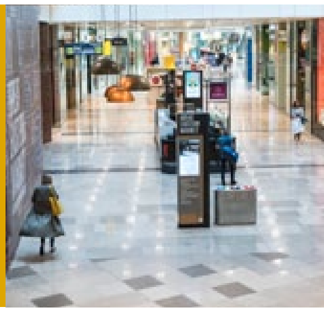
Sustainability Study



Life-cycle Assessment of Floor Coverings

Contents

Sustainable Building Using Natural Stone

Sustainable building has gained in importance in recent years. The meaning of *Sustainable building* is the consideration of ecological, economic and social aspects in planning and construction processes and real estate management. Germany has been working on the fundamentals and guidelines for the *Sustainable Building Round Table*, established by the Federal Ministry of Building, since 2001. One of the results of this work is the *Guide to Sustainable Building* by the Federal Ministry for Environment, Nature, Building and Nuclear Safety, which is used as a planning guideline for public construction projects
A certification system for sustainably designed and constructed buildings has been developed, in particular thanks to the activities of the German Sustainable Building Council *(Deutsche Gesellschaft für Nachhaltiges Bauen)*.
The German *Sustainable Building* seal of quality includes a catalogue of around 50 criteria which quantify numerous aspects for planners, architects, builders, etc.
Internationally, *sustainable building* is often equated with the term *green building*. A similar certification system has existed in Great Britain for many years. The BREEAM system also assesses the buildings environmental performance, including social and health aspects, but does not evaluate economic performance. In the US, the LEED system was developed by the US Green Building Council. The system is now also used outside the United States for planning energy-efficient and green buildings. To date, the LEED system does not use a total building life-cycle assessment to evaluate the ecological performance of a building, but instead bases the ecologically motivated selection of materials on the evaluation of individual properties. For example, in the LEED system, a rating is given for materials and construction products that are transported less than 800 kilometres to the construction site.
Today, the topic of reducing energy demand and CO_2 emissions is becoming increasingly important. Because the construction sector makes a major contribution to global CO_2 emissions and energy consumption, construction products should also have the lowest possible environmental impact in their manufacture and use, right through to disposal, taking economic aspects into account. Each year, more than 350 million square metres of new floor coverings are laid in buildings in Germany alone.
For these reasons, the Deutscher Naturwerkstein-Verband e.V. (*DNV – German Natural Stone Association*) commissioned a study by the Institute of Construction Materials at the University of Stuttgart, which compares the ecological and economic impacts of different floor coverings from the production to the use phase.

Joachim Grüter
President of the German Natural Stone Association

1 Summary

The object of this study is to determine the ecological performance of different floor coverings used in a variety of public and commercial applications. The ecological impact of a load-bearing structure comprising concrete base, insulation layers and screed for the different floor coverings, including the necessary mortar, was also studied in a life-cycle screening procedure. The data was collected from existing environmental product declarations (EPD) issued by the various building material manufacturers.

Natural stone floor coverings predictably achieve very good life-cycle assessment results, due to the low primary energy demand of the stone. According to the German *Bundesverband Baustoffe – Steine und Erden* (Federal Construction Materials Association – Non-metals), the costs of energy consumption for processing natural stone are a mere 3.3% of the production value.

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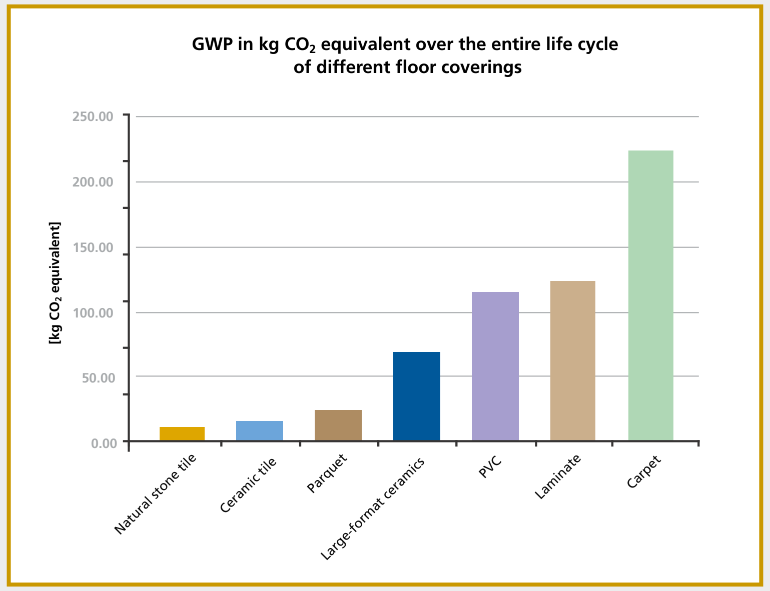
1+2: Art Gallery, Auckland, New Zealand Dietfurt Limestone

3: Ludwig-Erhard-Haus, Berlin Krastal Marble

A comparison of all floor coverings showed that those produced from natural stone cause a significantly lower environmental impact in their production, installation and use than large-format ceramics, carpets, PVC, laminates and parquet.

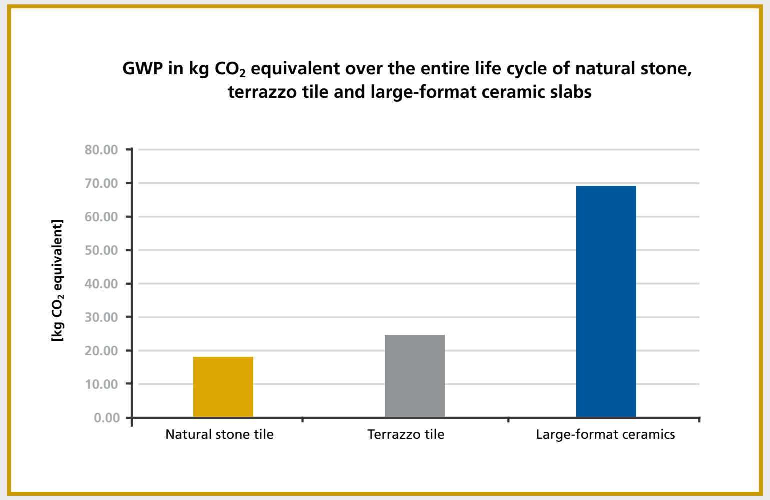
In the especially important category of global warming potential (GWP) impact, the production and utilisation of floor coverings using natural stone tiles display significantly lower CO_2 equivalents than the production and use of other covering materials. At 10.9 kilograms CO_2 equivalent, the lowest emissions are attributed to the GWP of natural stone tiles, together with the associated adhesive mortar. The GWP of a carpet is with a value of approx. 223 kilograms CO_2 equiv. more than 20 times higher than for a natural stone tile (See Figure 1).

Figure 1: GWP for different floor coverings



When investigating coverings used for the highest performance floors, it was found that equivalence values for natural stone slabs are lower in all impact categories compared with terrazzo tiles. For example, the GWP of a natural stone slab is about 27% lower than that of an terrazzo tile and about 74% less than that of large-format ceramics.

Figure 2: GWP of slabs of different materials



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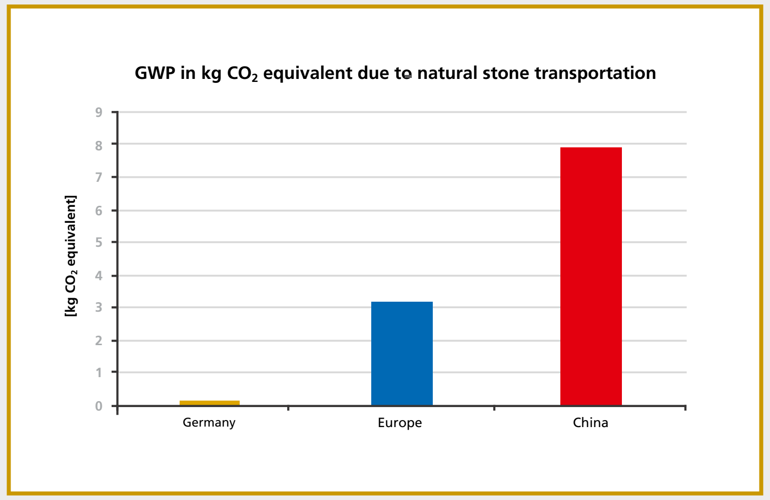
Another important aspect of using natural stone is the influence of transportation. While only 0.16 kilograms CO_2 equiv. are produced when using local natural stone (100 km lorry transport), this increases to 3.2 kilograms CO_2 equiv. in the case of transport within Europe (2000 km lorry transport) and 7.9 kilograms CO_2 equiv. per square metre of flooring for natural stone from China (18,600 km by ship, 150 km by lorry and 200 km rail transport).

Figure 3: GWP from transportation of dimension stone



Representative environmental product declarations were selected for all flooring products studied. They contain verified values that may be anticipated for the various environmental impacts. The EPD of a product group with available EPD was selected as being representative of the respective floor covering. Missing information or undeclared modules for individual life-cycle phases were supplemented with appropriate assumptions, employing data from comparable EPDs or available databases such as *Ökobaudat* (eco building database) for the analysis.

An analysis of life-cycle costs, which depend significantly on the level of cleaning costs, is also included in the LCA study (see Section 4).

4

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4: Shopping Centre Westfield, England Jura Limestone

5: Boutique, Munich Solnhofen Flooring

2 Adopted Methodology

2.1 Life-cycle assessment methodology

Initially, a uniform substructure was specified for the study and the structure of the overlying floor coverings determined. The layer thicknesses and the required quantities of building materials were also identified. Representative environmental product declarations were defined for each of the required products. They contain verified values that may be anticipated for the various environmental impacts. The EPD of a respective comparable product group with available EPD was selected as being representative of the respective floor covering. Missing information or undeclared modules for individual life-cycle phases were supplemented with appropriate assumptions, employing data from comparable EPDs or available databases such as *Ökobaudat* for the analysis. The values determined relate to a functional unit of one square metre. The EPDs and *Ökobaudat* datasets are prepared according to the Environmental Product Declaration Principles for the building products category compliance with EN 15804 [1] and therefore also conform to the life-cycle assessment principles and framework conditions in compliance with EN ISO 14040, and the requirements and instructions in compliance with EN ISO 14044 [2, 3]. The second section looks at life-cycle cost analysis. Here, the life-cycle costs are first explained and then calculated. The report concludes with a summary of the results.

The following LCA indicators are adopted:

Table 1: LCA indicators

LCA indicator	Unit
Life cycle inventory (LCI)	
Primary energy, (renewable and non-renewable)	MJ
Impact categories*	
Global warming potential (GWP)	[kg CO_2 equiv.]
Ozone depletion potential (ODP)	[kg R11 equiv.]
Acidification potential (AP)	[kg SO_2 equiv.]
Eutrophication potential (EP)	[kg phosphate equiv.]
Photochemical ozone creation potential (summer smog (POCP))	[kg ethylene equiv.]

*A detailed description of the impact categories can be found in Appendix A.

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2.2 Procedure

In the study, the specification was compiled for a uniform substructure and the following floor coverings using the example of a representative product or a representative product group: natural stone tiles and natural stone slabs, terrazzo tile, ceramic tiles and large-format ceramics, carpet, laminate, parquet and PVC.

The aim of the study is to ecologically evaluate and compare typical floor coverings used in commercial premises over a period of 50 years. All life-cycle phases from production to use were taken into consideration.

2.2.1 Floor construction

A model uniform floor structure was defined for all floor coverings, which is illustrated in Figure 4. According to Anton Pech [4], this represents a suitable floor structure for commercially used areas or public buildings. The data basis for individual layer accounting is provided by EPDs, from which the environmental indicator values were taken. A primer was used in the standard construction. The service life of the primer depends on the particular floor covering, because it is generally also renewed when the flooring is replaced.

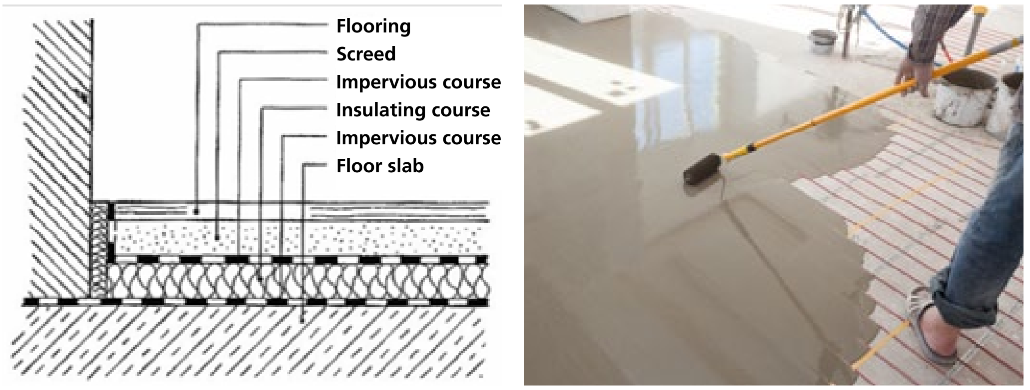


Figure 4: Floor construction

6: Application of the screed

Table 2 (page 10) lists the environmental product declarations of the substructure used in the study, with names and numbers, as well as the layer thicknesses and resulting quantities. The required densities or weight data were taken from the respective building material EPDs.

The EPD of the concrete refers to the average composition of concrete in Germany for use in structural components for structural engineering, geotechnical engineering and civil engineering, as ready-made or prefabricated concrete. The EPD is based on data collected in 2010/2011 from the members of the *Bundesverband der Deutschen Transportbetonindustrie e.V.* (German Ready-Mixed Concrete Association) and the *Forschungsvereinigung der deutschen Beton- und Fertigteilindustrie e.V.* (Research Association of the German Concrete and Precast Concrete Industry).

Specific data for reinforcing steel adopted is taken from the *Badische Stahlwerke GmbH* 2011 financial year. These data were collected on site in the factory in Kehl and are partly derived from ledgers and partly from readings taken directly.

The PE bubble foil dataset was modelled in compliance with European Standard EN 15804 for sustainable building. Results are mapped into modules that allow the structured expression of results throughout the entire life-cycle. The dataset source is *thinkstep*.

The EPD of the impact sound insulation describes EPS rigid foam products used in the thermal and acoustic insulation of walls, roofs and floors. This EPD is only valid for products using the Polymer-FR flame retardant. The source of the declaration is *Industrieverband Hartschaum e.V.* (Rigid Foam Industry Federation).

The EPD for cement screed is a generic industry association EPD in which, to produce the life-cycle assessment, the product with the highest environmental impact of a specific group has been selected. The source of the declaration is the *Industrieverband WerkMörtel e.V.* (Ready-made Mortars Industry Federation).

The primer is also a generic industry association EPD in which, to produce the life-cycle assessment, the product with the highest environmental impact of a specific group has been selected. The source of the declaration is *Deutsche Bauchemie e.V.* (German Construction Chemicals Association).

Table 2: Basic structure, selected products

Standard structure	EPD – declaration number	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Concrete slab	EPD-IZB-20130411-IBG2-DE (concrete)	Concrete, Informations-zentrum Beton GmbH	180	432
Reinforcement steel	EPD-BS-10.0 and BMG.10.1 (steel)	Reinforcing steel and reinforcing steel mats, Badische Stahlwerke GmbH	–	12
Separating foil	From Ökobaudat: "PE bubble foil for sealing"	PE bubble foil for sealing	0.2	0.18
Impact sound insulation	EPD-IHV-20140139-IBB2-DE	EPS, Industrieverband Hartschaum	20	0.518
Separating foil	From Ökobaudat: "PE bubble foil for sealing"	PE bubble foil for sealing	0.1	0.09
Cement screed	EPD-IWM-20130240-IBG1-DE	Screed mortar – cement screed, Industrieverband WerkMörtel	70	105
Primer	EPD-DIV-20140090-IBG1-DE	Dispersion-based primers, Deutsche Bauchemie	2	2

Table 3 to Table 9 show the respective layers of the various floor coverings, including mortar and adhesive, which are installed on top of the standard structure. The carpet, PVC and laminate floor coverings require a levelling compound, because these floor coverings demand lower tolerances in terms of flatness.

2.2.2 Configuration for natural stone

Table 3: Natural stone – EPD, layer thickness and quantity

Natural stone tile	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro No. 1 adhesive mortar	EPD-DIV-20130109-IBE1-DE	Modified mineral mortar, DBC, IVK, VdL	5	5
Natural stone tile	EPD-FRS-20170102-IBD1-DE	Jura Limestone, Franken-Schotter GmbH & Co. KG	10	26
Stone imp-regnation	Information provided by manufacturer, Akemi	–	–	0.054
Natural stone slab	**EPD**	**EPD – Name**	**Thickness [mm]**	**Quantity [kg/m²]**
Sopro No. 1 adhesive mortar	EPD-DIV-20130109-IBE1-DE	Modified mineral mortar, DBC, IVK, VdL	20	20
Natural stone slab	EPD-FRS-20170103-IBD1-DE	Jura Limestone, Franken-Schotter GmbH & Co. KG	20	52
Stone imp-regnation	Information provided by manufacturer, Akemi	–	–	0.054

The EPD of a Jura Limestone produced by *Franken-Schotter GmbH & Co. KG* was selected for natural stone flooring (see Table 3), the data for which are based on average values from all production sites. The natural stone is bonded to the screed (primer) using a bonding mortar from Sopro. The mineral mortar data are based on the industry association EPD for Group 1 modified mineral mortars (*Deutsche Bauchemie e.V.* (DBC), *Industrieverband Klebstoffe e.V.* (IVK) (Adhesives Industry Federation), *Verband der deutschen Lack- und Druckfarbenindustrie e.V.* (VdL) (German Paint and Printing Inks Industry Federation). According to the manufacturer, approximately one kilogram per millimetre of layer thickness per square metre is required.

2.2.3 Configuration for terrazzo tile

Because no EPD is available for a common indoor terrazzo tile floor, a *Klostermann GmbH & Co. KG* company precast concrete stone for exterior pavements was chosen as a similar alternative; the EPD is an average EPD (see Table 3). Here, too, the adhesive was a Sopro bonding mortar with the same EPD.

Table 4: Terrazzo tile – EPD, layer thickness and quantity

Artificial stone	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro No. 1 adhesive mortar	EPD-DIV-20130109-IBE1-DE	Modified mineral mortar, DBC, IVK, VdL	20	20
Terrazzo tile	EPD-KLO-20170147-IAC1-DE	Concrete paving stones, Klostermann GmbH & Co. KG	30	72

2.2.4 Configuration for ceramic tile

The EPD of ceramic tiles (see Table 5) comes from *Bundesverband für keramische Fliesen* (Federal Ceramic Tiles Industry Association). The data represent average values for several companies and factories. The mortar bed is also calculated for bonding using Sopro data. In addition, an EPD for large-format tiles, with dimensions between one and three metres and originating from *Laminam S.p.A.*, is also investigated to provide control data. The datasets reference a 25-year study.

Table 5: Ceramic tile – EPD, layer thickness and quantity

Ceramic tiles	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro No. 1 adhesive mortar	EPD-DIV-20130109-IBE1-DE	Modified mineral mortar, DBC, IVK, VdL	5	5
Ceramic tiles	EPD-BKF-20160002-IBE1-DE	Ceramic tiles and slabs, Bundesverband Keramische Fliese	10	18.65
Large-format ceramics	BREG EN EPD Number: 000148	Laminam 5 ceramic tile, Laminam S.p.A.	5.6	14

2.2.5 Configuration for parquet

The EPD for multi-layer parquet of the *Verband der Deutschen Parkettindustrie* (vdp) (German Parquet Industry Association) is used for the parquet flooring. The data are average values for several manufacturers and factories.

Table 6: Parquet – EPD, layer thickness and quantity

Parquet	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Primer	EPD-DIV-20140090-IBG1-DE	Dispersion-based primers, DBC, IVK, VdL	2	2
Adhesive	EPDDBC20130027-IBG1DE	Adhesives for parquet and floor coverings, DBC, IVK, VdL	1	1.5
Multi-layer parquet	EPD-VDP-20150263-IBG1-DE	Multi-layer parquet, Verband der Deutschen Parkettindustrie	15	8.878
Sealant	EPDDBC20130067-IBG1DE	Sealants for parquet flooring, DBC, IVK, VdL	0.6	0.75

The parquet is bonded. A generic industry association EPD is also adopted for calculations (see Table 6). 1.5 kilograms per millimetre of layer thickness per square metre are required. In addition sealing of the parquet is beneficial. Determination of the layer thickness (relative to one square metre) by density and application quantity yields approx. 0.6 millimetres with a weight of 0.75 kilograms. The environmental data are taken from the industry association EPD for parquet flooring, floor coatings and polyurethane based floor coverings.

2.2.6 Configuration for carpet

The EPD of a tufted Vetex carpet, which is based on average data, was selected for the carpet (see Table 7). Before the carpet can be bonded, a Sopro levelling compound is applied to even out the floor as well as possible. In this case, about 1.5 kilograms is used per millimetre layer thickness. The environmental data are taken from the industry association EPD (DBC, IVK, VdL) for modified Group 1 mineral mortars used as cement screeds, levelling compounds, smoothing compounds or liquid screeds. This is followed by carpet bonding using a Uzin adhesive from *Utz AG*.

Table 7: Carpet flooring – EPD, layer thickness and quantity

Carpet flooring	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro OFS 543 levelling compound	EPD-DIV-20130111-IBE1DE	Group 1 modified mineral mortars (DBC, IVK, VdL)	3	4.5
Adhesive	EPD-UTZ-20130065-IBA1-DE	Dispersion adhesive, Uzin Utz AG	1	0.45
Carpet	EPD-VET-20130290-CBD1-DE	Tufted carpet, VETEX	10	1.84


7


8

7: Elastic floor covering

8: Carpet flooring installation

2.2.7 Configuration for PVC

For the PVC, a European Resilient Flooring Manufacturers Institute (ERFMI) EPD was selected, representing a product family of 34-grade PVC floors (see Table 8). Here, too, the levelling compound is applied first. The flooring is then bonded using a PCI flooring adhesive. The data were taken from the *PCI-Augsburg GmbH* EPD for PCI flooring adhesive for textile and elastic coverings, which represents a product group.

Table 8: PVC – EPD, layer thickness and quantity

Polyvinyl chloride	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro OFS 543 levelling compound	EPD-DIV-20130111-IBE1DE	Group 1 modified mineral mortars (DBC, IVK, VdL)	3	4.5
Adhesive	EPD-PCI-20160205-IBG1-DE	PCI flooring adhesive, PCI Augsburg GmbH	1	0.25
PVC	EPD-ERF-2013211-E	Smooth rubber floor coverings, ERFMI	2	2.9

2.2.8 Configuration for laminate

A direct pressed laminate (DPL) was selected for the laminate flooring; the EPD originates from the *European Producers of Laminate Flooring e.V.* and comprises data averaged across several products and manufacturers (see Table 9). Because it is interlocking, it is not necessary to glue the laminate. A levelling compound is first applied to provide a flat surface and then impact sound insulation installed on top.

Table 9: Laminate – EPD, layer thickness and quantity

Laminate	EPD	EPD – Name	Thickness [mm]	Quantity [kg/m²]
Sopro OFS 543 levelling compound	EPD-DIV-20130111-IBE1DE	Group 1 modified mineral mortars (DBC, IVK, VdL)	3	4.5
Impact sound insulation	EPD-IHV-20140139-IBB2-DE	EPS, Industrieverband Hartschaum	2	0.0518
Laminate DPL	EPD-EPL-20150021-CBE1-EN	DPL Floor Covering, European Producers of Laminate Flooring	12	11.6

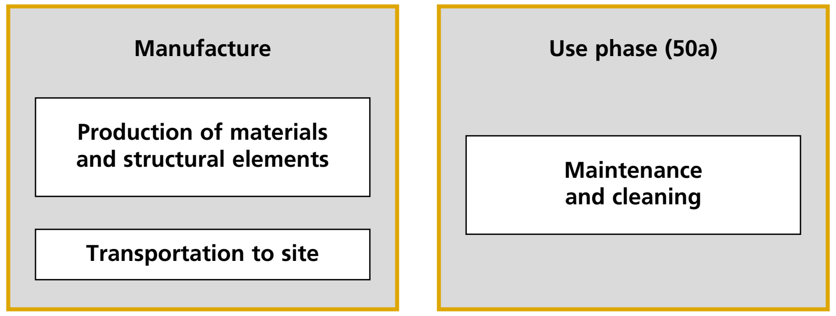
2.3 Study framework

2.3.1 Functional unit

The functional unit is always one square metre of floor covering, whereby different floor coverings for a variety of applications in commercial areas subject to medium load (e.g. offices, shops) and higher load (e.g. shopping centres and airport terminals) are studied.

2.3.2 System boundaries

The ecological life-cycle analysis covers production and use over a period of 50 years. As can be seen in the figure below, the life-cycle consists of both the production phase and the use phase.



The ecological life-cycle analysis begins with a consideration of the production of raw materials, together with the auxiliary materials used.
Processing raw materials into intermediate and end products is considered, as well as transporting the components to the construction site.

2.3.3 Analysis method

Using the available data, ecological accounting was performed for the entire life-cycle of each layer of the floor structure. The following impact indicator values relate to one square metre of floor structure and a duration of 50 years.

3 Life-cycle Assessment Results

3.1 General aspects

Selected impact categories are compared for the different floor structures below. Section 3.2, *Environmental impacts of the substructure*, illustrates the basic configuration of the structures, which is the same for all selected floor coverings.

This is followed in Section 3.4 by a study of the different floor coverings with regard to the main environmental impact *GWP greenhouse effect*, together with the necessary application products such as mortar, levelling compound and any sealant used. Furthermore, a compilation of the GWP results for hard floor coverings and the natural stone, terrazzo tile and large-format ceramics floor covering materials normally used in the highest performance applications are included.

The respective data bases used in the LCA calculations are included in Appendix B.

Environmental impacts: one square metre basic structure floor structure							
		Concrete structural slab	LDPE release liner	EPS hard foam	Cement screed	Primer	Total emissions
GWP	kg CO_2 equiv.	3.8410E+01	9.2342E-01	1.5257E+00	1.7228E+01	4.9500E+00	6.3034E+01
ODP	kg R11 equiv.	1.3454E-06	1.4775E-12	8.1804E-09	1.3860E-09	1.1470E-09	1.3561E-06
AP	kg SO_2 equiv.	6.1676E-02	1.5241E-03	3.4674E-03	2.6510E-02	4.8560E-02	1.4174E-01
EP	kg $(PO_4)^{3-}$ equiv.	9.7344E-03	1.6407E-04	3.2084E-04	5.1000E-03	1.5155E-03	1.6835E-02
POCP	kg ethylene equiv.	6.7492E-03	2.5681E-04	1.0826E-02	7.8047E-05	5.9264E-02	7.7174E-02
PERT	MJ	2.4854E+01	1.1166E+00	5.6436E-01	9.0146E+00	5.5858E+00	4.1135E+01
PENRT	MJ	2.5813E+02	2.7217E+01	4.4842E+01	1.2375E+02	1.0114E+02	5.5508E+02

Table 10: Basic structure of the emissions

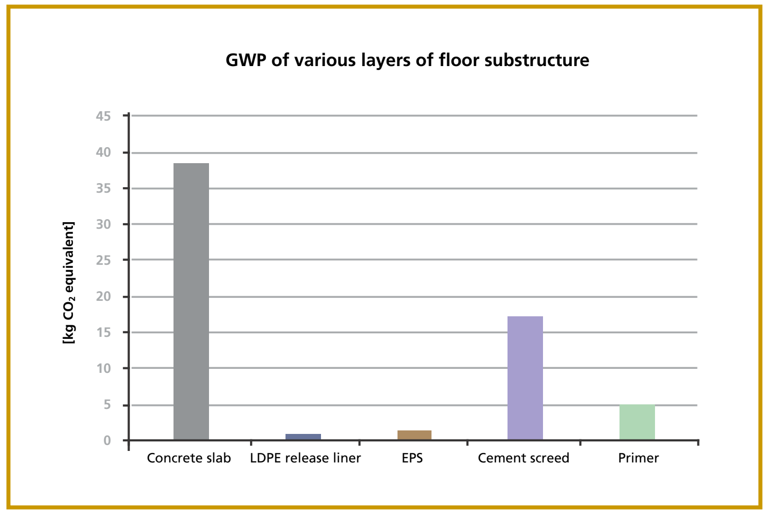
3.2 Environmental impacts of the substructure

Table 10 shows the indicator values and the energy consumption of the flooring substructure.

Many of the impact indicators are attributed to the concrete structural slab, followed by the mortar screed, with the primer also predominantly accounting for between 10% and 33% of the impact indicators. For example, 60.9% of GWP are attributed to the concrete structural slab, 27.3% to the screed and 7.9% to the primer. At 76.8%, the POCP alone is responsible for the largest share caused by the primer.
Energy is predominantly provided by non-renewable energy sources (see Table 10). For example, 258.1 MJ from non-renewable primary energy sources are used in the manufacture and use of the concrete slab and only 24.9 MJ from renewable primary energy sources. In total, 93% of the total primary energy demand for all products (concrete slab, LDPE release film, EPS, cement screed, primer) are derived from non-renewable energy sources; 6.9% are derived from renewable energy sources.

Figure 5 shows the proportions of the individual layers in the GWP (kg CO_2 equivalent) impact indicator per square metre of floor substructure.

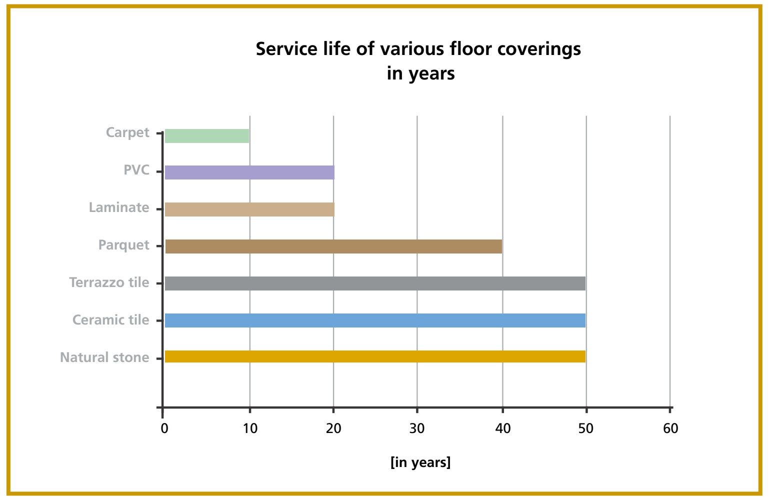
Figure 5:
GWP proportions
of various layers



3.3 Service life of the floor coverings

A study of the usual service lives reveals that the durability of all the stone floors is at least 50 years as stated in the EPDs. In contrast, the service life of the textile carpet floor covering is only ten years, that of the laminate and the elastic floor covering (PVC) 20 years, and a service life of 40 years is given in the EPD for parquet (see Figure 6).

Figure 6:
Service life
of various floor
coverings



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3.4 Environmental impacts of the floor coverings

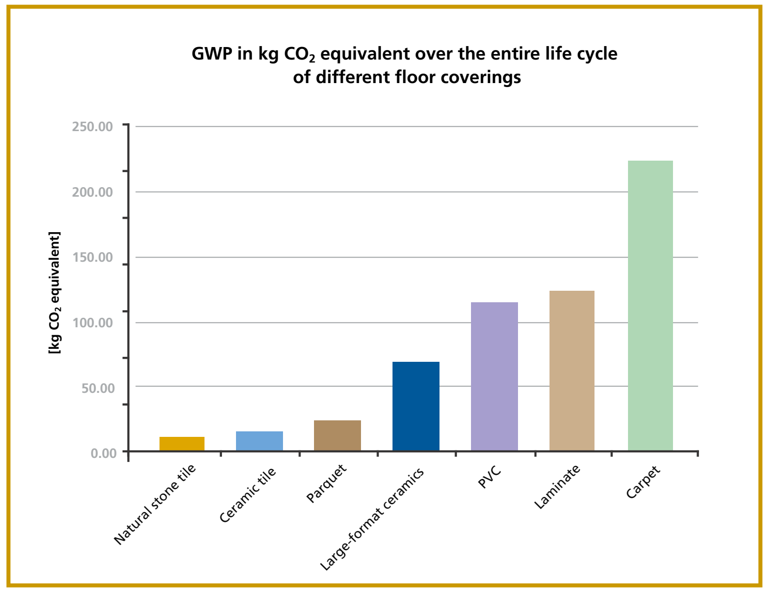
Table 11 below shows the environmental impact of the coverings over their entire life cycle, including the adhesive and mortar, as well as any levelling compounds, impregnators and sealants. The structure of the floor coverings is described in Section 2.

Environmental impacts of floor coverings									
	Nat. st. tile	Nat. st. slab	Terr. tile.	Ceram. tile	Ceram. Lf.	Parquet	PVC	Laminate	Carpet
GWP	1.09E+01	1.77E+01	2.43E+01	1.63E+01	6.91E+01	2.40E+01	1.14E+02	1.23E+02	2.23E+02
ODP	1.37E-07	1.12E-07	2.15E-07	2.64E-08	8.91E-06	1.83E-06	1.36E-07	8.98E-08	7.27E-07
AP	3.18E-02	5.28E-02	6.10E-02	3.74E-02	3.96E-01	1.62E-01	6.64E-01	6.45E-01	1.27E+00
EP	6.73E-03	6.82E-03	1.02E-02	5.02E-03	1.06E-01	3.22E-02	1.18E-01	1.39E-01	2.43E-01
POCP	2.79E-03	2.39E-03	2.89E-03	3.26E-03	5.51E-02	8.17E-02	8.78E-02	1.17E-01	1.58E-01
PERT	3.01E+02	1.11E+02	4.95E+01	3.11E+01	1.84E+02	4.48E+03	1.36E+02	7.49E+02	2.18E+02
PENRT	1.61E+02	2.63E+02	2.65E+02	2.90E+02	1.33E+03	1.16E+03	1.92E+03	1.31E+03	3.43E+03

Table 11:
Environmental
impacts of the
tested floor
coverings

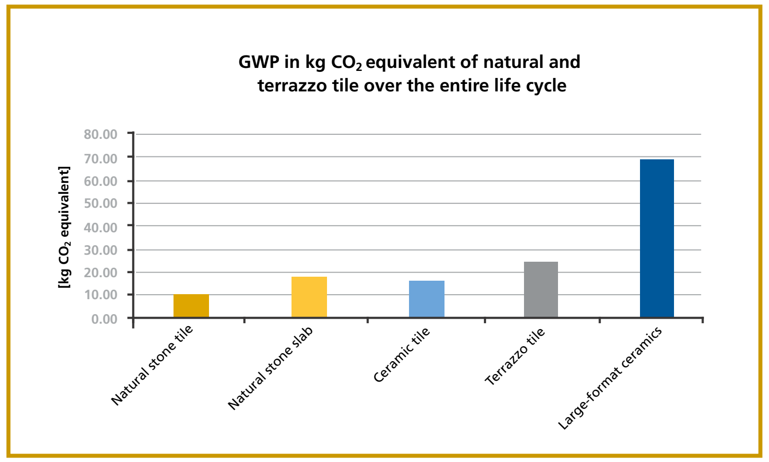
In Figure 7 below, the main environmental impact is the GWP greenhouse effect in kilograms CO_2 equiv. for floor coverings commonly used in office buildings and commercial areas.
At 10.9 kilograms CO_2 equivalent, the lowest emissions are attributed to the GWP of natural stone tiles, together with the associated adhesive mortar and impregnators. The GWP of a carpet is more than 20 times higher than for a natural stone tile, with a value of approx. 223 kilograms CO_2 equiv.

Figure 7:
GWP for different
floor coverings



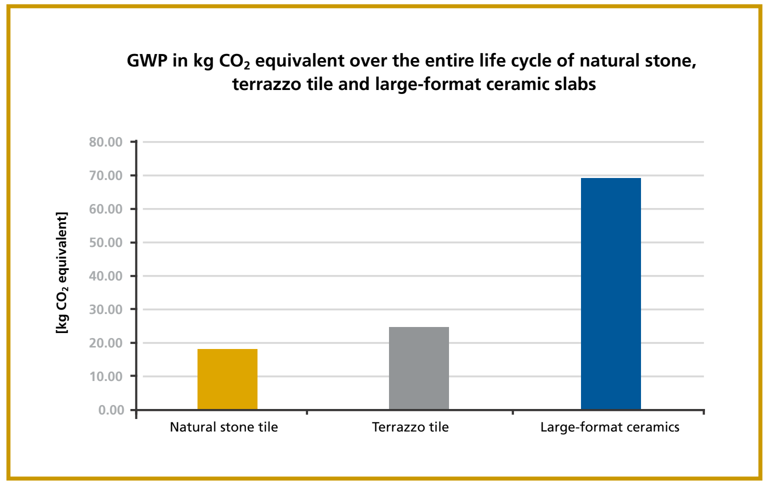
In a direct comparison of hard floor coverings in the global warming potential (GWP) impact category, it can be noted that natural stone floor coverings display very small kilograms CO_2 equivalent values and considerable ecological benefits, in particular when compared with large-format ceramics. The GWP of a natural stone tile is approximately 84% lower than that of a large-format ceramic tile.

Figure 8: GWP of tiles and slabs of various materials



Natural stone slab, terrazzo tile or large-format ceramic flooring is predominantly installed in the highest performance areas such as railway stations, airport terminals and shopping centres.
When investigating these coverings, it was found that lower equivalence values result for the natural stone slab in all impact categories in comparison with the terrazzo tile. For example, the GWP of a natural stone slab is about 27% lower than that of an terrazzo tile and about 74% less than that of large-format ceramics.

Figure 9: GWP of slabs of different materials



3.5 Benefits of natural stone

The results of the floor coverings study show that natural stone tiles and slabs have significant ecological advantages over other floor covering materials, especially PVC, laminate and carpet.

Natural stone is a material that has evolved over millions of years and is almost complete as a building material in its natural state. No energy is needed for its creation. Energy is only consumed during processing and transportation.
At 3.3% for working and processing natural stone, the share of energy costs in the gross production value is extremely low (see bbs 2016 figures).

Extraction in the quarry is kind to natural resources and does not require maximum fragmentation blasting. The unused spoil is utilised to backfill excavated sections of the quarry. Nothing is lost in the entire cycle of natural stone extraction, processing and return to nature. The rock residues

remaining after mining and processing can be used economically in gardening and landscaping, for masonry, for covering terraces, riparian works, for hydraulic engineering and to produce aggregate.

As a building material, natural stone contains no harmful substances and can be easily used in conjunction with foodstuffs. Even in case of fire, natural stone releases no harmful substances. It is incombustible and corresponds to building material class A compliant with DIN 4102.

The freedom of choice for format, shape and dimensions, the variety of different stone colours and figuring, also the diverse range of surface treatments allow almost unlimited design options when using natural stone. Using square, rectangular, polygonal and even circular natural stone modules, a great variety of patterns are made possible in the flooring surface design.

Building materials such as natural stone are back in focus with regard to sustainable construction methods because they ideally meet the demands for sustainable building materials. In detail, the most important ecological aspects of sustainable construction are:

A. Reduction in energy demand and operating resource use
No energy is required to manufacture natural stone – it has been provided for us by nature. Natural stone is available as a finished product in the quarry and does not need to be manufactured using mixture of raw materials and, as is the case for ceramics, fired at very high temperatures. Only relatively low energy input is needed during extraction in the quarry and subsequent finishing in a processing plant, to manufacture finished products of natural stone.

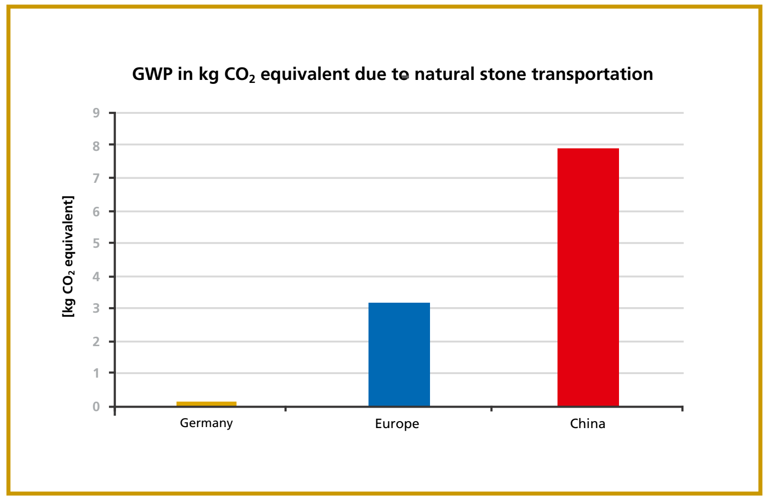
B. Prevention of transportation of building materials
There are natural stone resources in every country. Germany, in particular, has large quantities of workable natural stone. As a result of the great diversity of domestic granites, sandstones, limestones, shales, etc., the demand for dimension stone can generally be met by domestic resources. The use of local natural stone obviates the impact of long distance transportation and promotes building in harmony with the local landscape.
Natural stone transportation from the stone processing plant to the construction site plays a substantial role in terms of environmental impacts. This becomes obvious when comparing different production facilities.

Environmental impacts: Transportation						
	Transportation emissions to site					
Natural stone						
Distances		Germany	Europe	China		
		100 km lorry	2000 km lorry	18600 km container ship	150 km lorry	200 km train
GWP	kg CO_2 equiv.	1.5988E-01	3.1976E+00	7.5974E+00	2.3982E-01	1.0655E-01
∑	kg CO_2 equiv.	1.5988E-01	3.1976E+00	7.9438E+00		

Table 12: Transportation emissions

While only 0.16 kilograms CO_2 equiv. is produced when using local natural stone (100 km lorry transport), this increases to 3.2 kilograms CO_2 equiv. in the case of transport within Europe (2000 km lorry transport) and 7.9 kilograms CO_2 equiv. per square metre of flooring for natural stone from China (18,600 km by ship, 150 km by lorry and 200 km rail transport).

Figure 10: GWP from transportation of dimension stone

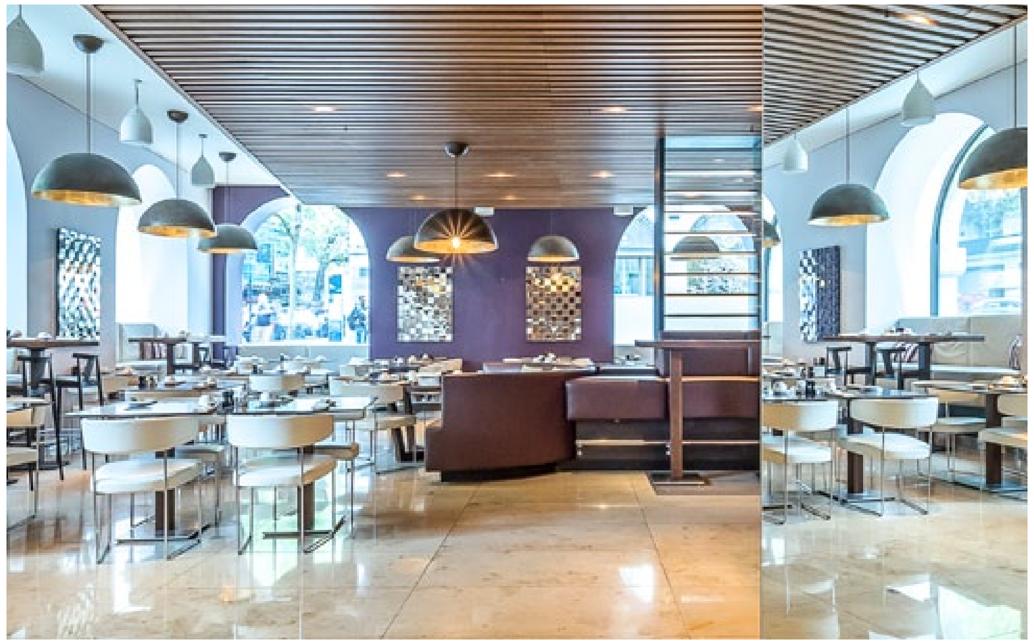


C. Use of reusable/recoverable building products
Natural stone products can be widely reused after the end of the structure's use phase. Many natural stone construction products, such as window sills, paving stones and bricks, for example, can be immediately used in new buildings. Solid workpieces such as gravestones can serve as a raw material for new natural stone products, façade slabs as floor coverings in gardens, etc. In addition, otherwise unusable natural stone slabs can be processed into crushed stone and gravel.

D. Extension of the service life of building products and structures
Natural stone has exceptionally long periods of use, measured in centuries. Natural stone coverings with heavy wear markings can be easily reground in situ, resulting in practically new coverings with minimal impact.

E. Return of building materials to the natural material cycle without hazards
Natural stone contains no pollutants and can easily be inserted into the natural material cycle.

9: London Restaurant Jura Limestone



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4 Life-cycle Costs

4.1 Data acquisition

The life-cycle costs of the floor coverings are identified and compared as part of this cost analysis. Both the cost of construction and costs incurred during the use of the floor coverings are incorporated. This is sometimes not taken into account when awarding contracts in line with the offer price. The mean service life anticipated for high and medium use floors was selected as the service life of the floor coverings. The costs relate to an area of 1500 square metres in order to simulate a large commercial or airport terminal area.

The costs were calculated using the German Federal Environmental Agency's *(Umweltbundesamt)* LCC tool. The interest rates used in the calculations are therefore those implemented in the Federal Environment Agency's database. Furthermore, numerical indicators are required to calculate the life-cycle costs of all eight floor coverings. The indicators used in the calculations are taken from a study by the *Forschungs- und Prüfinstitut für Facility Management GmbH* (Facility Management Research and Testing Institute), which was authored by Martin Lutz [7].
These indicators are average values taken from numerous suppliers and products and always relate to one square metre of floor covering. Subsequently, four sub-areas necessary to calculate the life-cycle costs are presented.

4.2 Procurement costs

Procurement costs, also known as partial construction costs, include the material costs, the costs for preparing the substrate together with installation, the costs for cutting and adhesives, also costs for jointing, where relevant. For example, skirting boards are not taken into consideration, because the options included too many different variations. The data uses the unit €/m².

4.3 Cleaning costs

All material and personnel costs are included in the cleaning and maintenance costs. The costs are influenced by such factors as the type of covering, cleaning frequency, method, quality and many others. In terms of cleaning quality, the value of high-quality cleaning was always selected. The costs use the unit €/m²/year.

4.4 Refurbishment costs

Some of the floor coverings require refurbishment during their technical service life. Refurbishments occur in intervals, which are given with the respective floor covering. They use the unit €/m².

4.5 Disposal costs

The costs of disposal in this case are also referred to as building maintenance costs. They take into account the resulting personnel and material costs for restoring or replacing worn floor coverings at the end of their technical service lives. In addition, they also include the disposal costs of the old flooring and the preparation of the substrate for the new flooring. These costs use the unit €/m².

4.6 Results

A summary of the costs for an area of 1,500 m² and the period of use of 50 years is shown in Table 13.

Cost analysis in euros								
	Nat. st. tile	Nat. st. slab	Terr. tile.	Ceram. tile	Parquet	PVC	Laminate	Carpet
Procurement	114,000 €	114,000 €	97,500 €	73,500 €	97,500 €	40,500 €	64,500 €	46,500 €
Cleaning	1,452,179 €	1,452,179 €	1,452,179 €	1,452,179 €	1,499,493 €	1,452,179 €	1,499,493 €	687,855 €
Refurbishment	– €	– €	– €	– €	118,415 €	30,912 €	– €	– €
Replacement	– €	– €	– €	– €	– €	33,015 €	207,852 €	144,754 €
Disposal	– €	– €	– €	– €	– €	57,046 €	– €	– €
Total costs	1,566,179 €	1,566,179 €	1,549,679 €	1,525,679 €	1,715,408 €	1,613,652 €	1,771,845 €	879,109 €

Table 13:
Cost analysis

A comparison of natural stone, terrazzo tile, ceramic tile, PVC, laminate, parquet and carpet floor coverings shows that cleaning costs account for a large proportion of the life-cycle costs. Increasing the quality of cleaning also increases the service life of the floor coverings. However, the cleaning costs increase simultaneously. If cleaning frequency is reduced, cleaning costs simultaneously decrease. In contrast, the service life of the floor coverings decreases. However, it is important that not only the cost aspect of cleaning is considered, but also the hygiene and the visual appearance of the floor. Because the lower the cleaning quality, the higher the degree of soiling of the floor and, consequently, the poorer the standard of hygiene. If both visual appeal and good hygiene are valued, cleaning costs should not be spared.

10: Lounge of Lufthansa Greywacke

10

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11+12: SAFE Haus der Energiewirtschaft, Salzburg Krastal Marble

Appendix A Description of Assessed Variables

Appendix A 1 Primary Energy Demand

Primary energy demand can be met by different types of energy sources. The primary energy demand is the amount of energy or directly extracted from the hydrosphere, atmosphere or geosphere, which has not yet undergone anthropogenic transformation. With regard to fossil fuels and uranium, for example, this equates to the quantity of resource extracted, expressed as an energy equivalent (energy content of energy resources). With regard to renewable energy sources, for example, the quantity of biomass used, characterised by its energy content, is described. In terms of hydropower, we refer to the quantity of energy gained from the change in potential energy (from the elevation difference) of the water. Aggregated values include the following primary energy sources:
The cumulative value for ***non-renewable total primary energy supply*** in MJ essentially characterises the use of the energy sources natural gas, crude oil, lignite, anthracite and uranium. Natural gas and crude oil are used both for power generation and as a constituent of plastics, for example. Coal is predominantly used for power generation. Uranium is used exclusively for power generation in nuclear power stations.
The cumulative value for ***renewable total primary energy supply***, given in MJ, is generally given separately and comprises wind and hydropower, solar energy and biomass.
It is important that the final energy consumed (for example, 1 kWh of electricity) and the primary energy used to achieve this are not offset against each other, otherwise the final energy production efficiency would not be taken into consideration.
The energy content of the manufactured products is reported as a material related energy content. It is characterised by the net calorific value of the product. It represents the remaining usable energy content.

Appendix A 2 Greenhouse Effect (GWP)

The active mechanism of the greenhouse effect can be observed on a smaller scale, as the name implies, in greenhouses. This effect also occurs on a global scale. Incoming short-wave solar radiation strikes the earth's surface where it is partially absorbed (which leads to direct warming) and partly reflected as infrared radiation. The reflected proportion is absorbed in the troposphere by what are known as greenhouse gases and radiated again in all directions, meaning that it is partially reflected back to earth. This leads to additional warming.
The global warming potential is given as a carbon dioxide equivalent (CO_2 equiv.). This means that all emissions are given with reference to CO_2 in terms of their potential greenhouse effect.

Appendix A 3 Acidification Potential (AP)

The acidification of soils and water bodies is caused mainly by the conversion of air pollutants into acids. This results in a reduction in the pH of rainwater, mist and fog from 5.6 to 4 and below. Relevant inputs are delivered by sulphur dioxide and nitrogen oxides with their acids (H_2SO_4 and HNO_3). This causes damage to ecosystems, the foremost effect being forest dieback.
The acidification potential is given as a sulphur dioxide equivalent (SO_2 equiv.).

Appendix A 4 Eutrophication Potential (EP)

By eutrophication or nutrient input, we refer to an accumulation of nutrients at a specific location. We differentiate between aquatic and terrestrial nutrient input. Atmospheric pollutants, waste water and agricultural fertilisers all contribute to eutrophication.
The eutrophication potential is given as the phosphate equivalent (PO_4 equiv.).

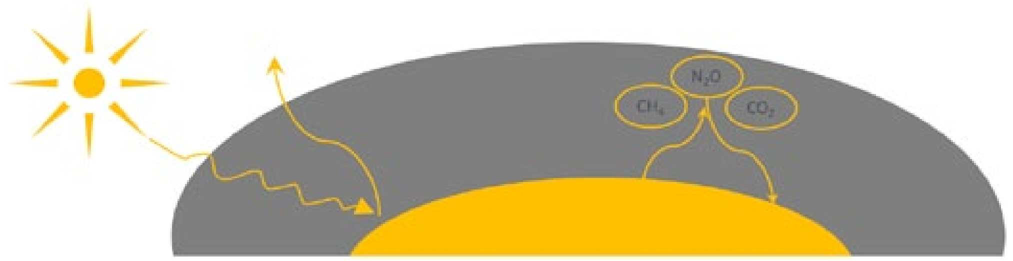
Appendix A 5 Photochemical Ozone Creation Potential (POCP)

In contrast to the protective function in the stratosphere, ground-level ozone is classified as a harmful trace gas. Photochemical ozone formation in the troposphere, also referred to as summer smog, is suspected of causing damage to vegetation and other materials. Higher concentrations of ozone are toxic to humans.
The photochemical ozone creation potential (POCP) is given as an ethylene equivalent (C_2H_4 equiv.) in the life-cycle assessment.

Appendix A 6 Ozone Depletion Potential (ODP)

Ozone is created at high altitudes by the irradiation of oxygen molecules by short-wave UV light. This leads to the formation of the so-called ozone layer in the stratosphere (15 – 50 km altitude). About 10% of the ozone passes into the troposphere through mixing processes. Despite its low concentration, the effect of ozone is important for life on earth. Ozone absorbs short-wave UV radiation and re-emits a longer wavelength in all directions, hence only some of the UV radiation reaches the earth. Anthropogenic emissions lead to depletion of the ozone layer.
The ozone depletion potential of the respective substance is given as an R11 equivalent.

GWP 100 – Global Warming Potential, given as kg CO_2 equivalent



- Impact of the anthropogenic greenhouse effect, which leads to global warming.
- Caused by greenhouse gases such as CO_2, dinitrogen monoxide (N_2O) and methane (CH_4); they reflect long-wave radiation and prevents it from passing through the atmosphere. Because of the varying residence times of the gases a time horizon is determined, usually 100 years.

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13: Global warming potential

Appendix B Life-cycle Assessment Study Data Calculation

B.1 Substructure Analysis

B.1.1 Concrete in compressive strength class C20/25

The declared product is an unreinforced concrete, which is delivered to the construction site as ready mixed concrete or precast concrete. The amount of reinforcing steel is considered separately. The reference service life of the concrete is designed for or specified as at least 50 years. The concrete is declared in the unit cubic metres. The EPD corresponds to the type *from the cradle to the factory gate with options*. The resulting values are listed in Table B1.

Environmental impacts: Concrete in compressive strength class C20/25					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	3.433E+01	7.830E-01	0	**3.511E+01**
ODP	kg R11 equiv.	1.208E-07	5.796E-10	0	**1.2136E-07**
AP	kg SO_2 equiv.	4.914E-02	3.344E-03	0	**5.2484E-02**
EP	kg (PO_4)△3 equiv.	7.830E-03	7.128E-04	0	**8.5428E-03**
POCP	kg ethylene equiv.	5.940E-03	3.328E-04	0	**6.2728E-03**
PERT	MJ	1.301E+01	3.654E-01	0	**1.3379E+01**
PENRT	MJ	1.523E+02	1.080E+01	0	**1.6308E+02**

Table B1: Concrete slab life-cycle assessment

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The emissions per cubic metre of concrete were multiplied by the thickness of the concrete slab of 0.18 metres. This results in the required function: emissions per square metre of concrete slab relative to a thickness of 18 centimetres.

Installation stage:
Modules A4 and A5 were also declared. The sum of the two modules was multiplied by the thickness of 0.18 metres, as for the production stage. The result is the emissions per square metre of the concrete slab relative to the layer thickness of 0.18 metres.

Use stage:
No environmental burdens occur during the reference service life of concrete elements, because no measures for cleaning or repair are generally necessary. Furthermore, the concrete is not replaced during the period of use studied here. For this reason, it is assumed that no, or only negligibly low, emissions are assigned to this stage.

B.1.2 Reinforcing steel for concrete reinforcement

The *Badischen Stahlwerke GmbH* reinforcing steel serves as reinforcement for the above-named concrete. According to the EPD, the reference service life is 50 years. The reinforcing steel was declared in kilograms, the EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B2.

Environmental impacts: Reinforcing steel for concrete reinforcement					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	3.1200E+00	1.8000E-01	0	**3.3000E+00**
ODP	kg R11 equiv.	1.2240E-06	3.1200E-12	0	**1.2240E-06**
AP	kg SO_2 equiv.	8.3640E-03	8.2800E-04	0	**9.1920E-03**
EP	kg (PO_4)△3 equiv.	9.9960E-04	1.9200E-04	0	**1.1916E-03**
POCP	kg ethylene equiv.	7.5240E-04	-2.7600E-04	0	**4.7640E-04**
PERT	MJ	1.1376E+01	9.8400E-02	0	**1.1474E+01**
PENRT	MJ	9.2532E+01	2.5200E+00	0	**9.5052E+01**

Table B2: Reinforcing steel life-cycle assessment

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. This aggregated module, which contains the emissions per kilogram of reinforcing steel, is multiplied by the 12 kilogram quantity required for one square metre of surface area.

Installation stage:
The A4 *transportation* module is declared. Module A5 is not declared. It is assumed that installation is performed manually. The delivery lorry is unloaded by crane, but this is recorded at the building level as a component of the site management. For this reason, no emissions are anticipated here for the A5 module.

Use stage:
For module B1, it is declared that no environmental burdens occur in the use stage. No emissions are anticipated during the given service life in the remaining modules B2 to B7.

B.1.3 PE bubble foil for sealing

The EPD of the PE bubble foil was adopted, simplified, for the PE foil, which is laid over the concrete slab and the impact sound insulation to prevent moisture absorption by the insulation. The reference service life is more than 50 years. The EPD is declared in units of square metre at a specific weight of 1.2 kg/m². The EPD type is *from the cradle to the factory gate*. The resulting values are listed in Table B3.

Environmental impacts: PE bubble foil separating foil					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	9.2115E-01	2.2654E-03	0	**9.2342E-01**
ODP	kg R11 equiv.	1.4771E-12	4.4767E-16	0	**1.4775E-12**
AP	kg SO_2 equiv.	1.5189E-03	5.1750E-06	0	**1.5241E-03**
EP	kg (PO_4) ≙3 equiv.	1.6286E-04	1.2103E-06	0	**1.6407E-04**
POCP	kg ethylene equiv.	2.5829E-04	-1.4785E-06	0	**2.5681E-04**
PERT	MJ	1.1146E+00	2.0667E-03	0	**1.1166E+00**
PENRT	MJ	2.7186E+01	3.0802E-02	0	**2.7217E+01**

Table B3: PE bubble foil life-cycle assessment

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The module was converted to the functional unit. The weight, which is approximately 0.276 kilograms, was determined for a thickness of 0.3 millimetres. Finally, this results in the emissions of the film for one square metre and a cumulative thickness of 0.3 millimetres (0.2 millimetres + 0.1 millimetre).

Installation stage:
Module A4 is not declared. It is assumed that the product is transported to the site by small lorry. The haulage capacity is 1000 kg/km. The emissions were determined for an assumed weight of 0.276 kg/m² and a transportation distance of 100 kilometres. It was assumed for module A5 that installation was performed manually and that this produces no environmental impacts.

Use stage:
The use stage is not declared. It is assumed that there are no emissions during use (module B1). Moreover, no maintenance (module B2), repair (module B3) or replacement (module B4) is assumed within the selected study period.

B.1.4 EPS rigid foam for ceilings and floors

This product is a rigid foam insulation product, which is laid as thermal and acoustic insulation under a floating screed. According to the EPD, the reference service life is 40 years, however, a floor structure would not be dismantled into its individual components after 40 years in order to allow replacement. For this reason, replacement of the impact sound insulation is not taken into consideration. The rigid foam is declared in the unit m³. The EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B4.

Environmental impacts: EPS Rigid Foam for Ceilings and Floors					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	1.5080E+00	1.7720E-02	0	**1.5257E+00**
ODP	kg R11 equiv.	8.1800E-09	3.7000E-13	0	**8.1804E-09**
AP	kg SO_2 equiv.	3.4200E-03	4.7400E-05	0	**3.4674E-03**
EP	kg (PO_4) ≙3 equiv.	3.1000E-04	1.0840E-05	0	**3.2084E-04**
POCP	kg ethylene equiv.	1.0840E-02	-1.3860E-05	0	**1.0826E-02**
PERT	MJ	5.5000E-01	1.4360E-02	0	**5.6436E-01**
PENRT	MJ	4.4600E+01	2.4200E-01	0	**4.4842E+01**

Table B4: Impact sound insulation life-cycle assessment

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The impact indicator values are multiplied by the thickness of the impact sound insulation of 0.02 metres and result in the emissions for one square metre of impact sound insulation relative to a thickness of two centimetres.

Installation stage:
Module A4 (transportation) was declared in the structure's installation stage. Installation (module A5) is performed by hand, any environmental impacts from tasks such as sawing to size, for example, are regarded as minor, meaning that negligible environmental impacts can be assumed. Packaging is not taken into account, because disposal is carried out by qualified waste disposal companies. The emissions for transportation are calculated identically to the production stage.

Use stage:
According to the EPD no environmental pollution occurs during use (module B1). In addition, maintenance, repair or replacement (modules B2, B3 and B4) are not anticipated during the study period, because the floor is not dismantled to allow the impact sound insulation to be replaced. It remains within the floor structure until it must be replaced or repaired as a whole. There are no energy inputs for water and energy (modules B6 and B7) during use.

B.1.5 Screed mortar, cement screed

This EPD describes the environmental impacts of mineral mortar in the form of cementitious screed, which is used as a floating screed in floor construction. According to the EPD, the reference service life is 50 years or longer. The product is declared in kilograms. The EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B5.

Environmental impacts: Screed mortar, cement screed					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	1.6380E+01	9.8700E-01	-1.3860E-01	**1.7228E+01**
ODP	kg R11 equiv.	1.3650E-09	2.1368E-11	0	**1.3864E-09**
AP	kg SO_2 equiv.	2.2785E-02	3.7246E-03	0	**2.6510E-02**
EP	kg $(PO_4)^{3-}$ equiv.	4.2000E-03	8.9997E-04	0	**5.1000E-03**
POCP	kg ethylene equiv.	1.3335E-03	-1.2555E-03	0	**7.8047E-05**
PERT	MJ	8.3370E+00	6.7757E-01	0	**9.0146E+00**
PENRT	MJ	1.1235E+02	1.1396E+01	0	**1.2375E+02**

Table B5: Cement screed life cycle assessment

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The weight of the cement screed layer can be determined with the aid of the bulk density and the selected screed layer thickness of seven centimetres. The weight is 105 kg/m². The impact indicator values are therefore multiplied by the factor 105.

Installation stage:
The declared transportation A4 and installation A5 modules are active in the structure installation stage. Both modules have defined values. The A5 values are based on incineration of the packaging. The functional unit is again achieved by multiplication with the factor 105.

Use stage:
According to the EPD, some carbon dioxide is bonded by carbonation during the use phase, which reduces the GWP slightly. Maintenance, repair, replacement or renewal (modules B2 to B5) are not anticipated. The functional unit is again achieved by multiplication with the factor 105.

B.1.6 Dispersion-based primers/bonding agents

This product is a primer that is applied to the previously installed screed to achieve a level surface and improved adhesion. One side effect of this is that it simultaneously facilitates a significantly extended service life. There are no specific reference service lives per se for either primers or adhesive mortars, because they fulfil many different and often specific tasks in the construction and furnishing of structures. The product is declared in kilograms. This EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B6.

Environmental impacts: Dispersion-based primers and bonding agents					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	4.5800E+00	3.6720E-01	0	**4.9472E+00**
ODP	kg R11 equiv.	1.1440E-09	3.0280E-12	0	**1.1470E-09**
AP	kg SO_2 equiv.	4.8200E-02	3.5760E-04	0	**4.8558E-02**
EP	kg $(PO_4)^{3-}$ equiv.	1.4280E-03	8.7480E-05	0	**1.5155E-03**
POCP	kg ethylene equiv.	3.4000E-03	5.5864E-02	0	**5.9264E-02**
PERT	MJ	5.5400E+00	4.5820E-02	0	**5.5858E+00**
PENRT	MJ	1.0040E+02	7.4200E-01	0	**1.0114E+02**

Table B6: Primer life cycle assessment

Production stage:
The production stage information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. It is assumed that approximately one kilogram of this product is used per square metre and one millimetre thick layer. The impact indicator values are therefore multiplied by the factor 2 for the two millimetre thick primer layer.

Installation stage:
Module A4 transportation and module A5 installation have defined values. The values of A5 are based on both the incineration of the packaging and emissions during installation. The required output quantity is determined as in the production stage.

Use stage:
The use stage was not declared. If the floor covering is replaced, new primer is also applied. This is allocated to module B4 replacement. Maintenance (module B2), repair (module B3) and renewal (module B5) are not anticipated.

B.2 Floor Covering Analysis

B.2.1 Natural stone tiles

An up-to-date (2017) *Franken-Schotter GmbH & Co. KG* EPD for Jura Limestone tiles was used for the life-cycle assessment of natural stone tiles, which are defined as natural stone products with a nominal thickness ≤ 12 mm compliant with German standard DIN EN 12057.

These coverings are used in both the private and commercial and in public sectors. According to the EPD, the reference service life is far greater than 50 years. The natural stone is declared in tonnes. The correction factors for varying natural stone thicknesses are incorporated in the conversion of the impacts to the reference unit square metres. The EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B7.

Environmental impacts: Jura Limestone natural stone tile					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	4.1501E+00	2.6988E-01	2.1646E+00	**6.5846E+00**
ODP	kg R11 equiv.	3.2262E-12	8.9800E-14	1.1194E-07	**1.1194E-07**
AP	kg SO_2 equiv.	1.4450E-02	6.0726E-04	4.9530E-03	**2.0010E-02**
EP	kg (PO_4) ≙ 3 equiv.	2.0656E-03	1.4964E-04	3.1787E-03	**5.3939E-03**
POCP	kg ethylene equiv.	1.0220E-03	-2.3291E-04	1.2539E-03	**2.0430E-03**
PERT	MJ	2.8631E+02	1.8454E-01	7.3518E+00	**2.9385E+02**
PENRT	MJ	5.0399E+01	2.1147E+00	3.0714E+01	**8.3227E+01**

Table B7: Natural stone tile life cycle assessment

Production stage:
In this case, the manufacturing phase information modules A1, A2 and A3 were all exactly declared and given as the aggregated module A1–A3. The EPD data were adapted using a correction factor for conversion to the functional unit. In addition, the corrected values must be divided by 38.46 to arrive at the emissions per square metre. The result is the emissions for one square metre of natural stone tile with a thickness of ten millimetres.

Installation stage:
Only module A4, which comprises transportation, is declared for the installation stage. In terms of installation A5, no information on the environmental impacts was provided. The values for ceramic tiles were used for this, because packaging and installation are comparable. The A4 emissions are calculated as described in the production stage.

Use stage:
The information modules in the use stage are not all declared. No emissions are caused during use (module B1). Module B2 has been declared in terms of maintenance and includes cleaning the floor covering for one year.

The cleaning emissions are then extended to the study period of 50 years. The modules B3–B5 have not been implemented in this EPD. It is assumed that repairs are negligible, and that replacement and modernisation do not take place.

B.2.2 Natural stone slabs

An up-to-date (2017) *Franken-Schotter GmbH & Co. KG* EPD for Jura Limestone slabs was used for the life-cycle assessment of natural stone slabs, which are defined as natural stone products with a nominal thickness > 12 mm compliant with German standard DIN EN 12058.


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14: Multi-purpose sports hall, Weißenhorn Kohlplatter Muschelkalk

15: Granite slabs packed for delivery on wooden pallets

Natural stone slabs are predominantly deployed in high-performance areas such as shopping-centres, railway stations and airport terminals. According to the EPD, the reference service life is far greater than 50 years. The natural stone is declared in tonnes. The correction factors for varying natural stone thicknesses are incorporated in the conversion of the impacts to the reference unit square metres. The EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B8.

The stages are not described here in detail because they correspond exactly to the natural stone tile processes. Because the thickness of the 10 millimetre thick tile is half that of the 20 millimetre slab, the corrected values should be divided by the correspondingly reduced factor of 19.23 to arrive at the emissions per square metre.

Environmental impacts: Natural stone slab (façade and wall facings)					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	4.0183E+00	4.2730E-01	1.5601E-01	**4.6016E+00**
ODP	kg R11 equiv.	4.5097E-12	1.1275E-13	8.6193E-09	**8.6240E-09**
AP	kg SO_2 equiv.	1.1045E-02	1.2137E-03	3.8027E-04	**1.2639E-02**
EP	kg (PO_4) ≙ 3 equiv.	1.6832E-03	3.0191E-04	2.4415E-04	**2.2293E-03**
POCP	kg ethylene equiv.	8.2553E-04	-4.7763E-04	9.6334E-05	**4.4424E-04**
PERT	MJ	8.4037E+01	3.0057E-01	5.8502E-01	**8.4923E+01**
PENRT	MJ	5.8941E+01	4.4105E+00	2.3791E+00	**6.5731E+01**

Table B8: Natural stone slab life cycle assessment

B.2.3 Terrazzo tile

The data taken from the EPD are converted to the required concrete slab dimensions. According to the EPD, the reference service life is greater than 50 years. The life-cycle assessment data are declared here per square metre. The EPD type is *from the cradle to the factory gate*. The resulting values are listed in Table B9.

Environmental impacts: Terrazzo tile/precast concrete blocks					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	9.5475E+00	7.9256E-01	2.1646E+00	**1.2505E+01**
ODP	kg R11 equiv.	2.0398E-11	2.0500E-13	1.1194E-07	**1.1196E-07**
AP	kg SO_2 equiv.	1.6571E-02	1.6332E-03	4.9530E-03	**2.3157E-02**
EP	kg (PO_4)≙3 equiv.	2.3419E-03	3.8299E-04	3.1787E-03	**5.9036E-03**
POCP	kg ethylene equiv.	5.1338E-04	-4.7457E-04	1.2539E-03	**1.2927E-03**
PERT	MJ	1.7108E+01	6.2327E-01	7.3518E+00	**2.5083E+01**
PENRT	MJ	6.5025E+01	9.3058E+00	3.0714E+01	**1.0504E+02**

Table B9: Terrazzo tile life-cycle assessment

Production stage:
The production stage information modules A1, A2 and A3 are declared and given separately. The EPD of the terrazzo tile is made with reference to a thickness of eight centimetres. The desired functional unit is arrived at by correlation to the required thickness of three centimetres.

Installation stage:
The installation stage is not declared. Suitable assumptions were made for transportation. The transportation emissions of a lorry in the *Ökobaudat* database (transportation distance 150 kilometre) were adopted for the analysis. The impact indicator values of the ceramic tiles were adopted for installation module A5, because installation and packaging are comparable for all three stone coverings.

Use stage:
Similarly, the use stage is not declared. It is stated for module B1 that given the intended use of the concrete slab, no environmental impacts are anticipated. Assumptions must be made for modules B2–B4 for maintenance, repair and replacement. With regard to B2, cleaning was adopted from the emissions for natural stone cleaning (with reference to 50 years) and converted accordingly. It is assumed that any repairs (module B3) such as the replacement of individual terrazzo tiles, are negligible. Replacement (module B4) or modernisation (module B5) are not anticipated within the 50-year period.

B.2.4 Ceramic tiles

This declared product is a ceramic tile. The reference service life is more than 50 years, and the expected life of this floor covering is empirically shown to be between 80 and 150 years. The covering is declared in units of square metres. The EPD type is *from the cradle to the grave*. The resulting values are listed in Table B10.

Environmental impacts: Ceramic tiles and slabs					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	1.294E+01	3.700E-01	0.000E+00	**1.331E+01**
ODP	kg R11 equiv.	5.660E-10	3.900E-13	4.342E-11	**6.098E-10**
AP	kg SO_2 equiv.	2.420E-02	6.610E-04	3.075E-03	**2.794E-02**
EP	kg (PO_4)≙3 equiv.	2.690E-03	1.824E-04	1.060E-03	**3.932E-03**
POCP	kg ethylene equiv.	2.100E-03	-1.895E-04	9.490E-04	**2.860E-03**
PERT	MJ	1.823E+01	2.700E-01	6.500E+00	**2.500E+01**
PENRT	MJ	2.203E+02	3.520E+00	2.600E+01	**2.498E+02**

Table B10: Ceramic tiles life cycle assessment

Production stage:
The production stage information modules A1, A2 and A1 are declared and given as an aggregated module A1–A3.

Installation stage:
The installation stage is also declared.

Use stage:
All modules in the use stage are declared. Module B1 describes the emissions during use. However, the tiles are not expected to give rise to any harmful substances. In module B2, the values result from incorporating cleaning of the floor covering and the necessary circumstances and materials over the 50-year period. Modules B3–B5 are also taken into account, but the environmental impacts here are negligible. Information modules B6 and B7 are declared; however, there is no environmental impact as neither water nor electricity are used.


16


17

16: Entrance area with polished concrete floor

17: Reception hall with ceramic tiles

B.2.5 Large-format ceramics

This declared product is a large-format ceramic tile by *Laminam*. The reference service life is more than 25 years. The covering is declared in units of square metres. The EPD type is *from the cradle to the grave*. The resulting values are listed in Table B11.

Environmental impacts: Large-format ceramics					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	1.9E+01	9.36E+00	3.78E+01	**6.62E+01**
ODP	kg R11 equiv.	3.04E-06	1.07E-06	4.78E-06	**8.88E-06**
AP	kg SO_2 equiv.	1.07E-01	5.95E-02	2.20E-01	**3.86E-01**
EP	kg (PO_4)≙3 equiv.	2.66E-02	1.68E-02	6.16E-02	**1.05E-01**
POCP	kg ethylene equiv.	1.13E-02	7.16E-03	3.62E-02	**5.47E-02**
PERT	MJ	5.18E+01	1.15E+01	1.14E+02	**1.78E+02**
PENRT	MJ	3.38E+02	1.62E+02	7.86E+02	**1.29E+03**

Table B11: Large-format ceramics life-cycle assessment

Production stage:
The production stage information modules A1, A2 and A1 are declared and given as an aggregated module A1–A3.

Installation stage:
The installation stage is also declared.

Use stage:
All modules in the use stage are declared. Module B1 describes the emissions during use. However, the tiles are not expected to give rise to any harmful substances. In module B2, the values result from incorporating cleaning the floor covering and the necessary circumstances and materials over a one-year period and extended to cover a 50-year study period. Modules B3 and B5 are also taken into account, but the environmental impacts here are negligible. Module B4 results from replacement of the covering after 25 years. This leads to emissions A1–A5 and C1–D. Information modules B6 and B7 are declared; however, there is no environmental impact as neither water nor electricity are used.

18: Restaurant with large-format ceramic slabs as floor covering

18

B.2.6 Parquet

This product is an Association of the German Parquet Industry multi-layer parquet. According to the EPD the service life of multi-layer parquet is 40 years. It can be installed either floating or bonded to a screed, and also over older floor coverings. The EPD is declared in m². The declaration type corresponds to a *from the cradle to the factory gate with options* EPD. The resulting values are listed in Table B12.

Environmental impacts: Multi-layer parquet					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	-5.2740E+00	1.0339E+00	4.2379E+00	**-2.2000E-03**
ODP	kg R11 equiv.	1.5397E-06	2.8044E-12	1.1543E-07	**1.6552E-06**
AP	kg SO_2 equiv.	4.4440E-02	2.5986E-04	3.8336E-02	**8.3036E-02**
EP	kg (PO_4)≙3 equiv.	9.8360E-03	5.5230E-05	9.8415E-03	**1.9733E-02**
POCP	kg ethylene equiv.	6.8370E-03	-3.9890E-05	6.3701E-03	**1.3167E-02**
PERT	MJ	4.8411E+02	9.1278E-02	4.7720E+02	**9.6140E+02**
PENRT	MJ	1.6960E+02	1.1808E+00	4.0495E+01	**2.1128E+02**

Table B12: Multi-layer parquet

Production stage:
In the production stage, modules A1–A3 are given and declared separately, in reference to one square metre.

Installation stage:
No data is available for transportation and installation (modules A4 and A5), meaning that suitable assumptions needed to be made. The *Meister Longlife Parquet* dataset in the *Ökobaudat* database was used for this purpose. It was possible to convert both modules to one square metre by applying of the specific weight of 8.8 kg/m².

Use stage:
It can be assumed that no emissions are caused during use, nor is any maintenance, repair and modernisation assumed (modules B1, B3–B5).

19: Office loft with parquet flooring

19

B.2.7 Carpet flooring

This product is a tufted, rolled carpet. The EPD is with reference to one square metre. The EPD type is *from cradle to grave*. According to the EPD, the carpet is classified compliant with DIN EN 1307 [5] as usage class 33, i. e. it is suitable for heavy use in commercial applications. DIN EN 1307 refers to the classification defined in compliance with EN ISO 10874 [6]. According to the EPD the service life of the carpet is at least ten years. The values are listed in Table B13.

Environmental impacts: Tufted carpet					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	1.39E+01	2.1400E+00	7.8120E+01	**9.4160E+01**
ODP	kg R11 equiv.	4.94E-08	3.0101E-08	3.6545E-07	**4.4495E-07**
AP	kg SO_2 equiv.	2.81E-02	4.3320E-03	1.9248E-01	**2.2491E-01**
EP	kg (PO_4)≙3 equiv.	4.35E-03	1.0937E-03	3.0245E-02	**3.5689E-02**
POCP	kg ethylene equiv.	4.22E-03	4.4300E-04	2.7294E-02	**3.1957E-02**
PERT	MJ	1.05E+01	3.2700E+00	8.0800E+01	**9.4570E+01**
PENRT	MJ	2.67E+02	3.0900E+01	1.3437E+03	**1.6416E+03**

Table B13: Tufted carpet flooring

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3.

Installation stage:
The installation stage was also declared.

Use stage:
The use module B1 is declared and emissions are caused in the course of its first year of use, which are multiplied by four because the carpet is replaced four times. Cleaning is included in module B2. Here, the emissions are multiplied by 50 years, because the declared figures are with reference to one year. Furthermore, replacement (module B4) occurs. Modules A1–A5 and C2–D are cumulated for this purpose and then multiplied by four, because replacement occurs four times. No environmental impacts are anticipated for the remaining modules.

20: Carpet in shop

20

B.2.8 PVC

According to the EPD, this product group covers two millimetre thick PVC floor coverings. The reference service life is 20 years. The coverings were declared in units of square metres, the EPD deals with all life-cycle stages. According to the EPD the products comply with usage class 34 and are therefore suitable for very high-performance commercial applications. The resulting values are listed in Table B14.

Environmental impacts: PVC					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	7.80E+00	1.080E+00	3.9042E+01	**4.7922E+01**
ODP	kg R11 equiv.	1.70E-08	2.752E-10	4.7469E-08	**6.4745E-08**
AP	kg SO_2 equiv.	1.60E-02	2.500E-03	1.1670E-01	**1.3520E-01**
EP	kg (PO_4)≙3 equiv.	2.00E-03	4.700E-04	1.1457E-02	**1.3927E-02**
POCP	kg ethylene equiv.	5.60E-03	-2.700E-04	1.9028E-02	**2.4358E-02**
PERT	MJ	8.50E+00	1.760E+00	6.1794E+01	**7.2054E+01**
PENRT	MJ	1.80E+02	1.610E+01	8.0346E+02	**9.9956E+02**

Table B14: PVC

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3.

Installation stage:
The installation stage was also declared.

Use stage:
In this stage only the B2 module, which incorporates the emissions generated by cleaning the PVC, is declared. With regard to replacement (module B4), it was determined that the emissions for all modules are incurred twice in this stage, because the covering must be replaced twice. The remaining use stage modules are assumed to be *zero*.

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21: Vinyl flooring in shoe shop

B.2.9 Laminate

This EPD describes a product group in usage classes 31-34. The EPD refers to a product with a thickness of 9 millimetres and is extended to a thickness of 12 millimetres using existing conversion coefficients. The service life of the laminate is 20 years, thus the covering is exchanged twice within the study period. The EPD type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B15.

Environmental impacts: Laminate					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	-3.91E+00	3.806E-01	5.4635E+01	**5.1108E+01**
ODP	kg R11 equiv.	1.51E-09	1.478E-12	-6.2101E-09	**-4.6957E-09**
AP	kg SO_2 equiv.	3.38E-02	6.308E-04	7.6029E-02	**1.1048E-01**
EP	kg (PO_4) ≙ 3 equiv.	8.10E-03	1.562E-04	2.6397E-02	**3.4654E-02**
POCP	kg ethylene equiv.	5.46E-03	-1.968E-04	1.6419E-02	**2.1684E-02**
PERT	MJ	2.39E+02	1.098E-01	4.4740E+02	**6.8691E+02**
PENRT	MJ	1.86E+02	1.917E+00	1.1047E+02	**2.9803E+02**

Table B15: Laminate

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3 for one square metre.

Installation stage:
The installation stage was also declared. The A4 transportation module and the A5 installation module, which incorporates installation, are listed and provided with impacts. These modules were cumulated and result in the environmental impacts.

Use stage:
In this stage only the B2 module, which incorporates the emissions generated by cleaning the laminate, is declared. Emissions A1–A5, C2, C3 and D are adopted twice for the B4 replacement module, because the covering must be replaced twice. Negligible, low emissions are assumed for the remaining modules and the values therefore adopted as *zero*.

22+23: Laminate flooring

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B.2.10 Sopro adhesive for terrazzo tile, natural stone and ceramic tiles

This declared product is a refined, cement-based adhesive mortar used to install the floor coverings. The service life depends on the replacement of the floor covering requiring the adhesive. It is declared in kilograms. This EPD comprises the type *from the cradle to the factory gate with options*. The resulting values are listed in Table B16.

Environmental impacts: Sopro's No. 1 Flexkleber					
	5 mm	Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	2.3250E+00	6.2200E-01	0	**2.9470E+00**
ODP	kg R11 equiv.	2.5800E-08	6.7150E-12	0	**2.5807E-08**
AP	kg SO_2 equiv.	8.6000E-03	8.6050E-04	0	**9.4605E-03**
EP	kg (PO_4) ≙ 3 equiv.	8.7500E-04	2.1110E-04	0	**1.0861E-03**
POCP	kg ethylene equiv.	7.3000E-04	-3.3010E-04	0	**3.9990E-04**
PERT	MJ	6.0000E+00	1.1030E-01	0	**6.1103E+00**
PENRT	MJ	3.8100E+01	1.8015E+00	0	**3.9902E+01**
	20 mm	Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	9.3000E+00	2.4880E+00	0	**1.1788E+01**
ODP	kg R11 equiv.	1.0320E-07	2.6860E-11	0	**1.0323E-07**
AP	kg SO_2 equiv.	3.4400E-02	3.4420E-03	0	**3.7842E-02**
EP	kg (PO_4) ≙ 3 equiv.	3.5000E-03	8.4440E-04	0	**4.3444E-03**
POCP	kg ethylene equiv.	2.9200E-03	-1.3204E-03	0	**1.5996E-03**
PERT	MJ	2.4000E+01	4.4120E-01	0	**2.4441E+01**
PENRT	MJ	1.5240E+02	7.2060E+00	0	**1.5961E+02**

Table B16: Adhesive mortar

Production stage:
The production stage information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The manufacturer claims that approximately one kilogram of the product is required per square metre and per millimetre of thickness. The values are therefore multiplied by the respective layer thickness (5 millimetres or 20 millimetres).

Installation stage:
Module A4 transportation and module A5 installation are declared. For calculations, the values are therefore again multiplied by the respective layer thicknesses (5 millimetres or 20 millimetres).

Use stage:
The use stage is not declared. Repair (module B3) or replacement (module B4) would only be necessary if a tile/slab needed replacement. However, this is regarded as being unlikely. For the remaining modules of the use stage it may be assumed that no emissions occur or the emissions that do occur are insignificant.

B.2.11 Akemi stone impregnation for natural stone

This *Akemi* product is used to impregnate stone floor coverings or other materials and thus prevent soiling. The ecological data originate from Akemi and are strictly confidential. The data comprise the manufacturing phase with the life-cycle phases A1–A3 and are given in kilograms.

Production stage:
According to *Akemi*, the Jura Limestone, which is ground to C220, will be initially treated with a single coating based on a yield of 14 m²/l. The emissions should be multiplied by the density of 0.76 kg/l and divided by the yield of 14 m²/l to return the environmental impact per square metre.

Installation stage:
For the transportation module it is assumed that the product is transported 100 kilometres by small lorry to the site. The small lorry dataset in the *Ökobaudat* database was used for this purpose.

Use stage:
Three refresher treatments within ten years are recommended for interior floor coverings, where a yield of 23 m²/l per treatment may be assumed. Thus, 15 refresher treatments in 50 years can be anticipated. The production stage values are therefore multiplied by 0.76 and 15 and then divided by 23.

B.2.12 Parquet adhesive

This product is an adhesive for parquet and polyurethane or SMP-based floor coverings, filled or water-based and solvent-free. Their use significantly improves the serviceability of structures and substantially extends their original service life. The anticipated reference service life depends on the specific installation situation and the associated product exposure. It can be influenced by weathering as well as by mechanical or chemical stresses. The product is declared in kilograms. Its density results in a quantity of 0.75 kilograms for a layer thickness of one millimetre per square metre. The EPD comprises the type *from the cradle to the factory gate with options*. The resulting values are listed in Table B17.

Environmental impacts: Multi-layer parquet adhesives					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	6.9900E+00	2.2620E-01	7.7798E+00	**1.4996E+01**
ODP	kg R11 equiv.	5.1000E-08	2.1375E-10	5.1562E-08	**1.0278E-07**
AP	kg SO_2 equiv.	2.1450E-02	2.6775E-04	2.1245E-02	**4.2963E-02**
EP	kg $(PO_4)^{3-}$ equiv.	4.0050E-03	6.5310E-05	4.0288E-03	**8.0991E-03**
POCP	kg ethylene equiv.	3.7500E-03	-1.0350E-04	3.5807E-03	**7.2272E-03**
PERT	MJ	4.7700E+00	3.4980E+03	3.5027E+03	**7.0054E+03**
PENRT	MJ	1.3380E+02	4.9740E+02	6.2871E+02	**1.2599E+03**

Table B17: Parquet adhesives

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. To allow conversion to the functional unit, the EPD values were multiplied by 0.75 in order to identify the necessary quantity for one square metre.

Installation stage:
The installation stage is declared. The emissions for transportation and installation of the adhesive are therefore given. They are multiplied by the factor 0.75 as in the production stage.

Use stage:
The entire use stage is not declared in this EPD. Assumptions are therefore necessary. It is assumed that the use, maintenance and repair stages (modules B1 to B3), and module B5 with information on modernisation, do not cause any environmental impacts. Replacement (module B4), however, causes environmental impacts, because the parquet, and thus also the adhesive, must be replaced once in the 50-year period.

B.2.13 Parquet sealant

The product comprises sealants for parquet flooring, floor coatings and polyurethane based floor coverings; solvent-based with a solvent content of less than 10%. Reactive resins are used to protect the surface of wood and parquet floors. Their use significantly improves the serviceability of structures and substantially extends their original service life. The anticipated reference service life depends on the specific installation situation and the associated product exposure. It is assumed that the sealant needs to be renewed four times. The EPD is declared in kilograms. The declaration type is *from the cradle to the factory gate with options*. The resulting values are listed in Table B18.

Environmental impacts: Multi-layer parquet sealant					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	3.2550E+00	1.1310E-01	1.3097E+01	**1.6466E+01**
ODP	kg R11 equiv.	2.4450E-08	4.4100E-12	9.7416E-08	**1.2187E-07**
AP	kg SO_2 equiv.	1.1625E-02	1.3388E-04	4.6091E-02	**5.7849E-02**
EP	kg $(PO_4)^{3-}$ equiv.	1.6650E-03	3.2655E-05	6.7075E-03	**8.4052E-03**
POCP	kg ethylene equiv.	1.8075E-03	1.1197E-02	5.1887E-02	**6.4892E-02**
PERT	MJ	3.2025E+00	1.2293E-02	1.2657E+01	**1.5872E+01**
PENRT	MJ	6.3825E+01	2.8920E-01	2.5148E+02	**3.1559E+02**

Table B18: Parquet sealant

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. To allow conversion to the functional unit, the EPD values were multiplied by the factor 0.75, because a quantity of 0.75 kilograms is required for a sealant layer thickness of 0.6 millimetres. This results in the emissions for one square metre of sealant.

Installation stage:
The installation stage was also declared in detail. The A4 transportation module and the A5 installation module are declared. These modules are cumulated and multiplied by the factor 0.75.

Use stage:
It is assumed that no emissions will be caused by use (module B1). In addition, it is assumed that no, or only negligible, maintenance, repair or modernisation measures (modules B3–B5) will be necessary. Because the sealant is renewed four times, the B4 replacement module incorporates the environmental impacts of modules A1–A5 and D four times. The disposal stage does not apply, because it is assumed that the sealant is disposed of together with the parquet and is negligibly low.

B.2.14 Levelling compound for laminate, carpet and PVC

This product is a floor levelling compound. By using Sopro OFS 543 levelling compound, the serviceability of structures can be improved and their original service life extended. The resulting values are listed in Table B19.

Environmental impacts: Levelling compound					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	2.0925E+00	5.5980E-01	1.2540E+02	**1.2805E+02**
ODP	kg R11 equiv.	2.3220E-08	6.0435E-12	9.4520E-08	**1.1775E-07**
AP	kg SO_2 equiv.	7.7400E-03	7.7445E-04	1.0356E+00	**1.0441E+00**
EP	kg $(PO_4)^{\triangleq 3}$ equiv.	7.8750E-04	1.8999E-04	2.0536E-01	**2.0633E-01**
POCP	kg ethylene equiv.	6.5700E-04	-2.9709E-04	1.2487E-01	**1.2523E-01**
PERT	MJ	5.4000E+00	9.9270E-02	1.1457E+02	**1.2007E+02**
PENRT	MJ	3.4290E+01	1.6214E+00	1.7266E+03	**1.7625E+03**

Table B19: Levelling compound

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. For conversion to the functional unit, the EPD data were multiplied by the factor 4.5.

Installation stage:
The installation stage was declared. The values were multiplied by the factor 4.5.

Use stage:
No modules were declared for the use stage. It was assumed that no, or negligibly low, environmental impacts may be anticipated from use, maintenance, repair and modernisation (modules B1, B3–B5). Because the levelling compound is also replaced when the floor covering is replaced, the environmental impacts of modules A1–A5 and C1–D (concrete C1–C4) reappear in module B4. In the previous table, the levelling compound is renewed 4 times. This process applies to the carpet flooring. The compound is renewed twice in the case of the PVC and laminate coverings.

B.2.15 Dispersion adhesive

The adhesive is a heavy-duty, solvent-free and very low-emission dispersion adhesive for textile floor coverings of all kinds and for linoleum. The service life of dispersion adhesives depends on the service life of the floor covering. The service life of textile coverings is approximately ten years. The EPD is declared in kilograms. It is of the type: *from cradle to factory gate with options*. The resulting values are listed in Table B20.

Environmental impacts: Dispersion adhesive for carpet					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	4.1358E-02	5.2605E-02	8.4878E-01	**9.4275E-01**
ODP	kg R11 equiv.	3.2968E-08	1.4715E-12	1.3180E-07	**1.6477E-07**
AP	kg SO_2 equiv.	9.3870E-04	7.3575E-05	3.9725E-03	**4.9848E-03**
EP	kg $(PO_4)^{\triangleq 3}$ equiv.	2.4224E-04	1.8180E-05	1.0603E-03	**1.3208E-03**
POCP	kg ethylene equiv.	1.5683E-04	-3.0245E-05	4.7405E-04	**6.0063E-04**
PERT	MJ	8.4659E-01	6.5925E-03	2.9817E+00	**3.8349E+00**
PENRT	MJ	6.9701E+00	1.6038E-01	2.2645E+01	**2.9775E+01**

Table B20: Dispersion adhesive

Production stage:
Modules A1–A3 are declared in the production stage. 0.45 kilograms are required for a layer thickness of one millimetre. The emissions are thus multiplied by the factor 0.45.

Installation stage:
The installation stage was also declared in detail. The A4 transportation module and the A5 installation module are declared. They are multiplied by the factor 0.45.

Use stage:
No modules were declared within the use stage. It is assumed that no emissions are caused as a result of use, maintenance, repair and modernisation, with the exception of replacement (module B4). Because the adhesive is renewed four times, the environmental impacts of modules A1–A5 and C2–D occur four times.

B.2.16 Flooring adhesive

This product is a flooring adhesive for textile and elastic coverings with a yield of 0.25 kg/m². The use of flooring adhesives significantly improves the serviceability of structures and substantially extends their original service life. The service life is dependent on the overlying covering. The declared unit is kilogram. The declaration is thus *from the cradle to the factory gate with options*. The resulting values are listed in Table B21.

Environmental impacts: Flooring adhesive for elastic flooring					
		Production stage	Installation stage	Use stage	Sum of emissions per square metre
GWP	kg CO_2 equiv.	2.3875E-01	4.5900E-02	7.8037E-01	**1.0650E+00**
ODP	kg R11 equiv.	5.8500E-11	3.7850E-13	2.8908E-10	**3.4796E-10**
AP	kg SO_2 equiv.	6.3500E-04	4.4700E-05	1.4286E-03	**2.1083E-03**
EP	kg $(PO_4)^{3-}$ equiv.	7.6000E-05	1.0935E-05	1.8896E-04	**2.7590E-04**
POCP	kg ethylene equiv.	1.4700E-04	7.4475E-05	4.4459E-04	**6.6607E-04**
PERT	MJ	3.7000E-01	5.7275E-03	7.0474E-01	**1.0805E+00**
PENRT	MJ	6.6750E+00	9.2750E-02	1.3113E+01	**1.9881E+01**

Table B21: Flooring adhesive

Production stage:
The manufacturing phase information modules A1, A2 and A3 are declared and given as the aggregated module A1–A3. The required functional unit is given by multiplying by the yield.

Installation stage:
The installation stage was also declared. The A4 transportation module and the A5 installation module are multiplied by the 0.25 kg/m² yield factor.

Use stage:
This stage was not declared at all. It is assumed that the adhesive, in analogy to the PVC covering, is replaced twice and the values for this module are consequently given by the sum of the values for modules A1–A5 and C2–D. The remaining information modules are adopted at *zero*.

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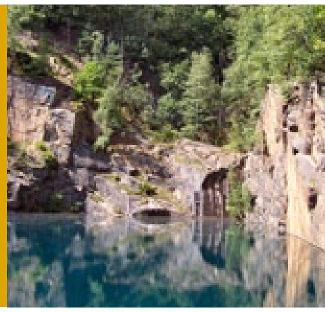

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