default composition, which represents a higher variability of cement (at the upper bound) compared to other recipes.
Block lightweight	A1_Cement > A1_aggregates (coarse, artificial) > A5 >> A2, A4	A3_energy > A1_Cement, A1_agregates > A2	
Floor plate prestressed	A5 (casting mortar) >> A1_Cement > A1_steel > D	A3_energy, A1_Cement > A1_steel, A2	
Beam prestressed	A1_Cement, A1_steel > D	A3_energy > A1_Cement > A1_steel, A2 > D	Variability in % is higher than for floor plate prestressed, because A5 is much lower for the beam
Hollow reinforced insulated	A1_Cement > A5 > A1_insulation > A1_steel > C4	A3_energy > A1_Cement > A2	
Panel reinforced insulated	A1_Cement > A1_steel > A1_insulation > C4	A3_energy > A1_Cement > A2 > A1_steel	
Paving flag white cement	A1_Cement >> A2 > A3_energy, A5 > A4	A3_energy > A1_Cement > A2	
Curb pigments	A1_Cement > A5 >> A1_pigment, A2 > A3_energy	A3_energy > A1_Cement > A2 > A1_pigment	
Manhole base	A1_Cement >> A5 > A2, A3_energy, A4	A3_energy > A1_Cement > A2	

Pipe fibered	A5 > A1_Cement >> A1_steel , D	A3_energy > A1_Cement, A2 > A1_steel	
Pipe reinforced	A1_Cement > A5 >> A4, > A2, A1_steel, C1	A3_energy, A1_Cement > A2	
Pit rainwater	A1_Cement >> A1_steel > A4, A2 , A3_energy, A5	A3_energy > A1_Cement > A2	
Façade reinforced pigment	A1_Cement > A1_steel > A1_pigment > A5 , A4 , A3_energy, A2	A3_energy > A1_Cement > A2 > A1_pigment	

For climate change, min and max results vary in the range of -9% to +18% for most products. Min or max results are observed outside this range for:

- roof tile with pigments (+31%), because there is a large variation in cement content for this concrete recipe, at the upper bound, and the cement production dominates the results for this product;
- prestressed beam (+22%), because steel production contributes as much to climate change results than cement production and other steps contribute much less; the variability of both steps adds to each other;
- paving flag with white cement (-13%), because there is a large variation in cement content for this concrete recipe, at the lower bound, the white cement production dominates by far the results for this product.

The discussion of the variability that will be added to each EPD is illustrated in the next section for one product.

V.2.4. VARIABILITY FOR TILES WITH PIGMENT

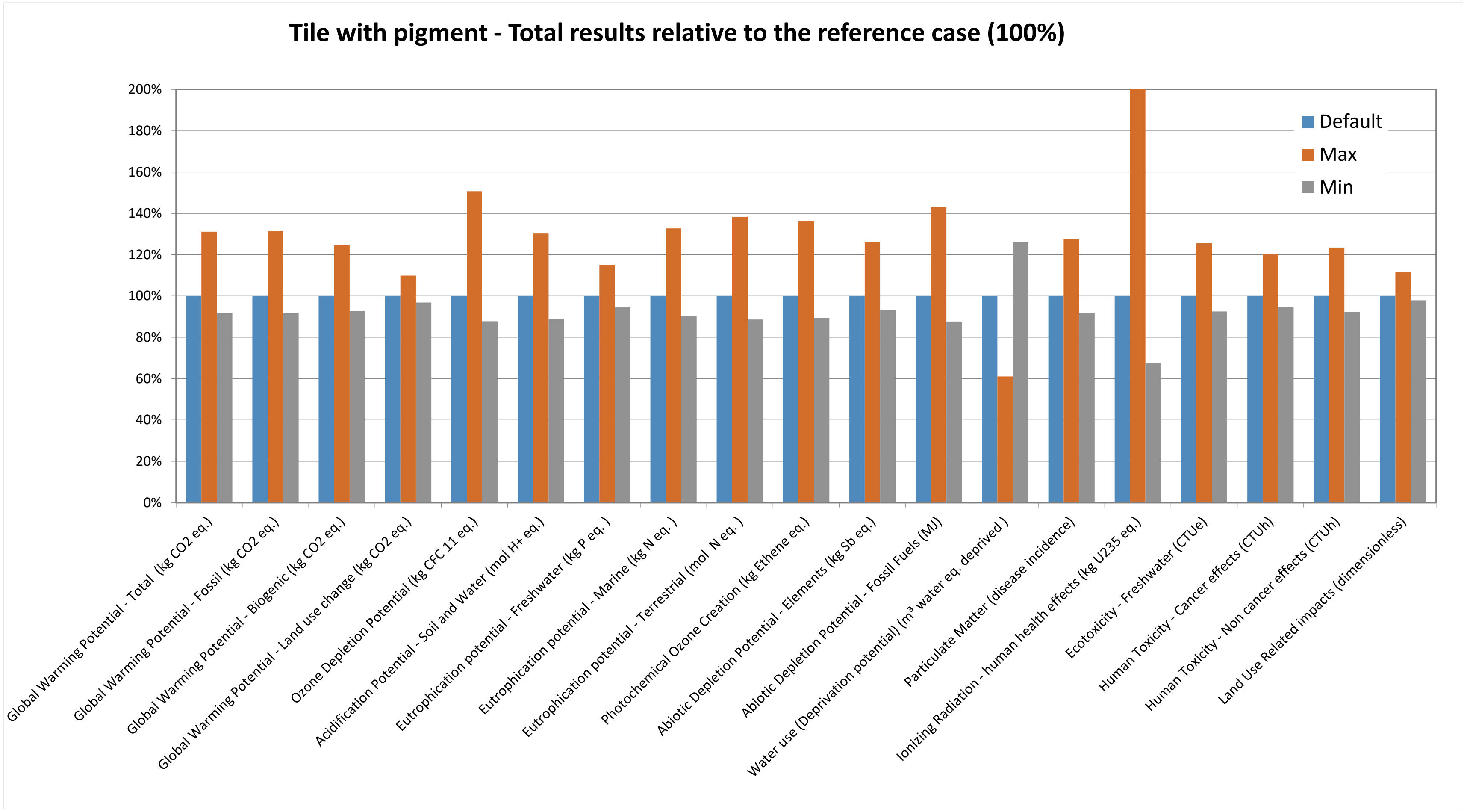


Figure 9: Variability of results for tiles with pigment for all impact categories

Looking at the ratio for all environmental impact indicators, the lower and upper bounds of ratios lie within the interval for "climate change -Total", except for the following impact categories:

- Ionising radiation: through nuclear power, electricity use at manufacturing (A3) contribute far more, in relative, to ionising radiation impacts than for other impact categories. The interval of variation is more sensitive to the large variability considered for this module.
- Ozone depletion, Abiotic depletion – fossil, Eutrophication – freshwater, Eutrophication – marine and Photochemical Ozone Creation: due to a higher relative contribution of module A3 – energy to the total results for these indicators, the ratios of variability are still higher than for climate change.
- Resource depletion – water: with the current modelling, total results are negative because of module D. Indeed, the process "gravel, round" is used for modelling the gravel avoided by waste concrete recycling. This process has a high contribution to this impact category, which sur-compensates all water depletion from all other modules. The choice of this dataset is conservative for other categories like GWP but not for water depletion.

V.3. Data quality assessment

Data sources and data quality assessment have already been discussed and are available in section III.4 (and Appendix 5).

V.4. Value-choices, rationales and expert judgement

Majority of value-choices, rationales and expert judgement are based on existing documentsIII.2.6. The table below gives an exhaustive list of the sources for value-choices.

Table V-2 : List of the sources for the value-choices

Module	Parameter	Source/expert
Module A1	product/concrete composition	User of the tool and FEBE expert judgement
Module A2	distances and transport type	User of the tool and FEBE expert judgement
Module A3	manufacturing data	User of the tool and survey with 15 producers
	packaging data	User of the tool and FEBE expert judgement
Module A4	distances and transport type to the construction site	B-EPD PCR (BE) and *Bepalingsmethode* (NL) and user of the tool
Module A5	materials for the installation into the building	User of the tool and FEBE expert judgement and estimations

Module	Parameter	Source/expert
	energy consumption for the installation into the building	User of the tool and RDC hypothesis
	Disposal rates of packaging	B-EPD PCR
	Losses of product during A4+A5	FEBE expert judgement and existing EPDs
Module B1	carbonation process	PCR on concrete products (EN 16757:2017)
Module B2	Maintenance of products	PCR EN 16757:2017 and FEBE expert judgement
Module B3	/	Module considered as not relevant
Module B4	/	Module considered as not relevant
Module B5	/	Module considered as not relevant
Module B6	insulation energy savings	Not considered in the EPD tool (for avoiding double counting when assessing the performances at the building level)
Module B7	/	Module considered as not relevant
Module C1	Deconstruction and demolition process and rates	MMG document (BE) and *Bepalingsmethode* (NL)
Module C2	Transport distances	B-EPD PCR (BE) and *Bepalingsmethode* (NL)
Module C3	Waste processing	MMG document and B-EPD PCR (BE); Bepalingsmethode (NL)
Module C4	Waste disposal rates	B-EPD PCR (BE) and *Bepalingsmethode* (NL)
Module D	Recycling rates	B-EPD PCR (BE) and *Bepalingsmethode* (NL)
	Carbonation process	PCR EN 16757:2017
	Energy savings	B-EPD PCR (BE) and *Bepalingsmethode* (NL)

VI. Appendices

VI.1. Appendix 1: Compliance of the project report to the EN 15804+A2 requirements

Information (as required by the EN15804+A2)	Document/source
General aspects (I)	
Commissioner LCA study, internal or external practitioner of the LCA study	Project report, section I.1
Date of report	Project report, footer
Statement that the study has been conducted according to the requirements of the EN 15804	Project report, section I.2
Goal of the study (II)	
Reasons for carrying out the study and its intended application and audience	Project report, section I.2
Scope of the study (III)	
Declared/functional unit (a)	
Definition and technical data	Project report, section II.1
Calculation rule for averaging data e.g. when declared/functional unit is declared for - A group of similar products produced by different suppliers - The same product produced at different production sites	Project report, section II.4
System boundary according to modular approach (b)	
Omissions of life cycle stages, processes or data needs	Project report, section II.3
Quantification of energy and material inputs and outputs, taking into account how plant-level data is allocated to the declared products	Project report, section II.6.1
Assumptions about electricity production and other relevant background data	Project report, section III.2.12, and section III.2
Assumptions about the system boundaries should be included where relevant including how the net impacts are calculated in module D	Project report, section III.2.10
Cut-off criteria for initial inclusion of inputs and outputs, including (c)	
Description of the application of cut-off criteria and assumptions	Project report, section II.5
List of excluded processes	Project report, section II.5.2 and III.2

Life cycle inventory analysis (IV)	
Qualitative/quantitative description of unit processes necessary to model the life cycle stages of the declared unit, taking into account the provisions of EN ISO 14025 regarding data confidentiality	Project report, section III.2
An overview shall be given of the removals, emissions, transfers of biogenic carbon in the different modules, between product systems and of the biogenic carbon content of the functional or declared unit at factory gate	Project report, section III.2.13
Sources of generic data or literature used to conduct the LCA	Project report section, III.2 & III.3
Data quality assessment	Project report sections III.3 & III.4
Treatment of missing data	Project report section III.4.3
Documentation and justification of allocation procedures	Standard EN15804+A2, Project report section II.6
Uniform application of allocation procedures	
Life cycle impact assessment (V)	
LCIA procedures, calculations and results of the study	Project report, section IV.2
The relationship of the LCIA results to the LCI results	Project report, section IV.1
Reference to all characterization models, factors and methods used	Project report, section IV.2
A statement that the LCIA results are relative expressions	Project report, section IV.3
Life cycle interpretation (VI)	
Results	Not in the project report (cf. section IV.3)
Assumptions and limitations associated with the interpretation of results as declared in the EPD, both methodology and data related	Project report, section V.1 *Not applicable: data related interpretation*
The variance from the means of LCIA results should be described, if generic data are declared from several sources or for a range of similar products	Project report, section V.2
Data quality assessment	Project report, section III.4
Full transparency in terms of value-choices, rationales and expert judgements	Project report, section V.4

VI.2. Appendix 2: Modelling of transport

VI.2.1. TRANSPORT BY TRUCK (IN BELGIUM)

VI.2.1.1. Belgian model

Fuel consumptions and airborne emissions

Fuel consumptions and airborne emissions from trucks are obtained from the COPERT 5 tool and methodology (version 5.2.2).

COPERT is the EU standard vehicle emissions calculator. It uses vehicle population, mileage, speed and other data such as ambient temperature and calculates emissions and energy consumption. COPERT's methodology is published and peer-reviewed by experts of the UNECE LRTAP Convention. COPERT 5 is based on the "EMEP/EEA air pollutant emission inventory guidebook 2016 – Update Jul. 2018" (published by LRTAP and EEA).

COPERT estimates emissions of all major air pollutants (CO, NOx, VOC, PM, NH_3, SO_2, heavy metals) produced by different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles) as well as greenhouse gas emissions (CO_2, N_2O, CH_4). Emissions estimated are distinguished in three sources: Emissions produced during thermally stabilized engine operation (hot emissions), emissions occurring during engine start from ambient temperature (cold-start and warming-up effects) and NMVOC emissions due to fuel evaporation. Non-exhaust PM emissions from tyre and break wear are also included. The total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by the software.

For the FEBE model, COPERT data is extracted as emissions and fuel consumption calculated per kilometre driven by a fully loaded vehicle and for a slope equal to zero. Results can be distinguished in function of:

- size of the vehicle (gross weight)
- euro standard
- driving / traffic conditions:
  - rural (average speed for heavy duty vehicle of 82 km/h)
  - urban (average speed for heavy duty vehicle of 25 km/h)
  - highway (average speed for heavy duty vehicle of 91 km/h, not used in the model)

Maximum payload and gross weight

The size of the trucks depends on the type of transport. Table VI-1 presents the maximum payload of trucks used in the model in function of the transport step as well as the name of the corresponding trucks in the COPERT tool.

Table VI-1: Truck modelling in function of the maximum payload

Transport steps	Truck maximum payload		
	20t	24t	30t
Available selection of maximum payload			
A2 (from raw material producer to factory)	x	x	x
A4 (from factory to installation site)		x	
Other steps (Transport of waste)		x	
Modelling of truck using COPERT data			
Type of truck	Articulated	Articulated	Articulated
Gross vehicle weight according to COPERT classes	28-34t	34-40t	40-50t

Euro standards

For all type of trucks and of transport steps, the same mix of euro standards is used for the fleets (cf. Table VI-2).

Table VI-2: Euro standard mix

Euro standard for trucks	Share in fleet mix	Source
Euro 3	11%	Estimation based on vehicle age data from Eurostat for Europe in 2017
Euro 4	19%	
Euro 5	28%	
Euro 6	46%	

Type of area and traffic conditions

For most transport types, it is assumed by simplification that 100% of the distance is driven in rural area.

Parameters accessible in the interface and impact formula

Primary data can be used for the following parameters, available in the tool interface:

- Distance
- Max payload (choice only for module A2 transport)
- Effective payload (assumed to be full load for all transport steps, except for A4)

The following formula relates the COPERT data to the impacts associated with the functional unit, in function of the mentioned parameters.

Consumption or emissions per functional unit =

Number of trucks * Distance * (0.7+0.3*payload/max_payload + Empty_return_rate * 0.7) * x

Considering that:

- The number of trucks (or fraction of truck) is obtained as the weight to be transported per functional unit divided by the effective payload (e.g. if 2 kg have be transported per functional unit in a truck loaded at 20 t, the number of truck is 2E-03 / 20 = 1E-04)
- impacts for empty trucks amount 70% of those of trucks at full loading (the factor 70% is a coarse average value derived from the Copert 4 methodology by considering a set of trucks of various gross vehicle weights for both speed used respectively for rural and urban transportation).
- the 30% remaining varies linearly with the ratio of load to maximum payload (the hypothesis of linearity comes from Copert 3 methodology).
- Empty return rate is fixed in the model, at a value of 27% (European average).
- x is either the fuel consumption or the emissions of the fully loaded truck per km, obtained from COPERT.

VI.2.1.2. Infrastructure for trucks

A common modelling of infrastructure is adopted per vkm (vehicle.km), meaning that, by simplification, it does not depend on the size or effective loading of the truck. Table VI-3describes the included activities as well as the LCI and activity data used.

Table VI-3: Modelling of infrastructure for transport by truck

Type of infrastructure	Name of ecoinvent LCI (v3.7.1)	Unit of the process	Demand factor for 1 vkm (ecoinvent v2)	Calculation
Truck manufacturing and disposal	lorry production, 40 metric ton	unit	1.85 E-06	Vehicle lifespan = 540 000 km
Truck maintenance	maintenance, lorry 40 metric ton	unit	1.85 E-06	Vehicle lifespan = 540 000 km
Construction of roads (and road disposal)	road construction	ma (meters * year)	0.0085	Cf. comment of the ecoinvent 3.7.1 dataset (Allocation of European road network based on the part of gross ton.km driven by lorry >16t, according to ecoinvent data – ecoinvent v2, report n°14 Transport)
Maintenance of roads	road maintenance	ma (meters * year)	0.00129	Cf. comment of the ecoinvent 3.7.1 dataset

VI.2.1.3. Dutch model

The Dutch model follows the requirement of the *Bepalingsmethode*, meaning the use of the specific LCI *"Transport, freight, lorry, unspecified, GLO"* from ecoinvent.

VI.2.2. TRANSPORT BY TRAIN

In the tool, transport by train is only considered in module A2. Train is assumed to be fully electric.

The gross ton km (Gtkm) associated with the functional unit is determined as follows:

Gtkm per functional unit = Weight to be transported * Distance * (payload + tare)/payload

Considering that:

- Payload is the load in a wagon. In A2, wagon are considered loaded at full load, i.e. 54t (source: EcoTransIT 2019 for building materials)
- The tare of the wagon is fixed at 22t (source: source: EcoTransIT 2019 for building materials)

The energy consumption associated with the transport by train is calculated with the help of the following equation:

Energy consumption per functional unit = Gtkm per functional unit * specific energy consumption per Gtkm

The modelling of the specific energy consumption is based on the EcoTransIT methodology (source: EcoTransIT– Ecological Information Tool for Worldwide Transports – Methodology and Data; Update 2019). The energy consumed per gross ton km (Gtkm) is related to the gross ton weight of the whole train (GTW) by the following equation:

$$\text{Specific energy consumption [Wh/Gtkm]} = 1200 * GTW^{-0,62}$$

In the tool, the GTW is fixed at the value of 1 000 t, representing the typical average gross weight for international trains (source: EcoTransIT 2019, citing UIC 2009). Hence the specific energy is equal to 16.6 Wh/Gtkm.

The modelling of infrastructure, per Gtkm (gross ton km), is described in Table VI-4, with the included activities as well as the LCI and activity data used.

Table VI-4: Modelling of infrastructures for train

Type of infrastructure	Name of ecoinvent LCI (v3.7.1)	Unit of the process	Demand factor for 1 Gtkm	Source of the demand factors
Train manufacturing and end-of-life	locomotive production (including end-of-life)	unit	2.96E-10	Demand factors per Gtkm are obtained from the UPR of the ecoinvent activity "transport, freight train, electricity, Europe without Switzerland" (same as for diesel trains). The reference product of this dataset is 1 tkm. The demand factors of the UPR are divided by a factor 2.4 for obtaining the demand factor per Gtkm. The source of this value of 2.4 is the ecoinvent v2 report n°14 "Transport" (Table 6.1, line "Ratio gross tonne/carried goods").
	Goods wagon production	unit	1.91E-08	
Train maintenance	maintenance, goods wagon	unit	1.91E-08	
	maintenance, locomotive	unit	2.96E-10	
Construction, maintenance and end-of-life of tracks	railway track construction (including maintenance and end-of-life)	ma (m*year)	3.88E-05	

VI.2.3. TRANSPORT BY BARGE

The impacts of the transport by barge are based on the ecoinvent data "transport, freight, inland waterways, barge". This inventory is based on the consumption of 9.39 g of fuel per tkm.

Our modelling combines, in a fixed ratio, large barges (> 1500 t) and small barges (< 1500). The consumptions of fuel for both types (at average loading) are derived from data provided by a study of CE Delft in 2011.[33] Each type of barge is modelled by the mentioned ecoinvent process in proportion of the fuel consumption. Infrastructure is further modelled according to Ecoinvent report n°14 – Transport.

The parameter available in the tool is the distance.

The modelling is summarized in the following equation:

$$\text{Consumption} = \text{Distance} * x*(0.45*6.8+ (1-0.45)*10.4)/9.39\ (1+ \text{Empty\_return\_rate} * 0.6)$$

With x, the ecoinvent process for barge

0.45, the share of large barges (derived from ecoinvent v2 report 14)

[33] CE Delft. "Comparison of various transport modes on a EU scale with the STREAM database", July 2011

6.8 and 10.4, fuel consumption in g/tkm respectively for large and small barges (according to CE Delft 2011)

Empty_return_rate, fixed at a value of 80% (assumption)

0.6, the fuel consumption of an empty barge (source: Eco-transit 2010)

Remark: Barges are only modelled for transport in module A2. They are assumed to be fully loaded, which is most likely the case for raw material transport in A2.

VI.2.4. TRANSPORT BY CONVEYOR BELT AND/OR PUMPING

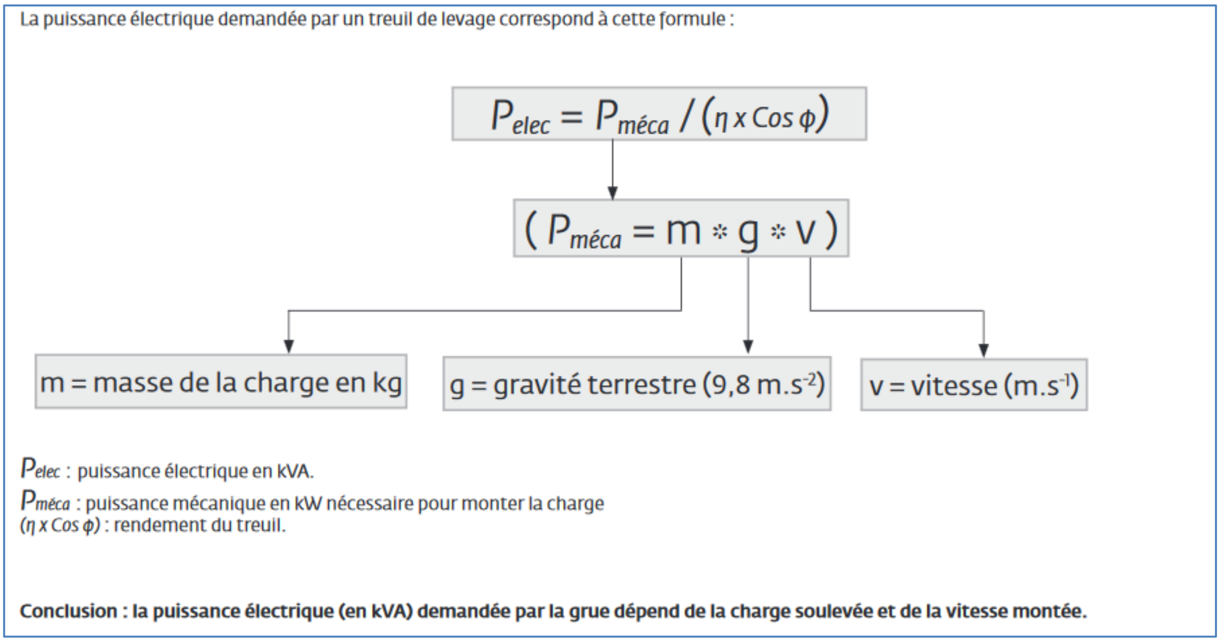
Pumping and conveyor belts are used for the transport of raw materials inside the manufacturing plant. The necessary energy for the use of these transport modes is however already included in the electricity consumption of the manufacturing plants. Concerning the infrastructures necessary for these kinds of transport, they have not been accounted for in this tool.

VI.3. Appendix 3: Main assumptions

Module A5: Transport on the construction site

The assumption has been made that ancillary materials and products are transported using a crane. The calculations for necessary energy for the crane are calculated based on a commercial document[34].

This document gives information on the energy requirement of a crane and how to calculate them. Following formulas have been used.



[34] Manitowoc : Potain - Alimentation électrique gamme 2012, Guide Produit - Réf : 608 2012 04 FR

La consommation électrique d'un treuil de levage correspond à cette formule :

$$E_e = \frac{m * g * h}{\eta * 3\,600\,000}$$

E_e : Consommation électrique en kWh.

m = Masse de la charge en kg.
g = Gravité terrestre (9,8 m.s-²).
h = Hauteur en m.

η = Rendement global du treuil.
3 600 000 = (60 min/h x 60 s/min) x 1000 (W->kW).

Il est intéressant de constater que la consommation d'énergie électrique ne dépend ni de la vitesse, ni de la puissance mécanique (en ch) du treuil.

These formulas allow to calculate both the necessary power of the crane, as well as the electric consumption. These formulas have been used, with following values:

- Height = 20m
- Yield (n) = 0.77

The obtained value for electric consumption, per kg = **7.07071E-05 kWh/kg**

The used value in the model is a conservative value, rounded at 1E-04 kWh/kg

Module A5: Vibration, compaction and pumping of materials

As explained in the report, ancillary materials such as sand, concrete or mortar need to be vibrated (in order to eliminate air bubbles), compacted (in order to stabilize and eliminate air bubbles) and pumped for good use.

The assumptions made in order to calculate the necessary energy for these operations are based on FEBE expert judgement.

Table VI-5 : Default values for vibration + compacting of ancillary products

Parameter	Unit	Value	Source
Power	W	1400	FEBE expert judgement
Time needed per m^3 ancillary material	min/m3	10	FEBE assumption
Total consumption	kWh/m3	**0.233**	Calculation: 1400/1000/(60/10) =0.233

per m^3 ancillary material			

For pumping, there is no default value for generic EPDs. (For specific EPDs, energetic consumption can be added to consumption for vibration or compaction).

Module C1: Modelling of water consumption during destruction

During the destruction of prefab concrete products, water is used in order to retain the particulate matter that is produced by the breakage. In order to make conservative assumptions, the following scenario has been adopted to calculate the water consumption:

The used hypothesis for the calculation of water use is that since water consumption has as goal to impede the emission of dust during the destruction of products, at least the same amount of water as the amount of dust produced is needed. In order to be conservative on this aspect, this initial amount has been multiplied by 100.

As a reminder:

Table VI-6 : Values of dust production for demolition of products (Source: MMG)

Parameter	Unit	Value
Demolition scenario		
Emission of particulate matter: PM < 2.5 µm	kg/kg material	$1.66*10^{-5}$
Emission of particulate matter: PM >2.5 µm & <10 µm	kg/kg material	$6.34*10^{-5}$
Emission of particulate matter: PM > 10 µm	kg/kg material	$8.35*10^{-5}$
TOTAL emission of particulate matter	kg/kg material	$16.35*10^{-5}$
TOTAL water consumption	l/kg material	$16.35*10^{-3}$

The used value in the model is thus of **0.0164 l of water/kg of material**.

VI.4. Appendix 4: Reaching the end-of-waste state

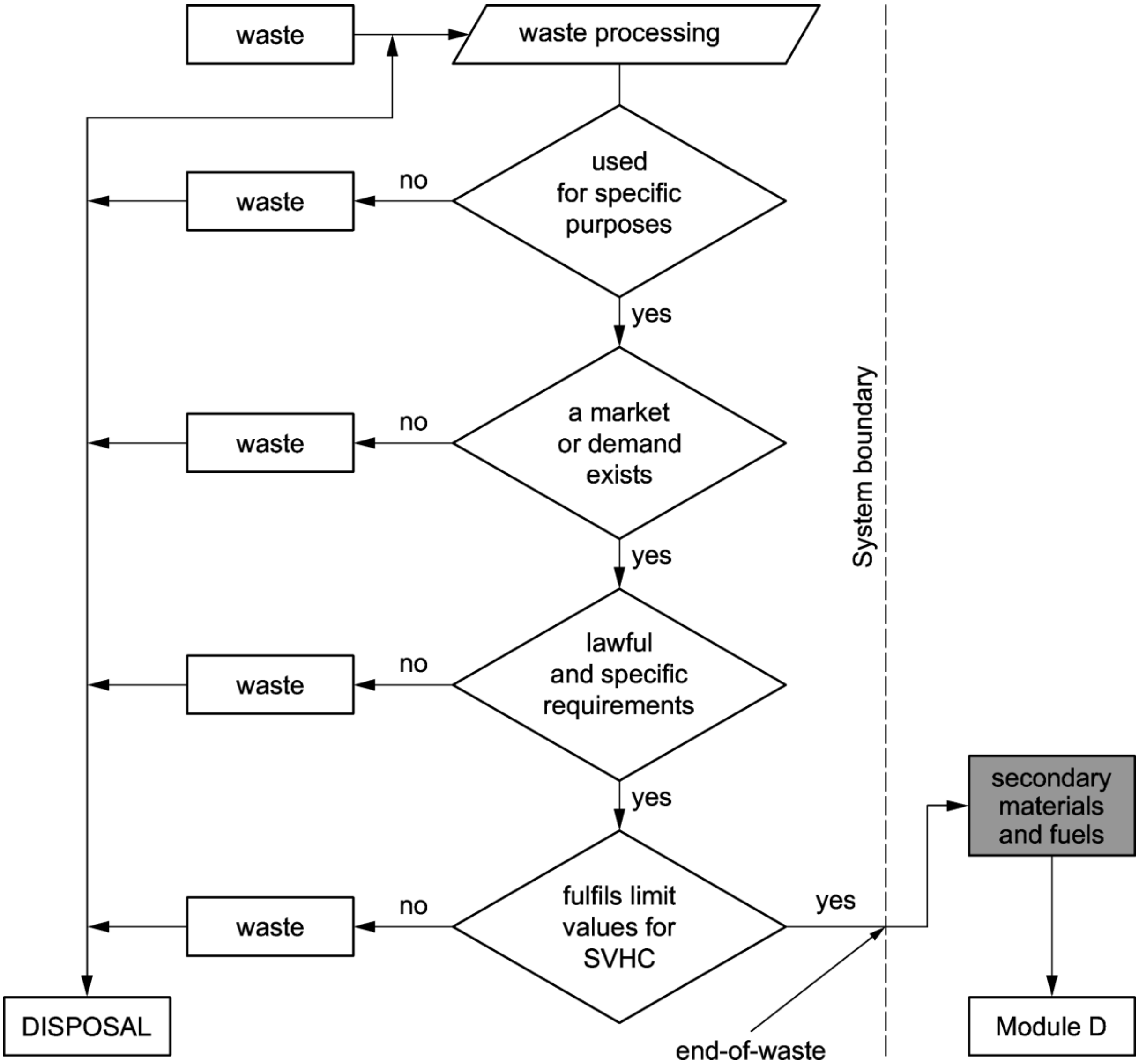


Figure 10 : Schematic representation of the end-of-waste state (Source: EN15804+A2)

The reaching of the end-of-waste state has been done according to the EN15804+A2 standard.

VI.5. Appendix 5: Application of DQA principles – secondary data

The representativeness of the LCI regarding geography, technology and time is assessed according to the levels defined in Table III-34. The influence of data on the results is mostly based on results obtained for the environmental impact "climate change", which constitutes a limit of the DQA.

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Module A1								
Cement – CEM I	CEMBUREAU EPD	"Portland Cement (CEM I) produced in Europe – CEMBUREAU"	2016	2020	2	1	2	+++
Cement – CEM II	CEMBUREAU EPD	"Portland-composite cement (CEM II) produced in Europe – CEMBUREAU"	2016	2020	2	1	2	+++
Cement – CEM III	CEMBUREAU EPD	"Blast furnace cement (CEM III) produced in Europe – CEMBUREAU"	2016	2020	2	1	2	+++
Cement – CEM V	EI 3.7.1	"Cement production, blast furnace slag 18-30% and 18-30% other alternative constituents, Europe without Switzerland"	2005-2020	2020	2	2	4	+++
White cement	EPD Aalborg	"Aalborg White® Cement". EPD published by Aalborg in 2021 for white cement produced in Denmark	2020	2021	3	1	1	+++
Fly ashes		No dataset associated since according to the allocation method, these products are considered as co-products from other processes, with no economic values (cf. II.6.2.1)						
Blast furnace slags	Worldsteel + EI 3.7.1	Data from Worldsteel 2014 + Impacts of granulation and grinding: "ground granulated blast furnace slag production – RoW"	2007 + 2001-2020	2014+ 2020	2	1	2	++
Limestone fillers	EI 3.7.1	Limestone production, crushed, washed - RoW	2000-2020	2020	2	2	5	+
Artificial aggregates (coarse granulates)	EI 3.7.1	Expanded clay production - DE	1995 - 2020	2020	3	2	5	++
Natural aggregates (coarse granulates)	EI 3.7.1	Gravel production, crushed – CH (with electricity mix of CH replaced by Europe without Switzerland)	2013-2020	2020	2	1	3	+

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Recycled aggregates (coarse granulates)	EI 3.7.1	"Treatment of waste concrete gravel, sorting plant – RoW" (without 'inert waste' processes) after subtraction of "treatment of waste concrete gravel, recycling"	1997 - 2020	2020	2	2	5	+
River/sea sand	EI 3.7.1	Sand quarry operation, extraction from river bed - RoW	2015-2020	2020	2	1	2	+
Quarry sand	EI 3.7.1	Gravel and sand quarry operation – sand – CH (with electricity mix of CH replaced by Europe without Switzerland)	1997 - 2001	2020	2	2	5	+
Crushed sand (temporarily "Quarry sand" in the tool interface)	EI 3.7.1	Gravel production, crushed – CH (with electricity mix of CH replaced by Europe without Switzerland)	2013 - 2020	2020	2	1	3	+
Pigment – carbon black	EI 3.7.1	Carbon black production - GLO	2000-2020	2020	2	3	5	+
Pigment – cobalt	EI 3.7.1	Cobalt production - GLO	2011-2020	2020	2	2	3	+
Pigment – chromium oxide	EI 3.7.1	Chromium oxide production, flakes - RER	2000-2020	2020	2	3	5	+
Pigment – titanium dioxide	EI 3.7.1	Market for titanium dioxide - RER	1997 - 2020	2020	2	2	5	+
Insulation – extruded polystyrene	EI 3.7.1	Polystyrene production, extruded, CO2 blown - RER	1994 - 2020	2020	2	1	5	++
Insulation – expanded polystyrene	EI 3.7.1	Polystyrene production, expandable - RER	2001-2020	2020	2	1	5	++
PUR	EI 3.7.1	Polyurethane production, rigid foam - RER	1997 - 2020	2020	2	1	5	++
PIR	EI 3.7.1	Polyurethane production, rigid foam - RER	1997 - 2020	2020	2	3	5	++
Reinforcing steel	EI 3.7.1	steel production, electric, low-alloyed – Europe without CH & AT	2013-202019	2020	2	2	3	+++

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
		+ hot rolling, steel – Europe without AT	97-2020				5	++
Steel for prestressing and steel fibres	Worldsteel	Steel wire rod	2012-2015	2019	2	1	3	+++
Steel for anchors	EI 3.7.1	steel production, chromium steel 18/8, hot rolled - RER	2000	2020	2	2	5	++
Manufacturing anchors	EI 3.7.1	Market for metal working, average for chromium steel product manufacturing GLO	2011	2020	2	2	3	+
Entraining admixtures	EI 3.7.1	plasticiser production, for concrete, based on sulfonated melamine formaldehyde GLO	2014	2020	2	4	3	+
Waterproofing admixtures					2	4	3	+
Set accelerators					2	4	3	+
Set retarders					2	4	3	+
Plastifiers and superplastifiers					2	2	3	+
Hardening accelerators					2	4	3	+
Synthetic rubber	EI 3.7.1	Synthetic rubber production - RER	1997-2020	2020	2	1	5	+
Release agent	EI 3.7.1	Lubricating oil production - RER	2000-2020	2020	2	1	5	+
Transport by truck – Modules A2, A4, A5, C2, C4, D; Train & barge: Module A2								
Truck transport operation	Copert 5 tool (v5.2.2)	Fuel consumption and on road emissions of truck (in function of euro standards and maximum payload)	2007-2016	2018	2	1	3	++
Truck transport infrastructure	EI 3.7.1	Lorry production, 40 metric ton - RER	1998 - 2020	2020	4	2	5	+
		Maintenance, lorry 40 metric ton - GLO	2011 - 2020	2020	4	2	5	+

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
		market for road - GLO	2011 - 2020	2020	4	2	5	+
		Road maintenance – Europe w/o CH	1990 - 2020	2020	4	2	5	+
Truck transport: diesel supply	EI 3.7.1	Market for diesel, low-sulfur – Europe without Switzerland	2000 - 2020	2020	2	1	4	++
Truck transport for EPD for Nertherlands	EI 3.7.1	Transport, freight, lorry, unspecified - GLO	2012-2020	2020	2	2	3	++
Train transport operation	EcoTransIT & LRTAP-EEA	Electricity or diesel consumption calculated according to formula from EcoTransIT & Emissions per kg diesel	2010 2005	2019 2016	2	1	3	+
Train transport infrastructure	EI 3.7.1	Locomotive production - RER	1993 - 2020	2020	4	2	5	+
		Goods wagon production - RER	1993 - 2020	2020	4	2	5	+
		Maintenance, goods wagon - RER	1993 - 2020	2020	4	2	5	+
		Maintenance, locomotive - RER	1993 - 2020	2020	4	2	5	+
		Railway track construction - RoW	1990 - 2020	2020	4	2	5	+
Barge transport	EI 3.7.1	Operation, barge, RER (including infrastructure)	1990 - 2020	2020	4	2	5	+
Module A2, A3, A5, B2, C1, C3, D								
Electricity mix	EI 3.7.1	Market for electricity, low voltage – BE (or NL)	2014-2020	2020	1	1	2-4	++
Module A3 – Manufacturing								
Infrastructures	EI 3.7.1	Concrete mixing factory construction - CH	1997 - 2020	2020	2	2	5	+

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Diesel	EI 3.7.1	Diesel, burned in building machine - GLO	1996 - 2020	2020	2	1	5	+
Natural gas	EI 3.7.1	Heat production, natural gas, at industrial furnace >100kW – Europe without Switzerland	2000 - 2020	2020	2	2	5	+
Light fuel oil	EI 3.7.1	Heat production, light fuel oil, at industrial furnace 1MW – Europe without Switzerland	1991 - 2020	2020	2	1	5	+
Heavy fuel oil	EI 3.7.1	Heat production, heavy fuel oil, at industrial furnace 1MW – Europe without Switzerland	2001-2020	2020	2	1	5	+
LPG	EI 3.7.1	Propane, burned in building machine - GLO	2013 - 2020	2020	2	1	5	+
Module A3 - Packaging								
LDPE film	EI 3.7.1	Packaging film production, low density polyethylene - RER	1993 - 2020	2020	2	1	5	+
Cardboard	EI 3.7.1	Containerboard production, linerboard, kraftliner - RER	2012-2020	2020	2	1	2	+
Strapping bands	EI 3.7.1	Polyester resin production, unsaturated - RER	1995 - 2020	2020	2	3	5	+
	EI 3.7.1	Extrusion production, plastic film - RER	1993 - 2020	2020	2	3	5	+
PE foam	EI 3.7.1	Polyethylene production, high density, granulate - RER	2011 - 2020	2020	2	2	3	+
	EI 3.7.1	Polymer foaming - RER	1995-2020	2020	2	2	5	+
Wooden pallets	EI 3.7.1	EUR-flat pallet production - RER	2000 - 2020	2020	2	1	5	+
Metal pallets	EI 3.7.1	steel production, electric, low-alloyed – Europe without CH & AT	2013	2020	2	3	3	+
Stacking plate PE	EI 3.7.1	Injection moulding - RER	1993 - 2020	2020	2	3	5	+

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
	EI 3.7.1	Polyethylene production, high density, granulate - RER	2011 - 2020	2020	2	1	3	+
Wooden wedges and slats	EI 3.7.1	market for particleboard, uncoated - RER	2012 - 2020	2020	2	3	3	+
	EI 3.7.1	Market for sawnwood, softwood, raw, dried (u=20%) - RER	2011 - 2020	2020	2	3	3	+
Module A5								
Bolts and nuts + manufacturing	EI 3.7.1	steel production, chromium steel 18/8, hot rolled RER	2000	2020	2	4	5	++
	EI 3.7.1	Market for metal working, average for chromium steel product manufacturing GLO	2011	2020	2	4	3	++
Classic & casting mortar	EI 3.7.1	Silica sand production - DE	1998 - 2001	2020	3	2	5	+
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
	EI 3.7.1	Cement production, Portland – Europe without Switzerland	1997 - 2001	2020	2	1	5	++
	EI 3.7.1	Plaster mixing – CH (with electricity mix of the installation country Belgium or NL)	2001 - 1017	2020	2	3	5	+
Casting concrete	EI 3.7.1	Silica sand production - DE	1998 - 2001	2020	3	2	5	++
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
	EI 3.7.1	gravel and sand quarry operation – gravel, round - RoW	1997-2020	2020	2	2	5	+
	EI 3.7.1	"Portland-composite cement (CEM II) produced in Europe – CEMBUREAU"	2016	2020	2	1	2	++
	EI 3.7.1	(Electricity BE and heat consumption, based on UPR dataset "unreinforced concrete production, with cement CEM II/A – CH")						++

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Water	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
Neoprene	EI 3.7.1	Synthetic rubber production - RER	2003	2020	2	4	5	+
Reinforcing steel	EI 3.7.1	steel production, electric, low-alloyed – Europe without CH & AT+ hot rolling, steel – Europe without AT	2013/ 1997-2020	2020	2	2	3 5	++
Fixing sand	EI 3.7.1	Gravel and sand quarry operation – sand – CH (with electricity mix of CH replaced by Europe without Switzerland)	1997 - 2020	2020	2	2	5	+
	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
	EI 3.7.1	Market for cement, unspecified – Europe without Switzerland	2013 - 2001	2020				++
Module B2								
Water	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
Module C1								
Water use for demolition of products	EI 3.7.1	Market group for tap water - RER	2011-2020	2020	2	2	3	+
Diesel consumption for demolition of products	EI 3.7.1	Diesel, burned in building machine - GLO	1996 - 2020	2020	2	2	5	+
Transport to recycling/treatment centre by truck		List of LCI for truck transport (see above)	/					+
Module C3								
Sorting plant infrastructure	EI 3.7.1	Sorting facility construction, for construction waste - CH	1996 - 2020	2020	3	2	5	+

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Module C4								
Concrete landfill disposal	EI 3.7.1	Treatment of waste concrete, inert material landfill – Europe without Switzerland	1995-2020	2020	2	1	5	+
Steel landfill disposal	EI 3.7.1	Treatment of scrap steel, inert material landfill – Europe without Switzerland	1995-2020	2020	2	1	5	+
PS landfill disposal	EI 3.7.1	Treatment of waste polystyrene, sanitary landfill– Europe without Switzerland	1994-2020	2020	2	1	5	+
XPS landfill disposal					2	1	5	+
PUR landfill disposal	EI 3.7.1	Treatment of waste polyurethane, inert material landfill – Europe without Switzerland	1995-2020	2020	2	1	5	+
PIR landfill disposal				2020	2	4	5	+
Neoprene landfill disposal	EI 3.7.1	Treatment of waste polyvinylchloride, sanitary landfill – Europe without Switzerland	1994-2020	2020	2	4	5	+
PS incineration	EI 3.7.1	Treatment of waste polystyrene, municipal incineration – Europe without Switzerland	2006-2020	2020	2	1	4	+
XPS incineration	EI 3.7.1	Treatment of waste expanded polystyrene, municipal incineration – Europe without Switzerland	2006-2020	2020	2	1	4	+
PUR and PIR incineration	EI 3.7.1	Treatment of waste polyurethane, municipal incineration – Europe without Switzerland	2006-2020	2020	2	1/4	4	+
Neoprene incineration	EI 3.7.1	Treatment of waste rubber, unspecified, municipal incineration – Europe without Switzerland	2006-2020	2020	2	4	4	+
Module D								
Part of modelling of wood recycling process	EI 3.7.1	wood chipping, industrial residual wood, stationary electric chipper - RER	1996 - 2020	2020	2	2	5	+
Operations for valorising secondary crushed concrete material	EI 3.7.1	"Treatment of waste concrete gravel, sorting plant – RoW" (without 'inert waste' processes) after subtraction of "treatment of waste concrete gravel, recycling"	1997 - 2020	2020	2	1	5	++

Use	Source	Dataset	Reference year	Publi-cation year	Geographical representativeness	Technological representativeness	Time representativeness	Influence on results
Replacement scenario of gravel by crushed concrete	EI 3.7.1	Gravel and sand quarry operation – Gravel, round – CH (with electricity mix of CH replaced by Europe without Switzerland)	1997 - 2001	2020	2	2	5	++
All steel except reinf. steel & metal pallet	Worldsteel	Value of scrap	2011	2019	2	3	3	+++
Reinforcing steel and metal pallelt	EI 3.7.1	Recycling: steel production, electric, low-alloyed – Europe without CH & AT Avoided virgin production: steel production, converter, low-alloyed – RER	2013-2020	2020	2	2	3	+
Cardboard recycling	EI 3.7.1	Treatment of recovered paper to linerboard, testliner - RER	2012-2020	2020	2	1	3	+
Recycling of PE films, foam, strapping band	EI 3.7.1	polyethylene production, high density, granulate, recycled	2010	2020	2	3	3	+
Heat recovery	EI 3.7.1	Heat production, natural gas, at industrial furnace >100kW	2000-2020	2020	2	2	5	+