Waibel Frankfurt GmbH

MASTER®
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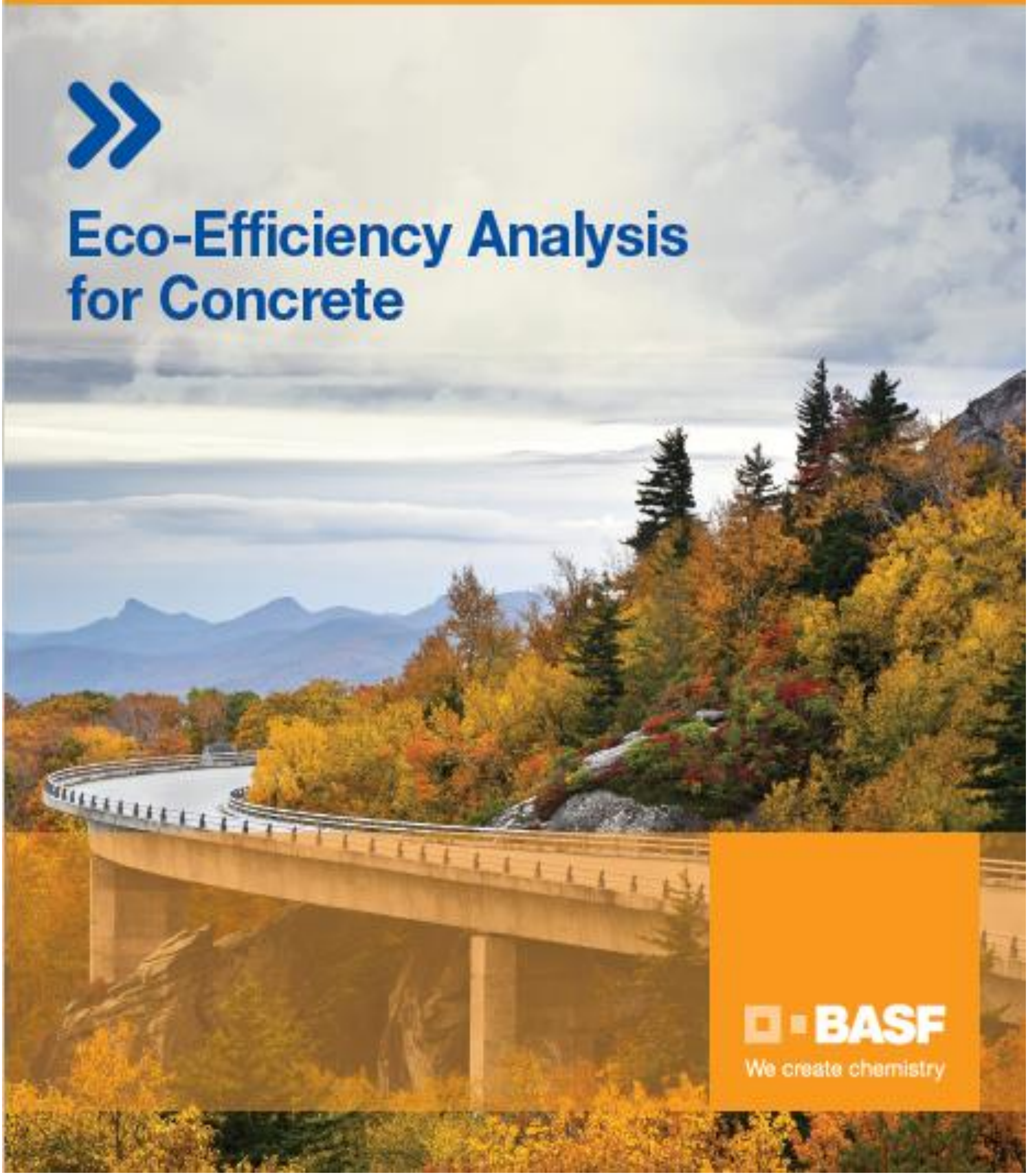
SOLUTIONS

Eco-Efficiency Analysis for Concrete



BASF
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Executive summary

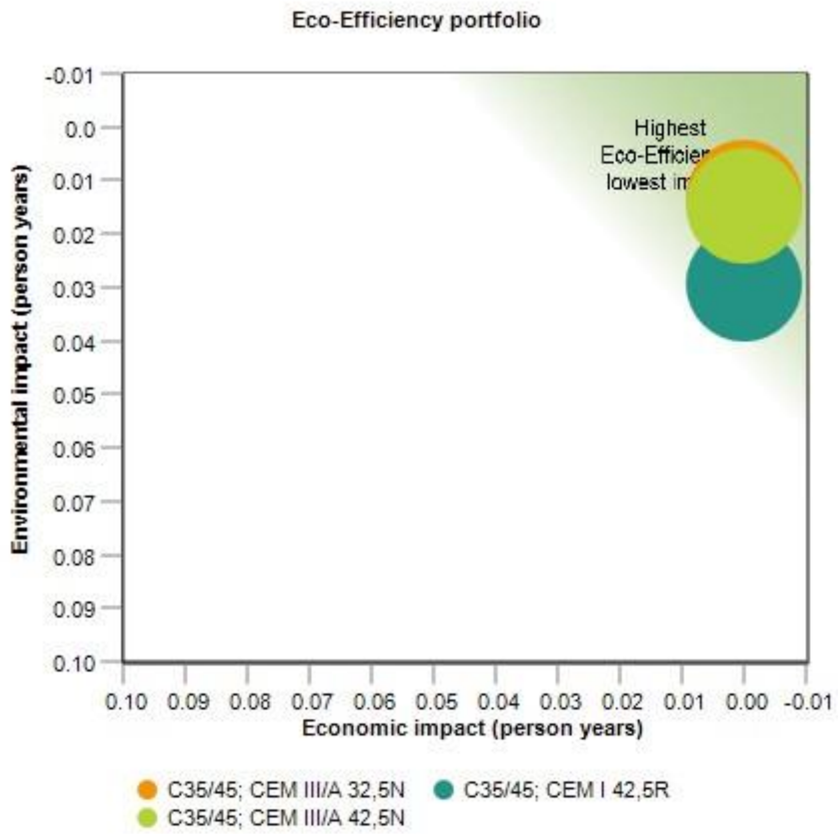
Goal and scope

The Master Builders Solutions Concrete Eco-Efficiency Analysis is developed to comprehensively define the environmental estimates of potential impacts for concrete products from a cradle-to-gate perspective. The results are an accurate comparison of impacts between the alternatives evaluated and include a wide range of environmental impact metrics.

The primary audience for this analysis is the concrete producer. The results can be utilized for the evaluation of existing or planned concrete mixture designs to determine the most eco-efficient solutions between the alternatives in the study and promote the results internally with employees and associates to recognize the organizations drive for more sustainable product solutions. Selected results may also be used to inform external groups along the value chain about more sustainable concrete designs and provide differentiation in concrete product selection for the construction industry.

Key results

The results for this specific analysis indicate that the cement content for the concrete mixture designs is responsible for the primary environmental impacts. As cement content is reduced, without impacting the performance or design requirements for the concrete mixtures based on performance testing, the overall eco-efficiency improves.



Concrete Mix Design by Waibel Frankfurt GmbH

Life Cycle Assessment according to ISO 14040:2006 and ISO 14044:2006

Eco-Efficiency Analysis according to ISO 14045:2012

1 Goal

1.1 Goal of the study

The Master Builders Solutions Concrete Eco-Efficiency Analysis (MBS EEA) is developed to:

1. Comprehensively define the environmental estimates of potential impacts for concrete products over the whole life cycle of the product system studied.

2. Provide an accurate comparison of impacts among the systems studied and

3. Provide an assessment of the influence of several key variables or characteristics, such as the intensity of the use of cement, alternative supplementary cementitious materials, and/or other aspects deemed critical to the end results.

1.2 Background and motivation

In line with the objectives of sustainable development and sustainable construction there is a need to investigate the estimated Master Builders Solutions Concrete study to quantify and compare the sustainability performance of similar concrete mixtures based on the principles of life cycle assessment

1.3 Intended application and audience

The main findings of the study are provided to Waibel Frankfurt GmbH for its evaluation of existing or planned concrete mixture designs to determine the most eco-efficient solutions between the alternatives evaluated.

The results will serve as a basis for promoting information internally with employees and associates to support the organizations drive to deliver more sustainable product solutions.

Selected results may also be used to inform external groups along the value chain about more sustainable concrete designs and provide differentiation in product selection for the concrete industry.

The primary audience for this analysis is the concrete producer. Additional interested parties may include contractors, engineers, specifiers, architects, owners and tenants.

1.4 Comparative assertion to be disclosed to the public

Per ISO 14044:2006, an environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function is regarded as a comparative assertion, and imposes additional requirements regarding the study. The comparison of concrete mixtures made in this study are all developed by Waibel Frankfurt GmbH and meet the same design and performance requirements.

Because the product systems under study do not always involve and affect the same interested parties, additional limitations for the communication of the study results and conclusions may apply.

The communication plan for this study must consider identifying and engaging with the relevant stakeholders/interested parties and appropriately align the communication regarding the results and conclusion of the study.

2 Scope of the study

2.1 Description of alternatives and systems

This study specifically evaluates different concrete mixture configurations and compares them to a reference concrete mixture. The cubic meter of concrete customer benefit was chosen as this is a standard unit of measure used by ready-mix concrete producers throughout the world and can be easily converted to other more specific products manufactured such as precast elements and manufactured concrete units. The overall study is a dynamic model and has the capability of evaluating an unlimited number of different mixture designs with similar design and performance characteristics. However, each individual analysis is limited to one reference mixture and up to five alternative mixtures.

2.2 Functional unit and reference flows

The functional unit provides a basis for comparing all life cycle components on a common basis: namely, the amount of that component required to fulfill the described function. It also allows direct comparisons among the product systems in question. The purpose of the product under study is to evaluate different concrete mixtures intended for the same final application to determine the most eco-efficient alternative.

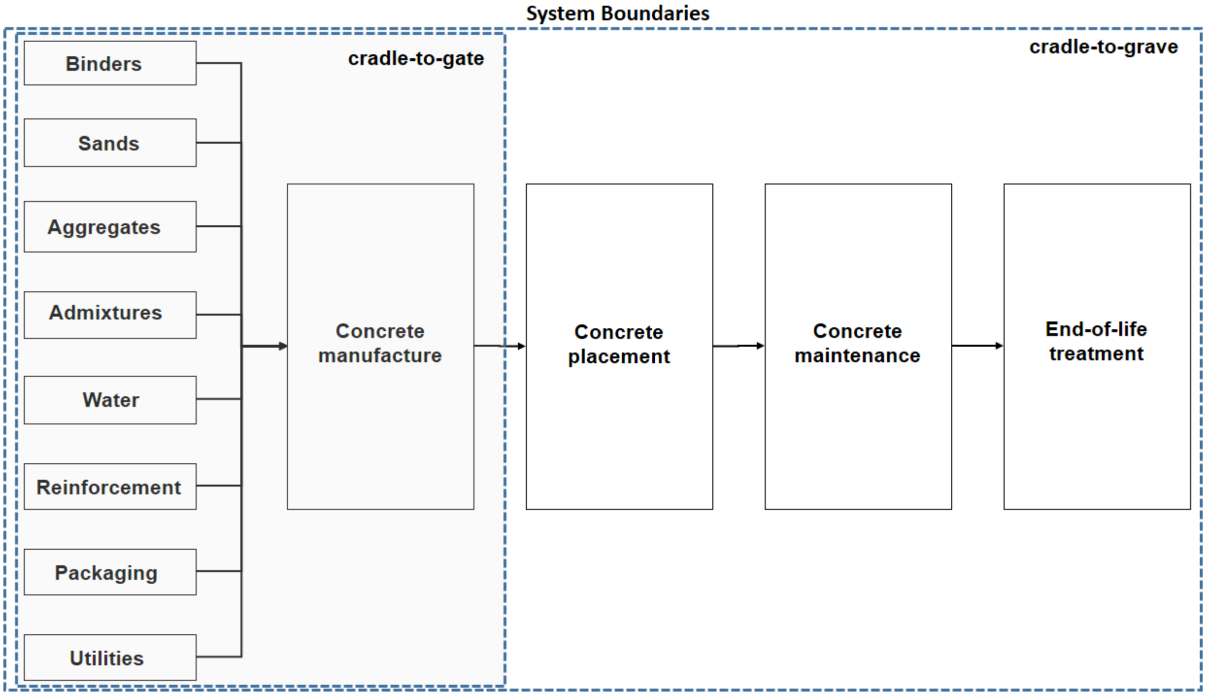
The customer benefit applied to all alternatives for this analysis is the evaluation of the inputs required to produce one (1) cubic meter of similar compressive strength concrete. This functional unit represents a typical service rate for concrete over a specific life time.

For some analyses, secondary functions such as pumping, placing, finishing, use and end of life disposition for the concrete mixture may not be included and are assumed to be equivalent among the systems. Therefore, the concrete mixtures can be evenly compared based on the primary function alone.

2.3 System boundaries

The following diagram provides an overview of the Master Builders Solutions concrete product system in GaBi.

Graphic 1: Overview of Master Builders Solutions Concrete analysis



The system boundaries for the Master Builders Solutions concrete analysis are determined prior to the initiation of a specific study. Many times, the boundaries will be cradle-to-gate based on the similarity in the additional stages of the life cycle and therefore will have no impact on the overall results. The model is flexible for a full cradle-to-grave or cradle-to-cradle analysis.

The following principle life cycle stages are evaluated in the study but may not all be included based on the scope of the study. Within each of the stages included in the analysis, the Eco-Efficiency Analysis considers raw material extraction, manufacturing, transport, use and end-of-life as relevant inputs and emissions.

2.3.1 Time coverage

The Eco-Efficiency Analysis considers the evaluation of the concrete mixture over the full lifetime when a full cradle to grave analysis is requested. The timeline for a cradle to grave analysis is generally considered to be 60 years but can be adjusted based on differing requirements. The eco-efficiency analysis may also be conducted as a cradle to gate analysis which will not include the use and end-of-life phases for the concrete product.

2.3.2 Technology coverage

The data sets and information generated for the Eco-Efficiency Analysis are relevant to the most current data and technology available for the manufacturing systems pertaining to this study.

2.3.3 Geographical coverage

The data sets and information generated for the Eco-Efficiency Analysis are based on the appropriate region when available. Data that is not available at a regional level was selected based on its similarity to the region within the study.

2.4 Allocation

The production of steel or ferro-silica metal products generate secondary materials that have pozzolanic properties making them excellent sources for cement replacement. In North America, these products (fly ash, silica fume, granulated blast furnace slag) are secondary products and not co-products therefore allocation was not considered for the North America analyses. However, per EN15804, economic allocation factors were calculated from data obtained from usgs.gov and resulted in allocation factors reflective of the output secondary product as a percentage of the input materials to produce the product.

2.5 Cut-off criteria

All inputs and outputs have been included in cases where the necessary information is readily available or a reasonable estimate can be made. In cases where information is not available, inputs and outputs may have been omitted only if their impacts are anticipated to fall well below 1% of the total system impacts.

2.6 Selection of LCIA methodology and types of impacts

2.6.1 Relevance check

The goal of the Relevance Check is to ensure sufficient environmental coverage, i.e. at least 80% of environmental impact, and to determine the most relevant environmental impact categories for each alternative in a study.

The Relevance Check was completed for the MBS Concrete analysis in accordance with the established requirements. The results of the Relevance Check confirm that the selected environmental impact categories cover at least 80% of environmental impact.

2.6.2 Impact assessment methods

The selected impact categories for the present study are presented as a list with references to literature and to the methodology Annex.

Impact category	Unit	LCIA method	Source
Acidification	kg SO_2 eq.	CML2001	CML2001 (Guinée et al., 2002)
Climate change	kg CO_2 eq.	CML2001	CML2001 (Guinée et al., 2002)
Eutrophication, overall	kg $PO_4{}^{3-}$ eq.	CML2001	CML2001 (Guinée et al., 2002)
Human Toxicity	toxicity points	BASF 2002	Landsiedel and Saling, 2002
Ozone depletion potential	kg CFC-11 eq.	CML2001	CML2001 (Guinée et al., 2002)
Photochemical ozone formation	kg ethylene eq	CML2001	CML2001 (Guinée et al., 2002)
Resource depletion, minerals	kg Sb eq.	CML2001 ultimate resources	CML2001 (Guinée et al., 2002)
Resource depletion, fossils	MJ	CML2001 ultimate resources	CML2001 (Guinée et al., 2002)
Resource depletion, water	m^3 world eq.	AWARE	WULCA (Boulay et al, 2016)

2.7 Data and data quality requirements

The process of developing a MBS EEA is often iterative. As data is collected and additional information is learned about the system, new data requirements or limitations may be identified. The new data may require changes in the inputs/outputs however the BASF EEA methodology requires an ongoing consideration of the appropriateness, accuracy and preciseness of input data throughout the study.

The geographic, technological and temporal appropriateness of the data is considered in the selection of input data. Sensitivity calculations can be used to determine whether any specific inputs, assumptions or life cycle inventories are critical for result stability.

Any critical uncertainties or sensitivities that have significant impact on the study results will be noted in Section 6.5 - Conclusions and Recommendations.

The Master Builders Solutions Concrete Eco-Efficiency Analysis was conducted using GaBi version 6.115 software and database.

2.8 Assumptions and limitations

Process steps: In most concrete studies, the use and end-of life process steps are excluded if the analysis is a cradle-to-gate study and these phases are identical for all product systems under consideration. The use and end-of-life phases are included in the study when a full cradle to grave analysis is conducted.

The study compares specific systems based on data from a selected sample of selected production sites and is not representative of all concrete products in the region or other countries.
All products are assumed to serve the same concrete construction market. The potential use in other applications is not considered in the present study.
Transportation mode and distance from a supplier to the concrete producer is included in the study. Fixed costs are assumed to be equal for all systems.

All inputs and outputs have been included in cases where the necessary information is readily available or a reasonable estimate can be made. In cases where information is not available, inputs and outputs may have been omitted only if their impacts are anticipated to fall well below 1% of the total system impacts.

Data availability: For certain input products, specific data for the process of manufacturing was not available and proxy data was selected. The two data sets represent river dredge sand and the MasterLife AMA 100 admixture.

2.9 Critical review

A critical review was conducted by NSF International. The verified report is available at: http://www.nsf.org/services/by-industry/sustainability-environment/claims-validation/eco-efficiency.

3 Life Cycle Inventory

3.1 Data collection and types of data sources

In obtaining and selecting appropriate data, representativeness, consistency, accuracy and geographic and temporal relevance have been considered.

The following data has been collected from the production sites as necessary based on the specific study: utility consumption, concrete mixture designs, batch water for concrete, cleaning water for concrete equipment, disposal of waste material all per m^3 of concrete production.

Some regional data may be selected from other areas or calculated based on availability for the specific region. For Middle East assessments, European proxies were used. (exception for water assessment)

The data collected for any of the input parameters for concrete mixture designs, transportation modes and distances, placement, use and end-of-life are actual. The use of estimated data is minimized.

Background life cycle inventory data is taken from the GaBi version 6.115 database which includes specific BASF processes.

3.2 Modeling

The scope of any MBS EEA is defined by its system boundaries, which provide the specific elements of raw material extraction, acquisition, transportation, production, use and disposal that are considered as part of the analysis. The studies consider the entire life cycle but then may concentrate on specific stages in a life cycle where the alternatives under consideration differ. Following the ISO guidance, the practitioners ensure that an overall view about alternatives is given and the concentration on specific life cycle stages do not change the overall order of alternatives compared in the system. The same life cycle stages must be included when analyzing each alternative.

3.3 Data quality assessment

The classification of data quality is done per Weidema et al.; ecoinvent report No. 1; Data quality guideline for the ecoinvent database version 3; St. Gallen, 2011.

4 Life cycle cost

The BASF EEA methodology assesses the economics of products or processes over their life cycle to determine an overall total cost of ownership per functional unit ($ or €).

Sales prices are used for products and utilities. Dependent on the life cycle steps, equipment use costs may be included. The costs incurred are summed and combined in appropriate units (e.g. dollar or EURO).

All relevant costs and revenues are considered (e.g. raw material, labor, energy, capital investment, maintenance, disposal etc.).
In addition to the total absolute costs, a normalized economic impact is obtained by dividing the total costs with the regional annual gross domestic product (GDP).

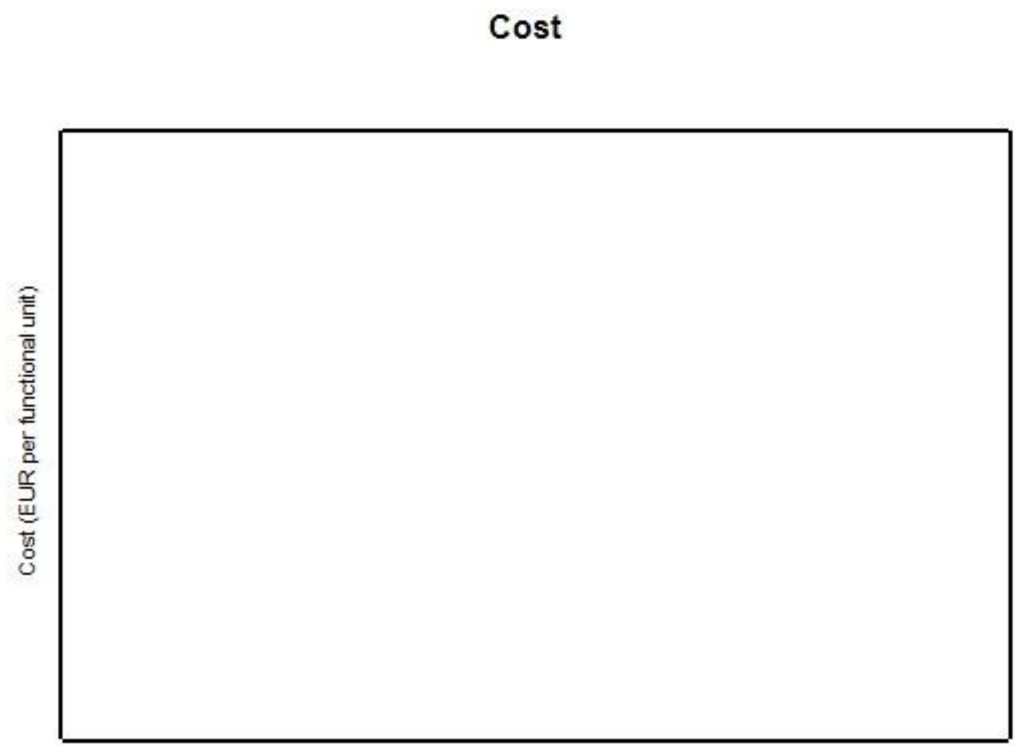


Table 3: Cost BASF (EUR per functional unit)

5 Life Cycle Impact Assessment
5.1 Life cycle impact assessment results
5.1.1 Acidification

Acidification (AP) summarizes the total emissions of acidic gases to air. Deposition of these emissions can acidify water bodies and soils and can cause building corrosion. AP-relevant gases include e.g. sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrochloric acid (HCL) and hydrofluoric acid (HF). Typical sources of acidifying emissions are fossil fuel combustion for electricity production, heating and transport and agriculture. The total impact is expressed in SO_2 equivalents.

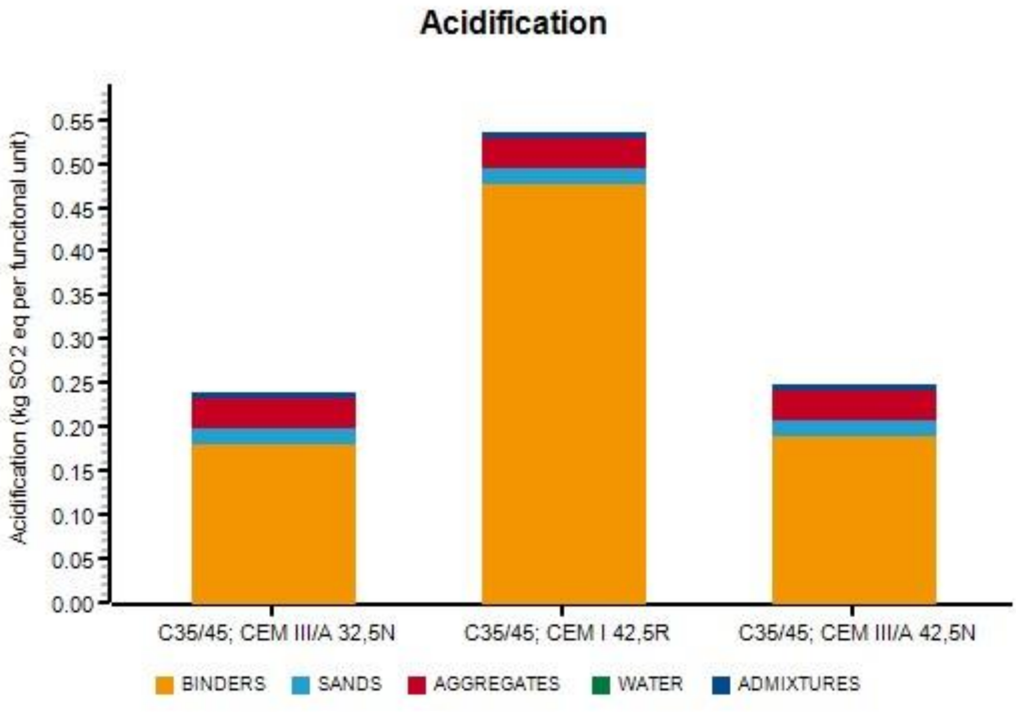


Table 4. Acidification (kg SO_2 eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	0.182	0.479	0.191
SANDS	0.018	0.018	0.018
AGGREGATES	0.034	0.034	0.034
WATER	0.000	0.000	0.000
ADMIXTURES	0.006	0.006	0.006
TOTAL	0.240	0.537	0.249

5.1.2 Climate change

Climate change is impacted by air emissions of greenhouse gases (GHGs). Increased GHGs in the troposphere result in warming of the earth's surface. The impact of greenhouse gas emissions such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are assessed over a fixed period of 100 years. The climate change category considers that different gases have different climate change impacts on global warming. The total impact is presented in CO_2 equivalents.

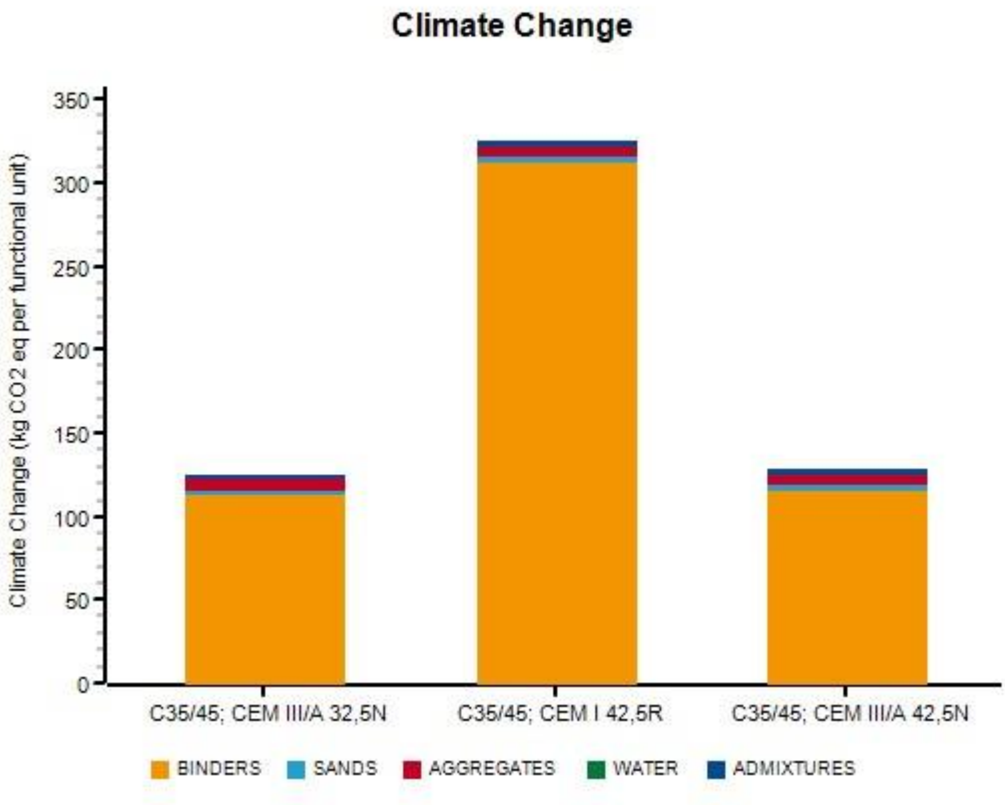


Table 5. Climate Change (kg CO_2 eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	113.53	313.73	116.61
SANDS	2.92	2.92	2.92
AGGREGATES	6.59	6.61	6.59
WATER	0.03	0.03	0.03
ADMIXTURES	1.82	1.82	1.82
TOTAL	124.88	325.12	127.96

5.1.3 Eutrophication

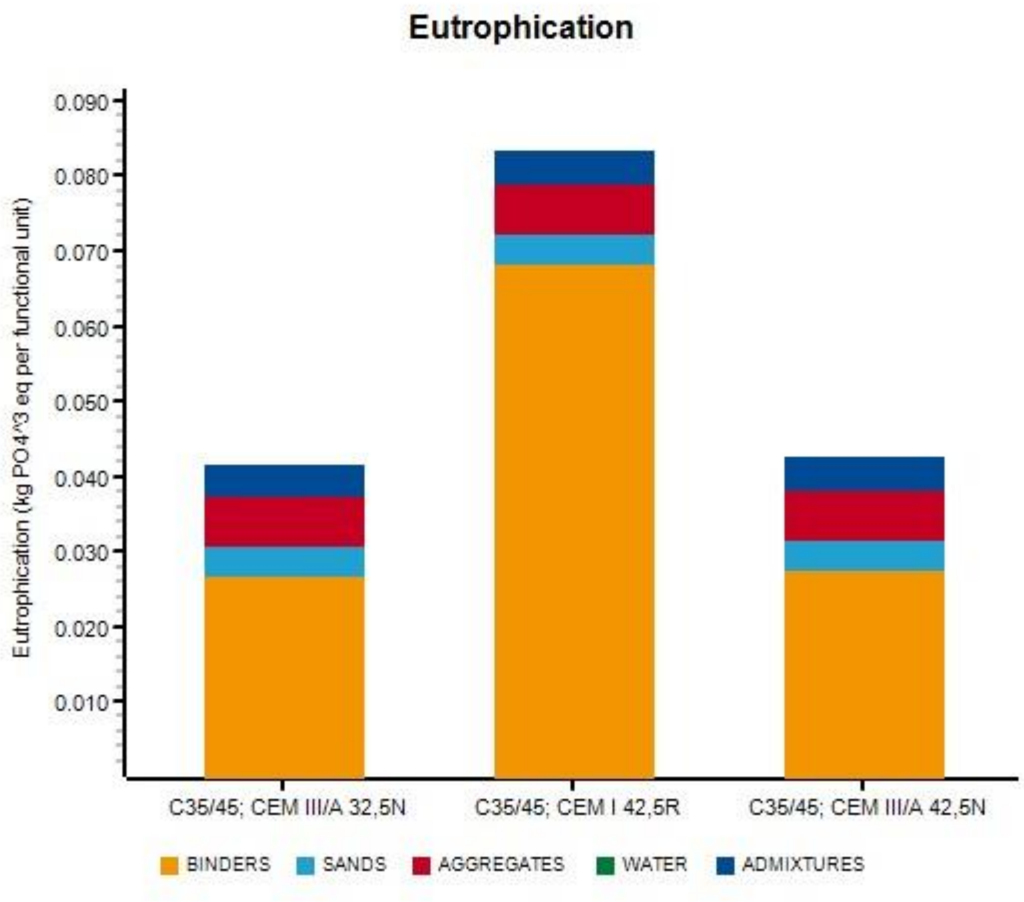


Table 6. Eutrophication (kg PO_4 [3] eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	2.7E-002	6.8E-002	2.8E-002
SANDS	4.0E-003	4.0E-003	4.0E-003
AGGREGATES	6.6E-003	6.6E-003	6.6E-003
WATER	6.9E-006	6.9E-006	6.9E-006
ADMIXTURES	4.2E-003	4.2E-003	4.2E-003
TOTAL	4.2E-002	8.3E-002	4.2E-002

5.1.4 Human toxicity

The human toxicity potential takes into consideration all substances handled at any time during the life cycle of a product. Only toxicity potentials are assessed, not actual risks. Substances are assigned toxicity points based on their hazard phrases (H-phrases) of the Globally Harmonized System (GHS). The H-phrases indicate human health hazards associated with exposure to specific substances. These toxicity points are multiplied with the amounts of substances used and report life cycle human toxicity potentials expressed in terms of dimensionless toxicity points. The method is described in detail in R. Landsiedel, P. Saling, Int. J. LCA 7 (5), 261-268, (2002).

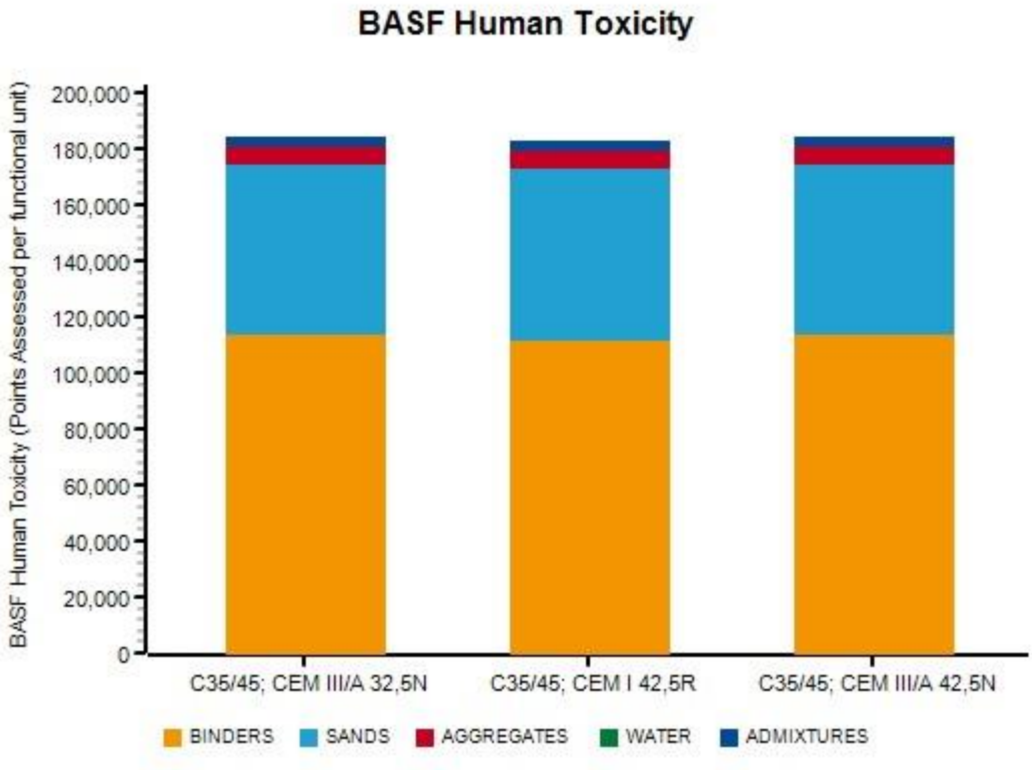


Table 7. BASF Human Toxicity (Points Assessed per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	114,149	112,605	114,149
SANDS	61,187	61,289	61,187
AGGREGATES	6,329	6,352	6,329
WATER	1	1	1
ADMIXTURES	2,975	2,975	2,975
TOTAL	184,641	183,221	184,641

5.1.5 Ozone depletion

The ozone depletion category reflects the depletion of stratospheric ozone due to the release of certain air emissions. Stratospheric ozone exists as a layer of naturally occurring gas in the upper atmosphere that protects living cells from over-exposure to solar ultraviolet (UV) radiation.

Ozone-depleting substances include molecules containing the halogen atoms chlorine or bromine that can cause chemical reactions that destroy ozone molecules. Different gases have different atmospheric lifetimes and therefore greater or lesser effects on ozone depletion. The results are expressed in terms of CFC-11 equivalents.

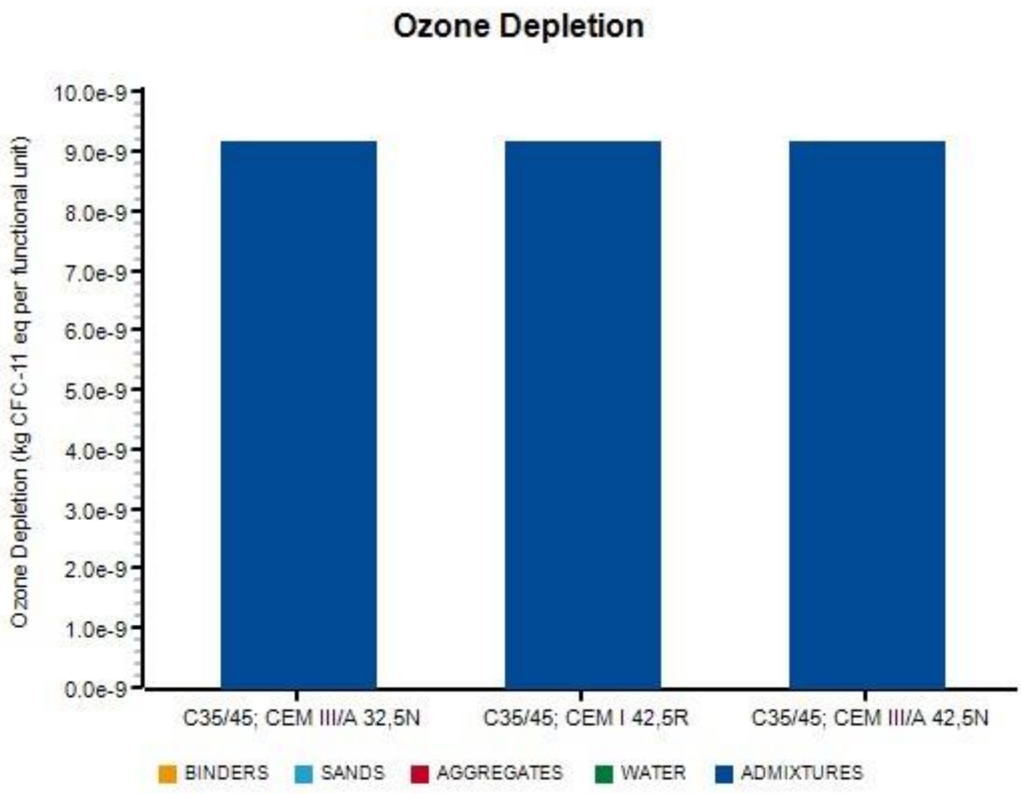


Table 8. Ozone Depletion (kg CFC-11 eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	3.2E-013	7.2E-013	4.1E-013
SANDS	1.6E-014	1.6E-014	1.6E-014
AGGREGATES	9.9E-015	9.9E-015	9.9E-015
WATER	7.3E-016	7.3E-016	7.3E-016
ADMIXTURES	9.2E-009	9.2E-009	9.2E-009
TOTAL	9.2E-009	9.2E-009	9.2E-009

5.1.6 Photochemical ozone formation

The photochemical ozone category reflects the impact on summer smog formation. Emissions of VOCs (volatile organic compounds) in the presence of nitrogen oxides (NO_x) and sunlight can lead to chemical reactions that form ozone close to the ground level (also known as photochemical or tropospheric smog). Ground level ozone can result in negative health effects, including eye irritation, respiratory tract and lung irritation, as well as damage to vegetation. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors and chemical solvents are some of the major sources of NO_x and VOC. Results are reported in kg ethylene eq.

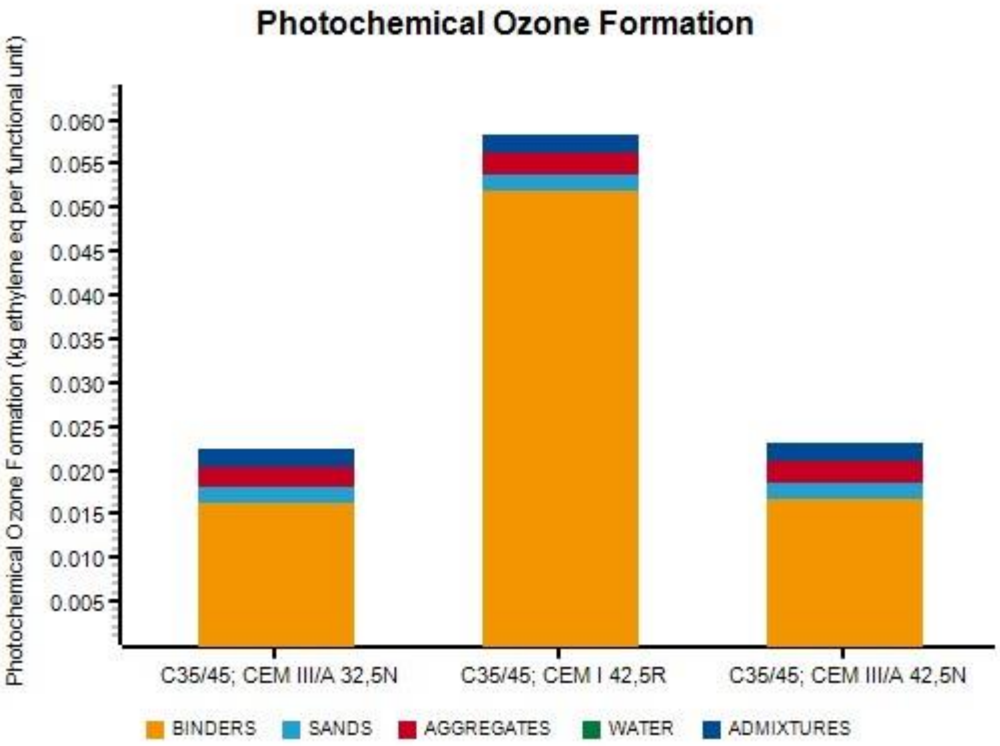


Table 9. Photochemical Ozone Formation (kg ethylene eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	1.6E-002	5.2E-002	1.7E-002
SANDS	1.8E-003	1.8E-003	1.8E-003
AGGREGATES	2.4E-003	2.4E-003	2.4E-003
WATER	4.7E-006	4.7E-006	4.7E-006
ADMIXTURES	1.8E-003	1.8E-003	1.8E-003
TOTAL	2.2E-002	5.8E-002	2.3E-002

5.1.7 Resource depletion minerals

Resource depletion, also called abiotic depletion potential (ADP) reflects the consumption of raw materials. Mineral and fossil fuel impacts (shown on separate charts) are assessed by taking into account the reserve base as well as the current global rates of consumption of each substance. Therefore, the use of raw materials with low reserves and/or high consumption rates is more critical.

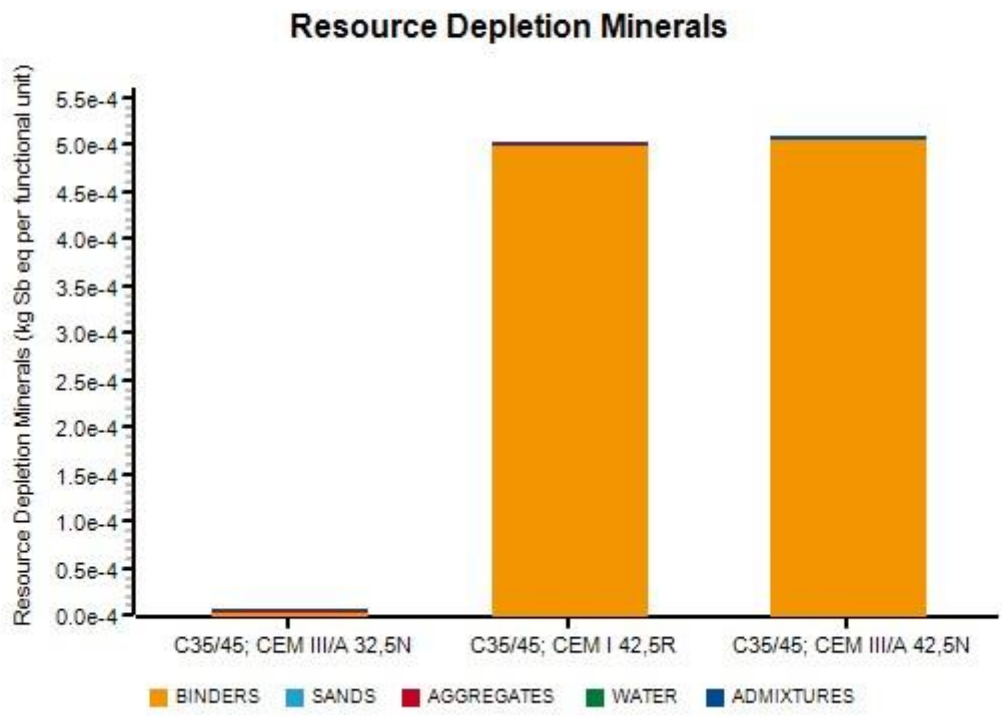


Table 1. Resource Depletion Minerals (kg Sb eq per functional unit)

	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	4.5E-006	5.0E-004	5.1E-004
SANDS	4.7E-007	4.7E-007	4.7E-007
AGGREGATES	5.6E-007	5.6E-007	5.6E-007
WATER	8.3E-009	8.3E-009	8.3E-009
ADMIXTURES	1.4E-006	1.4E-006	1.4E-006
TOTAL	7.0E-006	5.0E-004	5.1E-004

5.1.8 Resource depletion fossil fuels

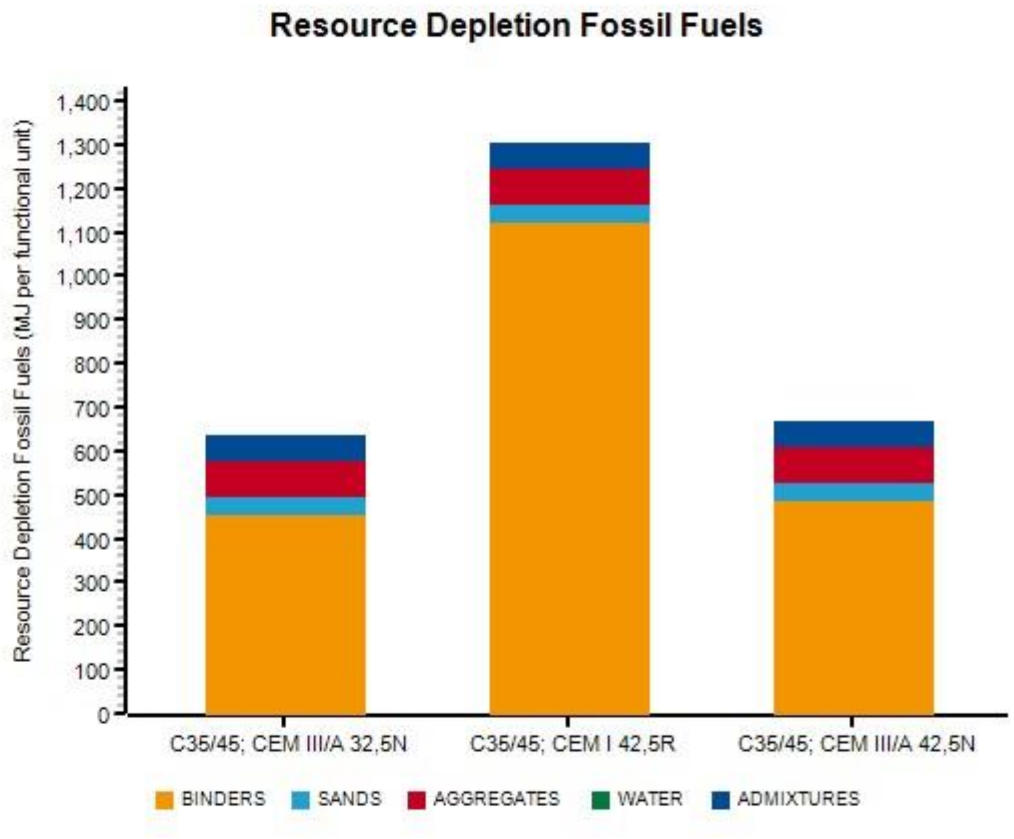


Table 2. Resource Depletion Fossil Fuels (MJ per functional unit)

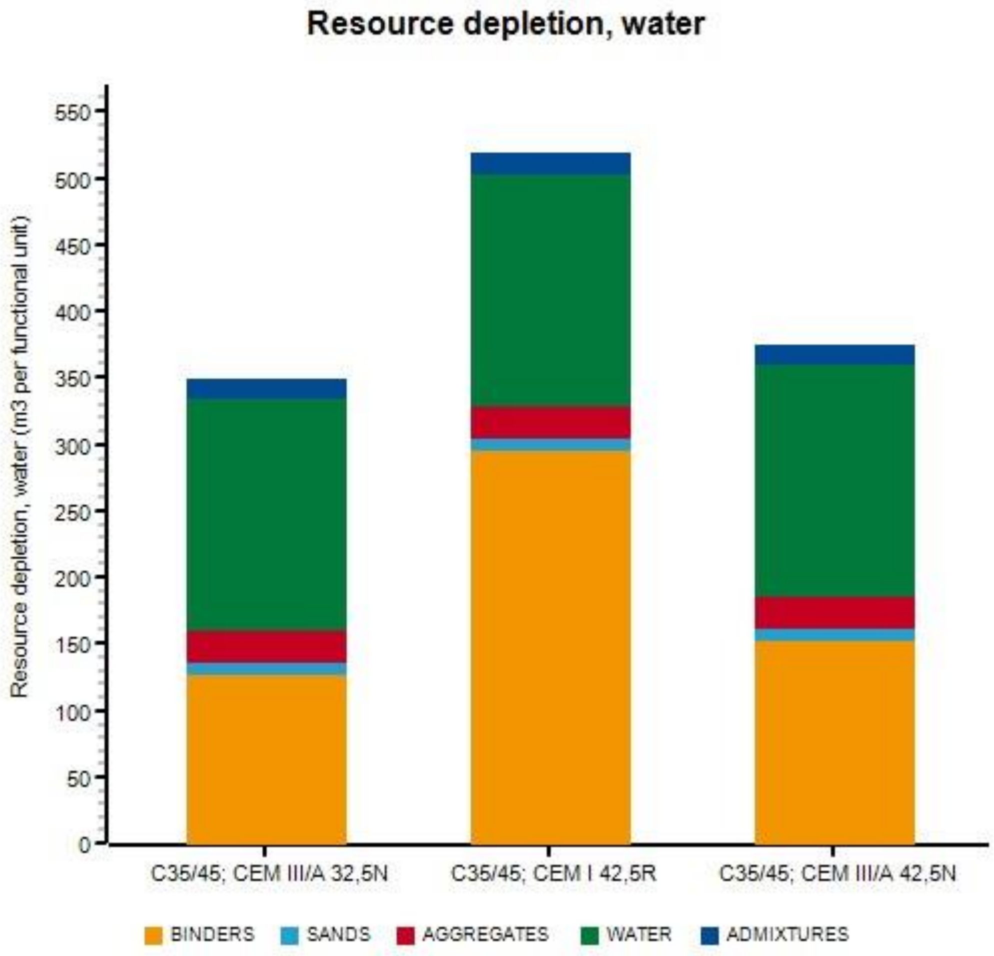
	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
BINDERS	458.07	1,125.62	491.09
SANDS	38.67	38.73	38.67
AGGREGATES	82.98	83.27	82.98
WATER	0.28	0.28	0.28
ADMIXTURES	53.85	53.85	53.85
TOTAL	633.84	1,301.75	666.86

5.1.9 Resource depletion water

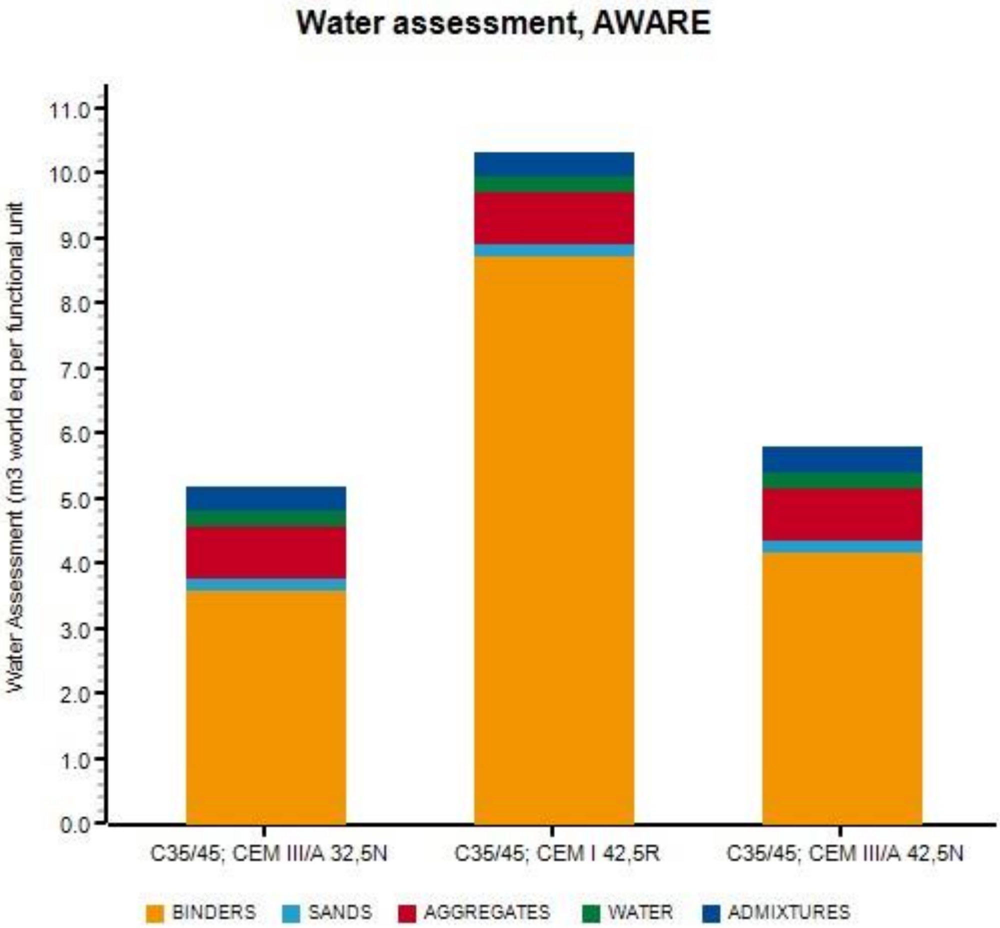
This area addresses freshwater consumption associated with products and processes. The impact assessment methodology considers water availability and demand in a region to determine the water footprint. The focus is exclusively on freshwater use.

Sea water is a resource with essentially infinite availability and has no impact on freshwater consumption. However, if seawater is used, the desalination of sea water will have an impact on other environmental categories such as the carbon footprint due to the large amounts of energy needed for the desalination process.

Freshwater and desalinated water were evaluated in this analysis however are not included in the environmental fingerprint or Eco-Efficiency Portfolio based on their relevance in the final results. However, the values associated with resource depletion, wate and water assessment are shown in the charts below recognizing that water use is still an important impact in concrete production.



AWARE water assessment is a methodology intended to provide consensual and consistent framework to assess, compare and disclose the environmental performance of products and operations regarding freshwater use. The result is a framework for water use impact assessment in life cycle assessment. The chart provides results based on currently available data which may include levels of uncertainty based on regional or regional average results. This assessment provides a snapshot overview of water impact in the region of concrete production.



5.2 Aggregation

5.2.1 Normalization

The total absolute LCIA results are normalized. Normalization values used in the BASF EEA are global statistical values (e.g. the CO_2 eq emissions emitted in the world in one year) provided with standard market tools. The normalized value is calculated from the alternative impact divided by the respective statistical value.

5.2.2 Weighting

Weighting factors presented in the following table for the EEA impact categories have been obtained from EU PEF weighting.

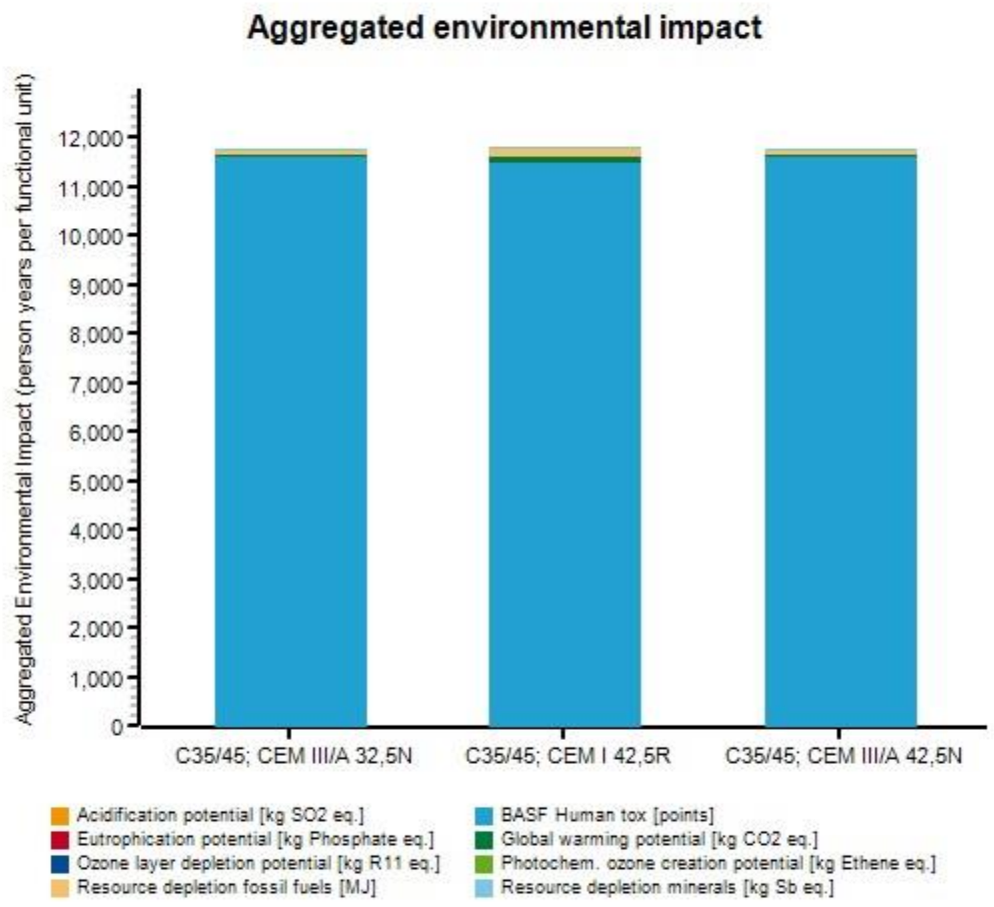
LCA Flex societal weighting factors	**Global**
Resource depletion minerals	11.8%
Resource depletion fossil fuels	13.0%
Acidification	9.7%
Climate change	33.0%
Eutrophication	8.9%
Human toxicity	6.3%
Ozone depletion	9.8%
Photochemical ozone formation	7.4%

The normalized values are multiplied by the weighting factors to obtain the weighted results.

5.2.3 Aggregated results

The normalized and weighted results are summed up to a total environmental impact using the EU PEF weighting factors for the impact category and the normalized value.

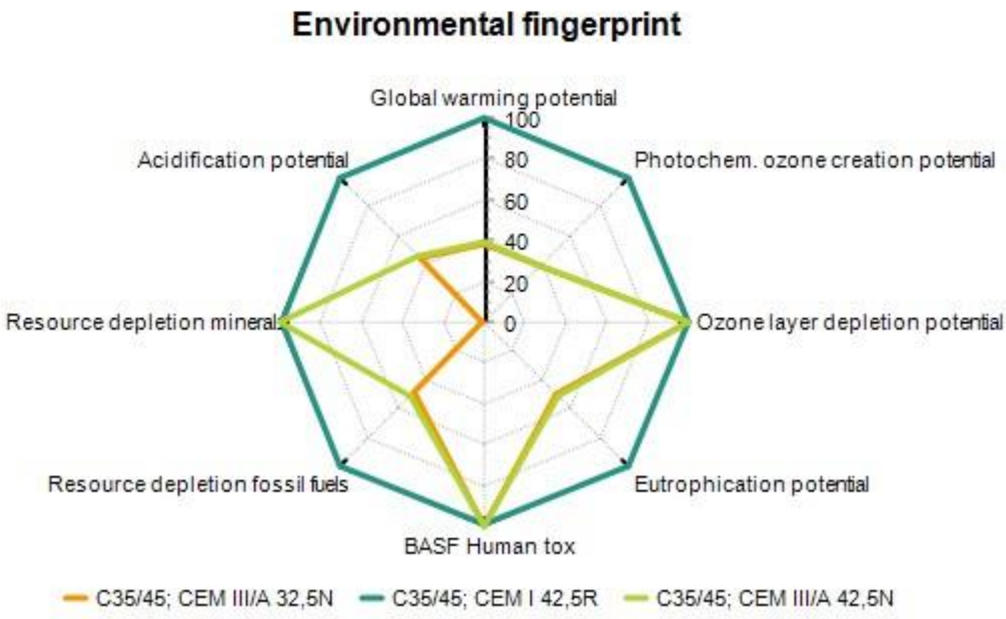
The total environmental impact is multiplied by the total population of the region to express the results in terms of person years (or person days, person minutes, etc.). The same calculation can also be conducted at an impact category level.



	C35/45; CEM III/A 32,5N 273 44 200 Waibel Frankfurt GmbH	C35/45; CEM I 42,5R 273 44 300 Waibel Frankfurt GmbH	C35/45; CEM III/A 42,5N 273 44 400 Waibel Frankfurt GmbH
Acidification potential	7.25E-004	1.62E-003	7.52E-004
BASF Human tox	3.00E-003	2.98E-003	3.00E-003
Eutrophication potential	1.75E-004	3.51E-004	1.79E-004
Global warming potential	7.27E-003	1.89E-002	7.45E-003
Ozone layer depletion potential	2.95E-008	2.95E-008	2.95E-008
Photochem. ozone creation potential	3.38E-004	8.75E-004	3.46E-004
Resource depletion fossil fuels	1.61E-003	3.31E-003	1.69E-003
Resource depletion minerals	1.70E-005	1.23E-003	1.24E-003

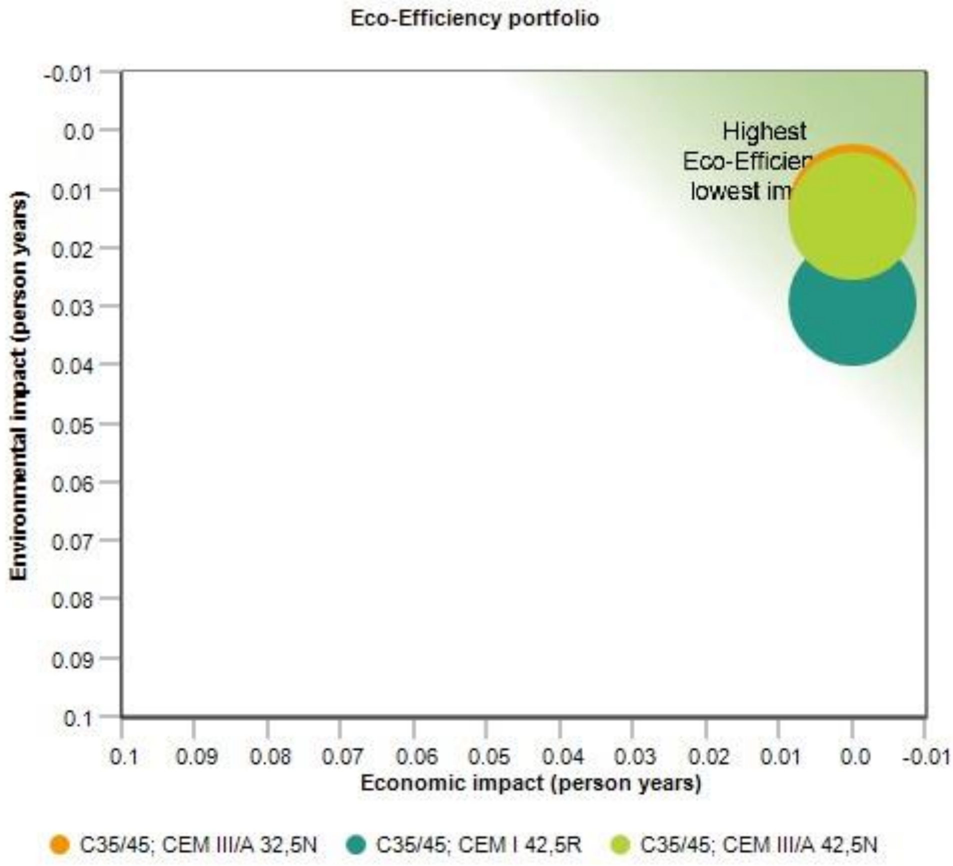
5.2.4 Environmental fingerprint

The Environmental Fingerprint shows the environmental advantages and disadvantages of the concrete mixtures relative to one another for each environmental impact category. All concrete mixtures are normalized between 0 and 100 with the concrete mixture having the greatest impact in each category designated at the furthest point from the origin. The closest results to the origin indicate the concrete mixture with the lowest environmental impact.



Concrete Mix Design by Waibel Frankfurt GmbH

5.2.5 Eco-Efficiency portfolio and index



Concrete Mix Design by Waibel Frankfurt GmbH

6 Interpretation

The results provided indicate the most eco-efficient concrete option when compared to the other concrete mixture alternatives in the study.

6.1 Identification of significant parameters

Generally, cement content is a significant contributor to the overall environmental results for a concrete mixture. Other parameters including transportation distances and modes, supplementary cementitious materials and some aggregate types may impact the overall results and are presented in the previous individual environmental bar charts.

6.2 Completeness and consistency

Completeness was checked at cradle-to-gate level for all process steps and inputs. All relevant processes regarding the different life cycle phases were considered and modeled in accordance with the goal and scope definition of the study and the defined system boundaries.

The data, methods and assumptions applied throughout the analysis were selected to ensure consistency and allow consistent statements.

6.3 Water Assessment Discussion

Water Assessment

Life Cycle Assessments (LCA) may include water assessments, known also as water footprints. Water footprints address freshwater consumption associated with products and processes.

AWARE is an impact assessment methodology that considers water availability and demand in a region to determine the water footprint. The methodology is recommended, for example, by the EU Product Environmental Footprint Guidance.

As with other water footprint methodologies, AWARE focuses exclusively on freshwater use; sea water is a resource with essentially infinite availability and thus the use of sea water has no impact on freshwater consumption. However, the desalination of sea water will have an impact in other environmental categories such as carbon footprint due to the large amounts of energy needed for the desalination process.

6.4 Conclusions and recommendations

The purpose of the present study is to investigate the differing environmental impacts originating from various options for concrete mixtures with similar engineering and design parameters as well as identical final applications.

The results are shown in the Eco-Efficiency portfolio. The most eco-efficient alternative will be located closest to the upper right hand quadrant.

7 Disclaimer

The present study results and its conclusions are based on specific comparisons of the life cycle steps of product systems and system boundaries for the described functional unit. Transfer of these results and conclusions to other production methods or products is expressly prohibited. Partial results may not be communicated to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions.

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Annex I - Description of impact categories

1. Acidification

- Also, referred to as acid rain and acidification potential (AP).

- This category summarizes the effect of total emissions of acidic gases to air. Deposition of these emissions can acidify water bodies and soils, and can cause building corrosion.

- AP-relevant gases include e.g. sulfur oxides (SOx), nitrogen oxides (NOx), hydrochloric acid (HCl) and hydrofloric acid (HF). Typical sources of acidifying emissions are fossil fuel combustion for electricity production, heating and transport, and agriculture.

- The total impact is expressed in mol+ equivalents (or in SO2 equivalents dependent on the impact assessment methodology).

2. Climate Change

- Also, referred to as global warming potential (GWP) and carbon footprint (CF).

- This category reflects the climate change impact of air emissions of greenhouse gases (GHGs). Increased GHGs in the troposphere result in warming of the earth's surface.

- The impact of greenhouse gas emissions – such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) – is assessed over a fixed period of 100 years.

- The climate change category considers that different gases have different climate change impacts on global warming. The total impact is described in CO2 equivalents.

3. Eutrophication: Marine and Freshwater

- Also, known as overfertilization and eutrification potential (NP).

- This category shows the impact of emissions (compounds containing phosphorus or nitrogen) on marine and freshwater bodies (lakes, slow moving rivers, estuaries, coastal areas etc.) that act as nutrients for vegetation.

- Nutrient emissions can lead to excessive plant and algal growth that depletes oxygen levels, killing, for example, fish, crustaceans, and plants to create dead zones.

- Water emissions differ in their effects on eutrophication. The impact is expressed in equivalent quantities of phosphorus (P) for freshwater and nitrogen (N) for marine eutrophication.

4. Freshwater Ecotoxicity

- Also, referred to as freshwater ecotoxicity potential.

- The ecotoxicity potential describes the environmental fate of chemical emissions and their impact on ecosystems.

- The methodology used to assess freshwater ecotoxicity is USEtox. USEtox is a consensus model developed within the framework of the UNEP-SETAC Life Cycle Initiative.

- The model evaluates the toxicological effects of a chemical emitted into the environment as a cause-effect chain that links emissions to impacts through three steps: environmental fate (behavior in the environment, i.e. movement within different environmental compartments), exposure and the effect on freshwater organisms.

- Freshwater ecotoxicity assessed using the USEtox model is reported in comparative toxic units (CTUe).

5. Human Toxicity

Health & Safety

- The human toxicity potential takes into consideration all substances handled at any time during the life cycle of a product. Only toxicity potentials are assessed, not actual risks.

- Substances are assigned toxicity points based on their hazard phrases (H-phrases) of the Globally Harmonized System (GHS). The H-phrases indicate human health hazards associated with exposure to specific substances. These toxicity points are multiplied with the amounts of substances used and report life cycle human toxicity potentials expressed in terms of dimensionless toxicity points.

- In cooperation with toxicologists, toxicity points were assigned to each H-phrase. For example, the classification H330 (fatal if inhaled) was assigned 750 toxicity points and the considerably less critical category H312 (harmful in contact with skin) 300 points.

- The method is described in detail in Landsiedel und Saling (2002).

6. Land Use

Biodiversity

- This category reflects the effect of occupation of land on ecosystems as damage to ecosystems.

- The Ecosystem Damage Potential (EDP) by Köllner 2008 characterizes generalized impacts of land occupation and transformation on biodiversity and is based on vascular plant species richness. Since the time needed to restore transformed land is considered, the land use damage is greatest for land use types with extended restoration (e.g. primary forest or peat bog).

- Only land occupation is taken into effect and the impact is expressed in square meters multiplied by years.

7. Ozone Depletion

- Also, referred to as ozone hole and ozone depletion potential (ODP).

- The ODP category reflects the depletion of stratospheric ozone due to the release of certain air emissions. Stratospheric ozone exists as a layer of naturally occurring gas in the upper atmosphere that protects living cells from over-exposure to solar ultraviolet (UV) radiation; over-exposure to UV radiation can cause, for example, skin cancer and reduced crop yields.

Emissions

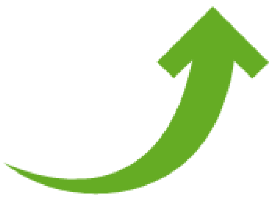
- Ozone-depleting substances include molecules containing the halogen atoms chlorine or bromine that can cause chemical reactions that destroy ozone molecules. Different gases have different atmospheric lifetimes and therefore greater or lesser effects on ozone depletion.

- The results are expressed in terms of CFC-11 equivalents.

8. Resource Depletion, mineral, fossils

- Also, called abiotic depletion potential (ADP).

- This category reflects the consumption of raw materials. It assesses minerals and fossil fuel considering the reserve base as well as current global rates of consumption of each substance. Therefore, use of raw materials with low reserves and/or high consumption rates is more critical.



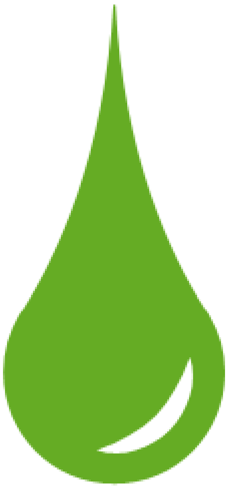
Resource Efficiency

- In the case of renewable raw materials, sustainable farming is assumed. This implies an endless reserve and thus a weighting factor of zero (in other words no consideration of biotic material depletion).

- The result is expressed in terms of Antimony (Sb)-equivalents.

9. Resource Depletion, water

- Also, called Water Scarcity Footprint.



Water

- While water cannot disappear, it can become unavailable to specific users either by displacement or quality degradation.

- The Pfister 2009 methodology assesses the consumptive freshwater use, referring to losses from a specific watershed. Consumptive water use includes freshwater lost due to evaporation, evapotranspiration by plants (note that only irrigation water is considered, not rainwater), incorporation into products and waste, release to different watersheds or into the sea after use. Consumption of water from precipitation or soil moisture is not included in consumptive water loss.

- Water depletion per the Pfister method is determined by multiplying the consumptive water use by a regional water stress index and is reported in liters of assessed water.

10. Photochemical Ozone Formation

- Also, referred to as summer smog and photochemical ozone creation potential (POCP).

Emissions

- This category reflects the impact of certain air emissions on summer smog formation. Emissions of VOCs (volatile organic compounds) in the presence of nitrogen oxides (NO_x) and sunlight can lead to chemical reactions that form ozone close to ground level (also called photochemical or tropospheric smog).

- Ground level ozone can result in negative health effects, including eye irritation, respiratory tract and lung irritation, as well as damage to vegetation.

- Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_x and VOC.

- Results are reported in kg NMVOC-equivalents (or in ethylene equivalents or O_3 equivalent dependent on the impact assessment methodology).

Energy

11. Energy Consumption

- Also, referred to as cumulative energy demand (CED).

- The cumulative energy demand is a key indicator in LCA and a useful screening indicator for the environmental performance of products or processes. However, it is not considered to be an environmental impact category and hence is not aggregated to the total environmental score.

- The cumulative energy demand includes direct and indirect use of energy throughout the life cycle, encompassing extraction, manufacture, use and disposal of a product. It considers energy conversion losses along the process chain. It considered all kinds of different energy carriers, i.e. fossil-based as well as renewables (biomass and non-biomass).

- The result is reported in MJ.

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