LIFE CYCLE ASSESSMENT (LCA) OF DIFFERENT CONCRETE MIXTURES AND AN APPLICATION IN A GREEN BUILDING

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LIFE CYCLE ASSESSMENT (LCA) OF DIFFERENT CONCRETE MIXTURES AND AN APPLICATION IN A GREEN BUILDING

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ABSTRACT

LIFE CYCLE ASSESSMENT (LCA) OF DIFFERENT CONCRETE MIXTURES AND AN APPLICATION IN A GREEN BUILDING

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Concrete is the most utilized building materials on a global scale. Raw materials and energy are required in high quantity for the production phase of the concrete which mainly consists of cement, aggregate, water and admixtures. This causes significant environmental concern for the sustainable development of the building sector. Therefore, environmental impact assessment studies conducted for concrete production are gaining importance, over the last two decades. Life Cycle Assessment (LCA) is the most effective and widespread method used to assess the impacts of the concrete production phases over their entire life from cradle to grave. Numerous LCA studies have been conducting to evaluate the environmental impacts of the green concrete mixtures produced by substituting the cement and natural aggregate with industrial by-products and recycled aggregate, respectively. In this study, it is aimed to analyze the environmental impacts of several green concrete mixtures by means of LCA. For this purpose, cradle to gate LCA analyses was conducted for 21 green concrete mixtures constituted by using multivariate combinations with supplementary cementitious materials such as fly ash, blast furnace slag, silica fume, natural pozzolan and limestone powder and / or recycled aggregate. In addition, environmental impacts of concrete were assessed cradle to grave through integration of these constituted green concrete mixtures to the LCA study which was conducted for the green building that certificated by Leadership in Energy and Environmental Design (LEED) rating system in Turkey. SimaPro software and CML impact assessment method was used in the LCA studies.

Keywords: Concrete Production, Supplementary Cementitious Materials, Life Cycle Assessment, Concrete Mixtures

ÖZ

FARKLI BETON MALZEMELERİN YAŞAM DÖNGÜSÜ ANALİZİ (YDA) VE BİR YEŞİL BİNADA UYGULANMASI

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Beton küresel ölçekte en çok kullanılan yapı malzemesidir. Temel olarak çimento, agrega, su ve katkı malzemelerinden oluşan beton için üretim aşamasında yüksek miktarda hammadde ve enerji gerekmektedir. Bu durum da yapı sektörü için sürdürülebilir kalkınma açısından önemli ölçüde çevresel endişeye sebep olmaktadır. Bu nedenle, özellikle son yirmi yılda, beton üretimi için yapılan çevresel etki değerlendirme çalışmaları önem kazanmaktadır. Beton üretim aşamalarının hayat boyu- beşikten mezara- tüm etkilerini değerlendirebilmek için kullanılan en etkili ve yaygın metot Yaşam Döngüsü Analizi (YDA)'dir. Çimento ve doğal agreganın sırası ile endüstriyel yan ürünler ve geri dönüşümlü agrega ile ikame edilmesi sonucu üretilen yeşil beton karışımlarının da çevresel etkilerinin değerlendirilmesi için çok sayıda YDA çalışması yürütülmektedir. Bu çalışmada, çeşitli yeşil beton karışımlarının YDA metodu kullanılarak çevresel etkilerinin analiz edilmesi hedeflenmiştir. Bu amaçla, uçucu kül, yüksek fırın cürufu, silika dumanı, doğal puzolan ve kireç taşı tozu gibi ilave çimento benzeri malzemeler ve/veya geri dönüşümlü agrega ile çok değişkenli kombinasyonlar yapılarak oluşturulmuş olan 21 adet yeşil beton karışımının beşikten kapıya YDA incelemesi yapılmıştır. Bu çalışmaya ek olarak, oluşturulan yeşil beton karışımları Türkiye'deki Leadership in

Energy and Environment (LEED) değerlendirme sistemi tarafından sertifikalandırılmış bir yeşil bina için yürütülen YDA çalışmasına entegre edilerek betonun çevresel etkileri beşikten mezara analiz edilmiştir. Yapılan YDA çalışmalarında SimaPro yazılımı ve CML etki değerlendirme metodu kullanılmıştır.

Anahtar Kelimeler: Beton Üretimi, İlave Çimento Benzeri Malzemeler, Yaşam Döngüsü Analizi, Beton Karışımları

To my family

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LIST OF ABBREVIATIONS

ABBREVIATIONS

ADP: Abiotic Depletion Potential
AP: Accredited Professional
AP: Acidification Potential
ASTM: The American Society for Testing and Materials
BMCC: Building Material and Component Combinations
BREEAM: Building Research Establishment Assessment Method
CASBEE: Comprehensive Assessment System for Building Environmental Efficiency
CDW: Construction and Demolition Waste
CG: Crushed Granite
CKD: Cement Kiln Dust
CL: Crushed Limestone
CS: Crushed Stone
DEB: Direct Energy Bound
DQI: Data Quality Indicator
EFCA: European Federation of Concrete Admixtures Associations Ltd.
EMPA: Swiss Federal Laboratories for Material Testing and Research
EP: Eutrophication Potential
EPA: Environmental Protection Agency
EPD: Environmental Product Declaration
EU: European Union
FA: Fly Ash
FAETP: Fresh-water Aquatic Ecotoxicity Potential
FS: Foundry Sand
G: Glenium

GBRS: Green Building Rating System
GGBFS: Ground Granulated Blast Furnace Slag
GHG: Greenhouse Gas
GLO: Global
GLP: Ground Limestone Powder
GWP: Global Warming Potential
HTP: Human Toxicity Potential
IgCC: International Green Construction Code
IRMA: Integrated Decontamination and Rehabilitation of Buildings, Structures and Materials in Urban Renewal
ISO: International Organization for Standardization
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
LEED: Leadership in Energy and Environmental Design
LP: Limestone Powder
LS: Limestone Sand
MAETP: Marine Aquatic Ecotoxicity Potential
MRI: Midwest Research Institute
NCA: Natural Coarse Aggregate
NP: Natural Pozzolan
NRS: Natural River Sand
ODP: Ozone Depletion Potential
P: Polycarboxylate
PC: Portland cement
PCA: Portland Cement Association
PCDD/Fs: Polychlorinated dibenzo-p-dioxins and dibenzofurans
PE: Polycarboxylic-ether
PG: Pea Gravel
POCP: Photochemical Ozone Creation Potential

PV: Photovoltaic

RA: Recycled Aggregate

REPA: Resource and Environmental Profile Analysis

RG: River Gravel

RS: River Sand

SCMs: Supplementary Cementitious Materials

SETAC: Society of Environmental Toxicology and Chemistry

SF: Silica Fume

SS: Steel Slag

TETP: Terrestrial Ecotoxicity Potential

UNEP: United Nations Environment

USGBC: The United State Green Building Council

VOC: Volatile Organic Carbon

VRV: Variable Refrigerant Volume

WPC: Whole Process of the Construction

CHAPTER 1

INTRODUCTION

1.1. General

In recent decades, environmental impacts of the buildings have become one of the main concerns since a major part of the natural resources such as raw materials and energy sources have been consumed by building sector while construction, operation, maintenance and demolition phases. Globally, about 32% of the natural resources are consumed by the building industry. In addition, 25% of the water consumption, 40% of the energy consumption, 12% of the land usage, 25% of the solid waste generation and 35% of the greenhouse gas (GHG) emissions are attributed to this industry, in global scale [1].

Construction materials are the second most consumed materials succeeding the water in the world and almost half of the annually extracted raw materials have been utilized by construction sector. Therefore, the environmental impacts resulting from building sector has been tackled on a global scale rather than local scale [2]. Concrete is the most consumed construction material with an annual production of 25 billion tons and its consumption is approximately twice the consumption of other construction materials such as wood, steel and aluminium [3]. Concrete manufacturing is responsible for 2.1 billion ton of global anthropogenic carbon dioxide emissions in which a major part of these emissions resulting from cement clinker production [4]. Hence, to improve resource efficiency, decrease GHG emissions and reduce landfill requirement for industrial wastes, green concrete mixtures have been developed and evaluated. In this respect, industrial wastes and by-products have partially been used as cementitious material, or natural aggregates have been replaced by recycled aggregates obtained from construction and demolition wastes (CDW). For example, fly ash, blast furnace slag and silica fume are the most commonly used by-products in the construction sector that are generated from different industries [5]. In addition to these by-products, limestone and natural pozzolan have been used as supplementary cementitious material to reduce environmental impacts mostly resulting from cement content [6].

In order to assess the environmental performance of concretes used in the buildings, one method could be the Life Cycle Assessment (LCA) approach [5]. LCA is an effective and systematic approach to assess total environmental impacts and costs of the products and services through their entire life. LCA is being used to identify and quantify the environmental impacts of the buildings and building materials. LCA is beneficial methodology since it provides scientific and objective justifications for decision making. LCA analysis comprises of four stages: goal and scope definition; life cycle inventory; impact assessment and interpretation [7].

Indeed, in the literature, there are many LCA studies conducted to assess the environmental performance of different concrete mixtures made by various cementitious materials and/or aggregate s. The system boundary for most of these studies is limited to “cradle-to-gate” and the scope does not transcend the production of concrete which means the construction, use and end of life phases are not considered. Mix design for the concrete including several important components for the concrete such as cement, water, fine and coarse aggregates, admixtures and binders is not wide range and assesses only a few SCMs and recycled aggregate concrete options. Moreover, the information of the life cycle inventory (LCI) belonging to the concrete mixtures are not provided in detail sufficiently [5], [8]–[11]. In addition, environmental impact categories included in such LCA studies are limited to global warming potential (GWP) and other important impact categories such as eutrophication potential, acidification potential and photochemical oxidant creation potential were mostly excluded [4]. Therefore, it can be inferred that there is a need for comprehensive LCA approach for green concrete mixtures designated by combining variety of applicable SCMs and/or recycled aggregates.

As pointed out in the previous paragraph, LCA studies conducted for alternative and/or green concrete mixtures are limited to cradle to gate approach and in most of these cases, the environmental impacts of the concrete mixtures applied to a building are not discussed considering the overall environmental impacts of the building. In the literature, there are several concrete LCA studies in which system boundary have been extended to cradle to grave system boundary by applying the green concrete mixtures into the case buildings [4], [12], [13]. However, in these studies, concrete mixtures made of different SCMs and/or recycled aggregates were applied only for conventional concrete buildings. Indeed, application of different green concrete mixtures on whole-life cycle of green buildings should also be required to determine how green building is actually green. In addition, no matter the scale of the environmental impacts of the concrete on the results, its application on building leads to more comprehensive outputs.

Therefore, in order to fulfil the above-mentioned gaps in the literature, environmental impacts of different green concrete mixtures have been analyzed through cradle to grave LCA, and these selected green concrete mixtures were also applied in the Prokon-Ekon Headquarter Building which is a Leadership in Energy and Environmental Design (LEED) Platinum certified green building located in Kahramankazan, Ankara - Turkey.

1.2. Objective and Scope of the Study

The objective of the study is to conduct a comprehensive LCA study for different green concrete mixtures and to apply these concrete mixtures on whole-lifespan of the case green building to assess the contribution of environmental burdens resulting from concrete production. In order to achieve this goal, the following steps have been applied:

- Literature was reviewed in order to select appropriate green concrete mixtures having 28-day compressive strengths around 35 MPa since the traditional concrete used in the case green building had a 28-day compressive strength of 35 MPa. As a result of literature review, 21 green concrete mixtures with different constituents and mixture proportions were selected for this study.

- Then, these green concrete production scenarios were evaluated by applying LCA methodology and the environmental impacts were compared with each other to determine which constituents and/or which mixture proportions have better environmental performance.
- Following the evaluation of scenarios, these 21 concrete mixtures were then applied for the Prokon-Ekon Headquarter Building to evaluate the impact contribution of concrete to the overall LCA of the building having 60-years lifespan. End-of-life stage was also included for the concrete products.

Data inventory for the building was provided by Ms. Merve Aygenç, LEED Accredited Professional (AP) and Ms. Tuba Yücel, the Project Manager of Prokon Engineering and Consultancy Co. In addition, the Prokon-Ekon Headquarter Building was visited on December 27th, 2018.

In order to evaluate the impact of concrete on the green building lifespan, the LCA study conducted for the Prokon-Ekon Headquarter Building by Ms. Merve Aygenç was used as a baseline. Concrete data were replaced with the selected green concrete mixtures and other components were not altered.

The LCA study was conducted by using SimaPro 8.4.1.0 software. In the scope of the study, system boundary for concrete scenarios was determined as cradle to gate and expanded to cradle to grave by applying these green concrete mixtures into case green building life cycle. The functional unit for the green concrete mixtures was selected as 1 m^3 of concrete whereas the functional unit for the whole building was selected as1 m^2 floor area. Lifespan of the Prokon Ekon Headquarter Building is selected as 60 years in accordance with the LEED.

Allocation is avoided and the consequential system model was applied both for green concrete mixture and building scenarios. CML-1A baseline impact assessment method was selected for this study; and characterization results were used in the interpretation of the results.

1.3. Thesis Overview

This master thesis comprises of seven chapters. Chapter 1 introduces the motivation of the study to assess environmental impacts of different concrete mixtures and their applications on the case study building, namely Prokon-Ekon Headquarter Building. In addition, objective and scope of the study has been stated within this chapter. Chapter 2 provides background information regarding LCA concept, green buildings, Green Building Rating System (GBRS), integration of GBRS to LCA approach and concrete and its components with their environmental impacts. LCA studies conducted for different concrete mixtures are also presented in Chapter 2. In Chapter 3, the structural and energy components of the case study building are introduced including the obtained credits for each environmental category under the LEED. Chapter 4 provides the research methodology including details of LCI and use of the SimaPro 8.4.1.0. In Chapter 5, results of the conducted LCA studies for both concrete mixtures and their application on the case building are presented and discussed. The conclusion of the research is summarized in Chapter 6 and, finally future recommendations are given in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

2.1. Life Cycle Assessment (LCA)

The importance of environmental protection and the awareness of the potential impacts of produced and consumed products increased the interest in developing methods to better understand and assess environmental impacts. For this purpose, LCA methodology was developed that helps to identify opportunities about environmental performance of products through their life cycle, notify decision makers and organizations (both governmental and non-governmental), and select related environmental indicators through judgements [14].

LCA is a scientific approach defined by ISO 14040 and ISO 14044 enabling to assess the environmental impacts of goods and services, namely products, through conducting comparative analyses by cradle-to-grave approach [15].

ISO 14040 defines the LCA as follow: *"LCA addresses the environmental aspects and potential environmental impacts) (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)."* [14]

In the cradle-to-grave approach, all important processes of product's life cycle are considered and involved into the LCA. Raw materials extraction, material production, final products, usage stage of products, waste management and transportation are one of the most important product life cycle stages. Transport, energy and co-products might be included into each unit processes [16]. Therefore, unlike traditional analyses, LCA enables to evaluation of cumulative environmental impacts of product life cycles by estimating all stages and including impacts [17]. The possible life cycle stages included into LCA and system inputs and outputs are presented in Figure 2.1.

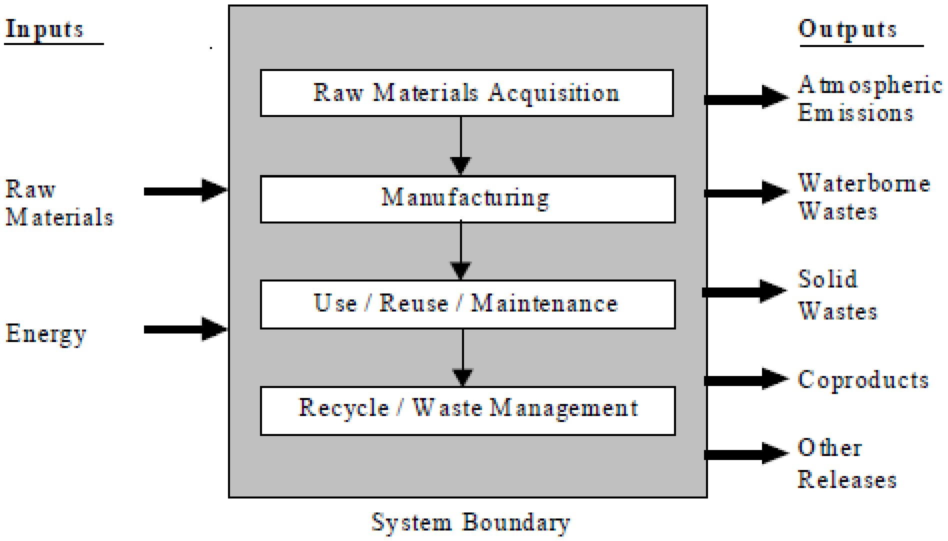


Figure 2.1. Life cycle stages [17]

Application of LCA emerged in between 1960s and 1970s when environmental issues were being arising and attracting public notice. Although several cradle-to-grave LCA studies had been conducting by Midwest Research Institute (MRI) through Resource and Environmental Profile Analysis (REPA) in between those years, just a few of these studies was published. At the beginning of 1980s, interest in LCA has started to grow quickly. Swiss Federal Laboratories for Material Testing and Research (EMPA) conducted a study in 1984 by introducing impact assessment methodology and providing a list of data that might be required in LCA studies. Therefore, the term in between 1970 and 1990 can be named as decades of conception as different approaches and results were executed [18].

In 1990s, the number of scientific studies on LCA increased, the first journal papers were published, workshops and forums started to be organized, and a number of LCA handbooks and guidelines were published. In order to establish a common framework and methodology, Society of Environmental Toxicology and Chemistry (SETAC) was lead to gather professionals, scientist and users together that interested in LCA. After SETAC, the International Organization for Standardization (ISO) has started to developed methods and procedures in 1984. ISO 14040: 2006 - Environmental management – Life Cycle Assessment - Principles and Framework' and ISO 14044: 2006 - Environmental Management – Life Cycle Assessment - Requirements and Guidelines are the current ISO standards for LCA. Therefore the period 1990-2000 can be considered as decade of standardization for LCA methodology [18].

In the first decade of 21th century, demand on LCA has been increased and thus, this period can be named as the decade of elaboration. Life Cycle Initiative, which was developed to put LCA into practice and to support LCA with better implementations, was established by the United Nations Environment (UNEP) and the SETAC, in 2002. For the last ten years, LCA sustainability analyses covering environment, economic and social dimensions have gaining importance [18].

LCA is a systematic approach that consist of four main components namely goal and scope definition phase, inventory analysis phase, the impact assessment phase and the interpretation phase. According to ISO 14040, the interaction between these steps is illustrated in Figure 2.2 [17].

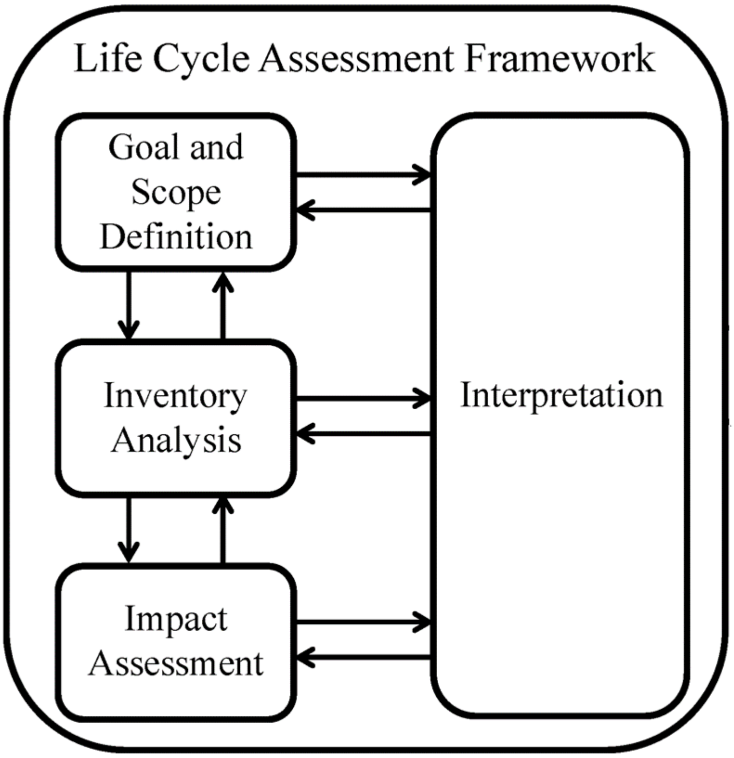


Figure 2.2. Phases of LCA [17]

2.1.1. Goal and Scope Definition

Goal and scope definition is the first step of LCA in which goal, scope, functional unit and systems boundaries of the study are defined and data quality is described. Goal and scope definition part is crucial due to strongly affecting the result of LCA through critical review process. The goal of the study should clearly state the purpose, reason and intended audience of an LCA study. According to results of the LCA study, the goal might be redefined. In the scope definition, the methods to be used and components of the system are defined. In this context, functional unit, systems boundaries, allocation procedures, the function of the systems, impact assessment methodology, types of impacts, data requirements, assumptions and limitations of the study are generally considered and described in defining scope of the study. Since the LCA is an iterative approach, scope of the study might be redefined during study such as in the interpretation phase, when necessary [19].

Definition of functional unit is an important step for LCA studies as it enables to compare two or more products based on an equivalent unit. Functional unit is also important for inventory analysis because data collection depends on selected functional unit. Therefore, functional unit that normalize input and output data can be considered as reference point for comparisons studies [19].

It may be difficult to follow all inputs and outputs of the product system. Therefore, system boundaries should be defined for the system which is under assessment. Ones, who apply LCA, may have difficulty in deciding whether production, usage, disposal and transportation are included in LCA or not. In this regard, one needs to consider the boundary with nature (i.e. a part of natural system or production system), and also to decide if the production and disposal of capital goods will be included or not. For the latter, there are three orders to consider. In the first order, only production and transportation stages are included in LCA (rarely used). In the second order of LCA, all processes are considered and included into LCA analysis, except capital goods. Lastly, in the third order, the capital goods are also included into LCA by considering production of the materials to be used in capital goods production [20].

2.1.2. Life Cycle Inventory Analysis

LCI is the second and most time consuming phase of LCA in which inputs and outputs for the entire life of product such as resource requirements, air emissions, water emissions, electricity and waste generation are gathered and quantified.

LCI provides a basis for LCA to compare the environmental impacts of products and/or processes through data collecting and classification. In this context, LCI can be beneficial in policy-making, comparing products, selection of materials and developing regulations.

Developing a flow diagram and data collection are the main steps to be followed during LCI.

After goal and scope definition in which the system boundaries of the system are determined, the inputs and outputs of the system should be presented by developing flow diagram. An example flow diagram developed by considering inputs and outputs of the system for generic unit process are presented in Figure 2.3.

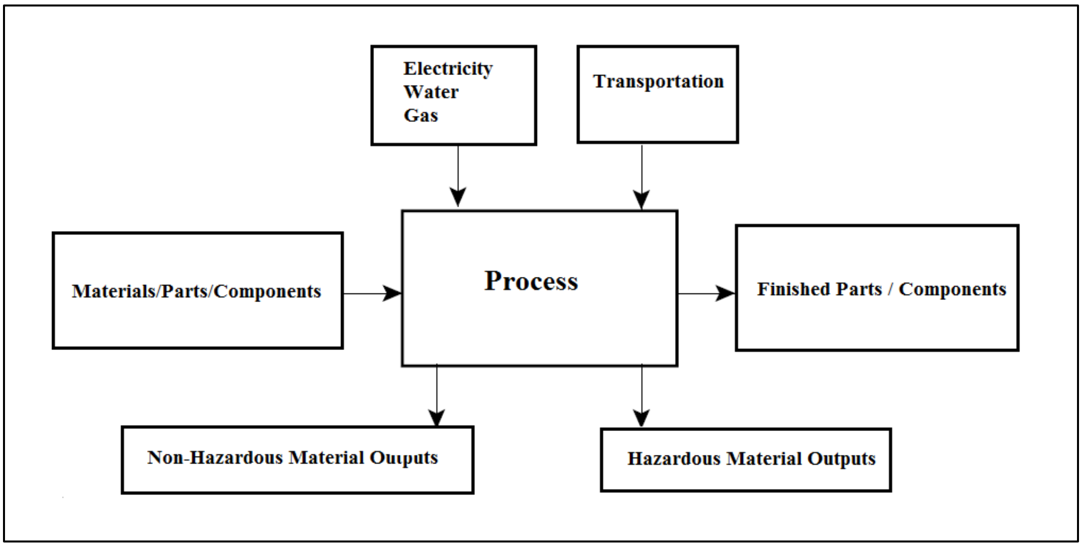


Figure 2.3. Generic unit process flow diagram [17]

After developing flow diagram, next step is data collection. A data collection plan should be prepared before data collection including the following steps: defining data quality goals, identifying data source and data quality indicators (DQI). As stated in the Environmental Protection Agency (EPA) LCA: Principles and Practice Guideline (2006) [17], the data source can be: meter readings from equipment; equipment operating logs/journals; industry data reports and databases; laboratory test results; government documents, reports and databases; other publicly available databases; journals, papers, books, and patents; reference books; trade associations; related/previous life cycle inventory studies; equipment and process specifications; and best engineering judgement.

Data collection can be a very complex and time consuming as it requires research, continuous interaction with experts and site visits.

The results of LCI enable to develop a list that quantifies the all inputs and outputs for the assessed system and/or product [17].

2.1.3. Life Cycle Impact Assessment

Life Cycle Impact Assessment ("LCIA") is the third step of the LCA methodology. Impacts of the products or services on environment and human health are assessed in this step by considering inputs and outputs of the system that defined in inventory phase. Stressors such as increase of greenhouse gases and excess nutrients are the main circumstances that may cause to impacts [17].

LCIA has composed of several elements. The compulsory elements stipulated by ISO 14040 and optional elements are listed below [15].

Compulsory elements:

- Selection and definition of impact categories, indicators and characterisation models
- Classification
- Characterization
- Category indicator results

Optional elements:

- Normalisation
- Grouping
- Weighting

Selection and definition of impact categories:

LCIA evaluates the impacts of inputs and outputs of the system by focusing human health, environment and natural resource utilization. Therefore, selection of suitable impact categories is very important. This step is conducted by also considering the goal and scope definition of the study. Common impact categories used in LCIA are listed as follow [17]:

- Global warming,
- Stratospheric ozone depletion,
- Acidification,
- Eutrophication,
- Photochemical smog,
- Terrestrial toxicity,
- Aquatic toxicity,
- Human health,
- Resource depletion,
- Land use, and
- Water use

Classification:

After selection and definition of impact categories, the results of life cycle inventory step are appointed into the impact categories in classification step. The LCI data can be classified into one impact category as well as two or more different impact categories at the same time [17]. For example, SO_2 can be assigned into an acidification impact category as well as human health impact category [20].

Characterization:

In characterization phase, characterization factors, or equivalency factors, are used in order to illustrate the contribution of life cycle inventory results to the selected impact categories. To characterize the impact categories, the following equation is used generally [17]:

Inventory Data * Characterization Factor = Impact Indicators [17]

For example, the contribution of NO_2 gases to global warming potential can be quantified by multiplying NO_2 characterisation factor by life cycle inventory results.

In characterization, the contribution of each different life cycle inventory data can be determined in an equal base by using appropriate characterisation factors [17].

Normalisation:

In normalisation step, impact category indicators are divided into "normal value" or "reference value" to demonstrate the impacts of inventory data on environment and/or human health. Through applying normalization, impact categories having less contribution among other impact categories can be removed from consideration thus, the number of concerns can be decreased. Also, the extent of contribution of impact categories to environmental problems can be shown by normalisation [20]. Common normal values used in normalisation are: determination of impact category indicators for a global, regional or local area; determination of impact category indicators for a given area during a year or on a per capita basis; and baseline values [17].

Grouping:

In order to interpret the results in an easier way, the impact category indicators can be grouped by ranking systems considering priority and classifying them according to property such as location [17].

Weighting:

In the weighting, the normalisation results are multiplied, and/or aggregated, by coefficients using one of the weighting methods to reveal which impact categories are more important. Weighting can be considered the most difficult step in LCA, especially when midpoint approach is used [20].

In the literature, there are numerous impact assessment methodologies which differ from each other by using the different impacts categories, characterisation and normalisation factors and evaluation methods [21]. These impact assessment methodologies are given below:

- BEES
- CML 1992
- CML 2001
- Cumulative Energy Demand
- Eco-Indicator 95
- Eco-Indicator 99
- Ecological Footprint
- Ecopoints 97
- Ecological Scarcity 2006
- Ecosystem Damage Potential
- EDIP 2003
- EPD 2000 – EPD 2007
- IMPACT 2002+
- IPCC 2001 GWP
- IPCC 2007
- TRACI

In LCIA, two approaches, namely midpoint and endpoint, are used while characterization and normalization the inventory data. A midpoint is considered to be an impact category indicator in between life cycle inventory results and endpoints in a cause effect diagram or environmental system. On the other hand, endpoint approach is used to demonstrate the final effects [22]. Relationship between midpoint and endpoint is shown in Figure 2.4.

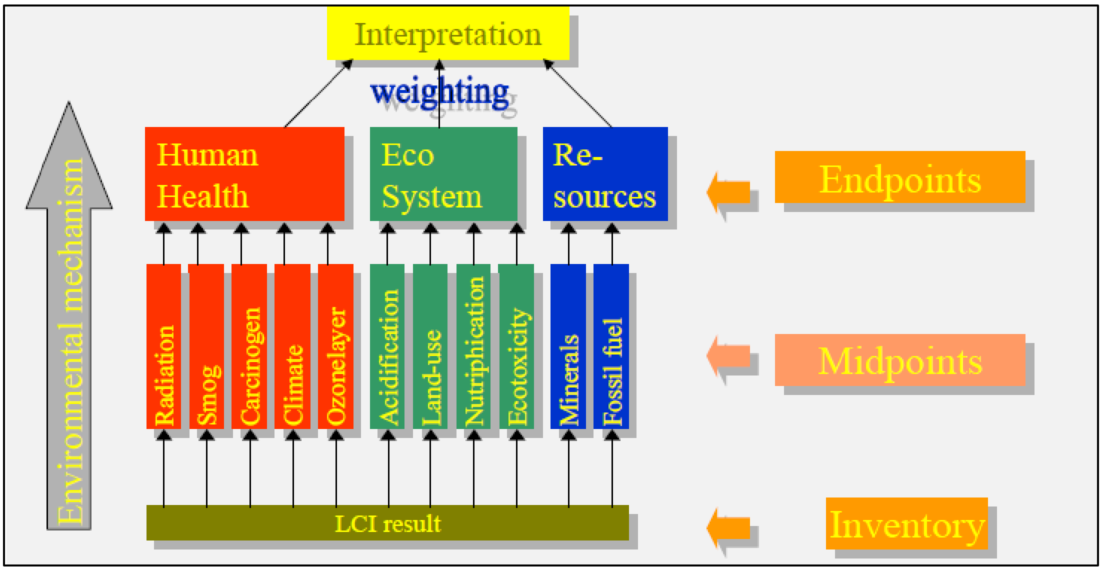


Figure 2.4. Relationship between midpoints and endpoints [20]

Midpoint impact category indicators have lower uncertainty as they close to the life cycle inventory results, however, endpoint impact category indicators are more understandable for decision-makers [22].

Midpoint and endpoint impact category indicators being used in common impact assessment methodologies such as IMPACT 2002, Eco-indicator 99, CML 2002 and Ecoinvent are given in Table 2.1.

Table 2.1. *Midpoint and Endpoint Impact Categories [23]*

Midpoint Impact Category	**Endpoint Impact Category**
Human toxicity (carcinogens+ non-carcinogens)	Human Health
Respiratory	
Ionizing radiations	
Ozone layer depletion	
Photochemical oxidation	Human Health Ecosystem Quality
Aquatic ecotoxicity	Ecosystem Quality
Terrestrial ecotoxicity	
Terrestrial acidification/nutrification	
Aquatic acidification	

Table 2.1. *Midpoint and Endpoint Impact Categories [23] - continued*

Midpoint Impact Category	Endpoint Impact Category
Aquatic eutrophication	Ecosystem Quality
Land occupation	
Global warming	Climate Change
Non-renewable energy	Resources
Mineral extraction	

All in all, LCIA is conducted to get meaningful basis for comparisons of life cycle inventory data.

2.1.4. Life Cycle Interpretation

Life cycle interpretation is the last phase of LCA methodology in which the results of life cycle inventory and life cycle impact assessment are evaluated in a systematic way and where the suggestions are made by considering the goal and scope of the study. The following steps are identified by ISO 14044 to conduct a life cycle interpretation step: "identification of the significant issues based on the results of the LCI and LCIA; an evaluation that considers completeness, sensitivity and consistency checks; and conclusions, limitations and recommendations." [16]. The relationship between these life cycle interpretation steps and other LCA phases is presented in Figure 2.5.

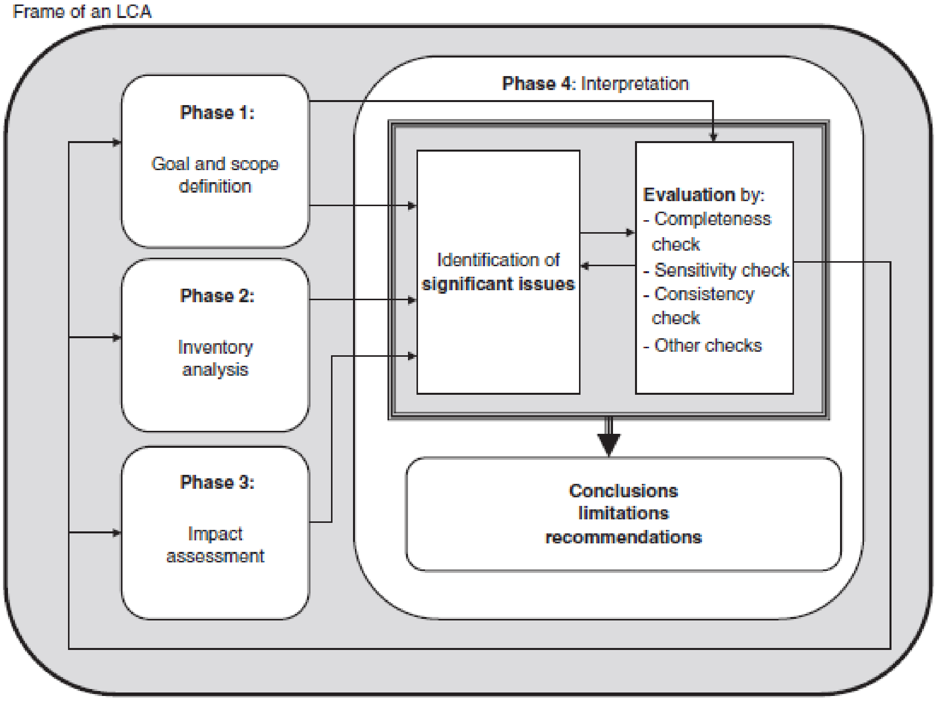


Figure 2.5. Interrelation of life cycle interpretation steps to other LCA phases [16]

After LCA study has been completed, the results, assumptions and limitations should be reported in a comprehensive and systematic manner. This prepared report should present the result of the study reasonably, clearly and accurately for the decision-makers or other who may interested in the results of conducted LCA study [17].

There are various commercially available LCA Software developed by institutions and companies to conduct complete LCA or only inventory phase of the LCA [19]. List of commonly used and commercially available LCA and LCI software tools are given in Table 2.2.

Table 2.2. *Common LCA and LCI Software Tools [17]*

Software Tool	**Supplier**	**Web Site**
Bousted Model	Bousted Consulting	-
BEES	NIST Building and Fire Research Laboratory	https://www.nist.gov/services-resources/software/bees
CMLCA	Faculty of Science Institute of Environmental Sciences	http://www.cmlca.eu/
Ecoinvent	Swiss Centre for Life Cycle Inventories	https://www.ecoinvent.org/
Environmental Impact Estimator	ATHENA Sustainable Materials Institute	-
GaBi	PE Europe GmbH and IKP University of Stuttgart	http://www.gabi-software.com/turkey/index/
EDIP PC-Tool	Danish LCA Center	https://lca-center.dk/
KCL-ECO	KCL	-
SimaPro	PRé Consultants	https://simapro.com/
TEAM		
Umberto	Ifu Hamburg GmbH	https://www.ifu.com/en/umberto/

2.2. Green Buildings

Environmental impacts of the buildings are becoming one of the main concerns since the natural sources are consumed mostly by building sector. The statistics indicate that 32% of natural resources comprising 12% water and 40% energy are consumed and used by building sector [24]. In addition, construction of buildings consumes 60% of the global raw materials [25]. 22% of hazardous waste in Europe and 35% of municipal solid waste in the United States has been producing as a consequence of construction activities and maintenance of buildings [24] [26]. Therefore, the idea of environmental friendly building was considered as beneficial techniques that help to decrease environmental impacts of buildings as well as to increase economic growth and sustainable development [27].

Over the last two decades, “green building” term is becoming popular and attracting the attention of public. However, there are still debate about precise definition and scope of green buildings [28]. The United State Green Building Council (USGBC) defines the green buildings as “*Green buildings are designed, constructed, and operated to boost environmental, economic, health and productivity performance over that of conventional building.”* [29]. In more specific way, green buildings can be defined as the high-performance structures using less natural resources and energy, providing comfort, protecting human health and having less operational cost. The materials used in construction of green buildings should have less environmental impact, utilize less water, prevent pollution, reduce waste generation and should be durable. Also, green buildings shall aim to increase indoor air quality, reduce natural resource and energy consumption and cost, and promote well-being and productivity [27].

The mainspring why green strategies are viewed as green is that these strategies work in line with the surrounding climatic and geographic conditions. Therefore, to design green buildings through sustainable way, architects and designers should identify, understand, consider and familiar with the site properties such as climatic conditions, environment, location, precipitation, winds, topography and vegetation cover. In addition to these issues, identifying and minimizing the required amount of resources to be utilized for green buildings construction is also another important concern to achieve sustainability. In this context, selection of suitable sites, achieving water and energy efficiency, selection of the environmental friendly materials, conservation of resources, better environmental air quality, and building operation and maintenance can be considered as one of the main components of sustainability and green buildings [30]. In order to achieve these green building criteria, the following comprehensive approaches are generally needed:

- Technological innovations such as cooling systems, waste control systems and solar PV panels encouraging the use of renewable energies in green buildings;
- Integrating LCA approach to analyse the environmental impacts of green buildings;
- Involvement of GBRS as managerial approach for green buildings; and
- Enhancements of stakeholder involvement and awareness through considering behavioural and cultural factors [28].

Green buildings have been attracting the interest of architects, designers, constructors and building owners since the oil crises of 1970, as they have numerous benefits and there are many programs offering several incentives [30]. Green buildings have both tangible and less tangible benefits. Reduction in energy and natural resource consumption, providing resource efficiency, reduction in waste generation, pollution prevention, utilizing less water, enhanced indoor air quality and less operating and maintenance cost are one of the main measurable benefits of green buildings. On the other hand, enriched occupant health and comfort, productivity, and increased reputation of the company by constructing green building can be considered as the less tangible benefits of green buildings [29].

In terms of environmental benefits, green buildings facilitate the protection of ecosystem through sustainable land use, reduction of material consumption and construction waste generation, and usage of recycled and reused materials at least in the ratio of 90% [28].

In economic perspective, green buildings can reduce operating and maintenance costs, increase building value, provide tax benefits with the promotion of government. In addition, economic benefits of green buildings might be as follows: reduction in carbon footprint by saving energy and water up to 50%; improve productivity; provide tax benefits for investments; improvements in occupant health, employee morale, recruitment, retention; better public relations; and provide risk management benefits through faster permitting and certification [31]. Even though researches reveal that green buildings require more upfront cost than conventional buildings, reduction in maintenance and operating cost will help to depreciate this cost difference [28].

Green buildings can improve the productivity of occupants and one's health by improving indoor air quality and thermal comfort. High level of indoor air quality may help to enhance the contentedness of occupants. In this context, green buildings reduce absenteeism, increase productivity by 25% and improve psychological wellbeing [28].

By considering the above mentioned environmental, economic and social benefits of green buildings, it can be concluded that sustainability for buildings can be achieved by integrated design and approach [30].

2.2.1. Green Building Rating Systems (GBRS)

GBRS are a tool which have been developing to standardize the green buildings and to set a course for monitoring of buildings. Materials, energy and water consumption, waste generation, indoor air quality, operation, management, design, construction and use are the main concerns of GBRS. Also, location and climate are other significant factors causing to develop their own rating systems for the countries [32]. GBRSs are utilized to assess, develop and encourage sustainable development for buildings by analysing, validating and comparing the information. In this context, GBRSs may help to improve building's operational performance, decrease building's environmental impacts, minimize natural resource consumption and, assess and calculate development of buildings [33]. Therefore, buildings, which are certified by GBRS, are considered to consume less energy, create a better environment and contribute to the property's overall reputation [34].

In spite of the fact that there are nearly 600 GBRSs that have been using in the world, Building Research Establishment Assessment Method (BREEAM), LEED, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), Green Star and Green Globe are the most utilized GBRSs [34].

Since the Prokon-Ekon Headquarter Building, which is case study building of this research, is certificated by LEED v3, only LEED is examined and detailed in this section.

The pilot version of LEED (V1.0) was developed in 1998 by the USGBC in US. After receiving feedbacks from users LEED V1.0 had been developed and LEED Version 2 (V2.0) and Version 3 (V3.0) were launched to the market in 2000 and 2009, respectively [35]. LEED v3 was developed for New Construction, Core & Shell, and Schools by addressing seven topics which are Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (IEQ), Innovation in Design (ID) and Regional Priority (RP). Grading scale for LEED v3 is as follow: 40-49 points "Certified"; 50-59 points "Silver"; 60-79 points "Gold"; 80 points and above "Platinum" [36].

The latest version of LEED, which is LEED v4, was developed and released in 2013 with variations for data centres, warehouses and distribution centres, hospitality, existing schools and retail and mid-rise residential projects [35]. Building Design and Construction (BD+C), Interior Design and Construction (ID+C), Building Operations and Maintenance (O+M) and Neighbourhood Development (ND) are the rating system included into LEED v4. There are nine different credit categories as following: Integrative Process, Location and Transportation (LT), Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (EQ), Innovation (IN) and Regional Priority (RP). In addition grading scale is same as LEED v3 [37].

As of today, LEED is one of the most demanding building rating systems and it has been adapted to many markets [35].

2.2.2. Integrating LCA to GBRS

Over the last decades, integrating LCA into GBRS has been becoming widespread since LCA enables systematic assessment of the building's environmental impacts, particularly for decision making and design stages. In addition, getting higher grades from GBRSs might not always mean lower environmental impacts, thus, it is suggested that LCA methods should be integrated into GBRS tools [38]. LEED, BREEAM, International Green Construction Code (IgCC) and Green Globes are one of the GBRS having LCA provisions with different requirements [25].

The IgCC which is the first rating tool for North American launched in 2009. LCA was integrated into the IgCC in 2012 version after several feedbacks and revisions. On the other hand, Green Globes-NC is the first commercial GBRS in North America that integrates LCA [39]. In addition, there are 6 extra points for material LCA and 3 extra points for full LCA in BREEAM [38].

In 2006, the idea of integrating LCA into LEED was occurred for the first time and LCA was integrated into LEED v2009 as pilot credit for building materials and assemblies to support the use of environmental friendly and sustainable building materials [32]. Then, LCA was integrated into LEED v4, latest version of LEED, under the Materials and Resource (MR) category with credits for conducting whole-building LCA, reuse and impact reducing [32]. As stated in the LEED v4- Reference Guide for Building Design and Construction, at least 10% reduction should be achieved comparing with baseline building by conducting LCA methodology in at least three impact categories such as global warming potential, acidification, eutrophication, depletion of stratospheric ozone layer, formation of tropospheric ozone and depletion of non-renewable energy resources. However, global warming potential must be one of the impact categories that should display reduction. By the same token, any of these impact categories should not show an increase by more than 5% as a result of LCA [40].

In literature, there are some case studies executing the importance of integrating LCA into LEED. Dekkiche and Taileb conducted a study in 2016 [41] for the LEED Gold building located in Canada by using ATHENA Impact Estimator LCA software to understand the fossil fuel consumption and GWP of different wall systems and building materials over building’s life cycle. In the study, two options were conducted and examined by using LCA methodology. In the first option, copper wall system was replaced with cedar cladding system and bricks were replaced with plaster in the second option. The results indicate that 33% fossil fuel consumption and 39.75% GWP reduction were attained through first option. In addition, 13% fossil fuel consumption and 13% GWP reduction were achieved by conducting second option. Therefore, they concluded that LCA is an important tool to evaluate building's sustainability and GBRS can give more valuable results when LCA is implemented. In this context, it is clear that LCA should be integrated into GBRS for more accurate and meaningful assessment results. There are also any other important literature studies ([25], [32], [40]) examine and explain through different scenarios or options why it is important to integrate LCA into GBRS. The results of these studies demonstrate that LCA should be included into GBRSs to assess the environmental impacts of building systems and materials more accurately and to get more remarkable results.

2.3. LCA Approach for Buildings

Buildings, which is emerging sector, consume high energy and natural resources, generates wastes, emits greenhouse gases, causes pollution, and damage environment [42]. Therefore, building sector has a remarkable amount of global environmental impact and energy cost [43]. Construction industry consumes 20-25% of total energy in China and 30-40% of total energy in developed countries. Therefore, buildings are becoming an important issue for sustainable development since some serious global issues ascending [44].

In order to quantify the above-mentioned environmental impacts during life span of buildings, LCA methodology has been applied to construction industry in recent decades [44]. In addition, LCA methodology has being utilized as a tool for decision making through scientific and objective justifications to improve sustainability [42]. LCA offers a holistic approach not only for energy performance but also for cost analysis through entire life of buildings [39]. LCA approach can be utilized in construction industry at four levels such as material level, product level, building level and industry level [45].

LCA approach for construction sector has become another working area because of the difficulties occurred in this sector [46]. Some of the reason for this complexity can be listed as below:

- Long life span to apply cradle-to-grave approach,
- Local impacts of buildings since they are site specific,
- LCA of buildings require several phases such as construction, use and demolition phases,
- Integration of buildings with several elements such as infrastructure,
- Buildings are not stationary, thus, the form of buildings may change over time,
- Environmental impacts occurred during operational phase of buildings,
- Buildings have different components and several functions,
- Absence of incentives, legal requirements and enforcements,
- System boundaries of buildings may not be certain,
- Embodied energy, and
- Stakeholders involved in building sectors [43] [46] [47].

There are two ways to apply LCA methodology into buildings namely building material and component combinations (BMCC) and the whole process of the construction (WPC) [42]. In BMCC, LCA is performed for a certain part of building, material and/or building components. In addition, if all material processes are included in the LCA, this level is called WPC and the appraisal will be characterized by a determined level [47].

As detailed in LCA section (Sec 2.1), there are four main steps as defined in ISO 14040 for LCA methodology as follows: 1. Goal and Scope Definition including life cycle definition, functional unit, system boundaries, data quality requirements and critical review process; 2. Inventory Analysis composed of data collection, refining system boundaries and calculation procedures; 3. Impact Assessment by performing category definition, classification, characterization and weighting; 4. Interpretation of results by reconsidering the definitions and assumptions in the Goal and Scope section [47].

In the following sub-section, four main LCA steps are detailed in case application of LCA into buildings.

Goal and Scope Definition:

This is the first step of LCA in which the purpose of study is identified and the questions are determined. In this step, objective and limitation of the study is specified and so, the results of the LCA studies may change according to goal and scope definition. Functional units and system boundaries for buildings are also specified at this stage [46].

In today, several functional units have been using for buildings regarding the scope of the studies. In this context, literature studies indicate that m^2 is one of the mostly used functional units for residential buildings. In addition, kg, m, m^2, m^2 internal space, m^2 floor area, m^3 and kWh have been used together in a single study conducted for whole building [38]. The comparison between results of different studies would be more easy if the studies have been conducted based on same functional units. Although there are some efforts to standardize the functional unit for buildings, there is not common functional unit that are commonly held for buildings [46].

Time periods and lifetime of buildings are also determined in goal and scope definition stage. Even though the life time of buildings are variable and dependent on the materials type and life span, lifetime for buildings are generally assumed in between 25 and 50 years depending on former building's data. As there is not any calculation method for time period of buildings, assumption may not be give exact results and may cause an error [38]. In order to overcome this problem, a research has been conducted by Aktas et al., which indicate the importance of lifespan on LCA results. This study reports that the average lifespan of residential building in U.S. is 61 years with a standard deviation according to the statistical analysis [48].

In addition to the functional unit and time period, system boundaries for buildings are also determined in the first step of LCA and cradle-to-grave approach is the most applied system boundary implemented into building LCA studies [38].

Inventory Analysis:

Inventory analysis is the second and most time consuming and complex stage of LCA as data collection and calculation processes are conducted while inventory analysis. Scope and /or objective of the LCA study might be change and needed to be redefined in case lack of data. Data inventory might be difficult for buildings because of several phases included such as pre-construction, construction, usage and demolition [46].

Allocation is not compulsory and not always required especially in case system boundary of the study is selected from-cradle-to grave [46].

The success and reliability of the study is mainly based on the data quality, therefore, it is important to choose the most appropriate data as far as possible. Reliability, completeness, temporal correlation, geographical correlation and technological correlation can be counted as the indicator score while data quality assessment for building LCA [46].

Flow diagram presenting the processes selected for LCA study shall be developed in detail to get more accurate results. An example of flow diagram for buildings and/or construction sector is given in Figure 6. Then, data collection procedures shall be determined to see inputs and outputs of each phase included in the process. Refining data to functional unit is very important step as functional unit can be differed for each component in case BMCC [46].

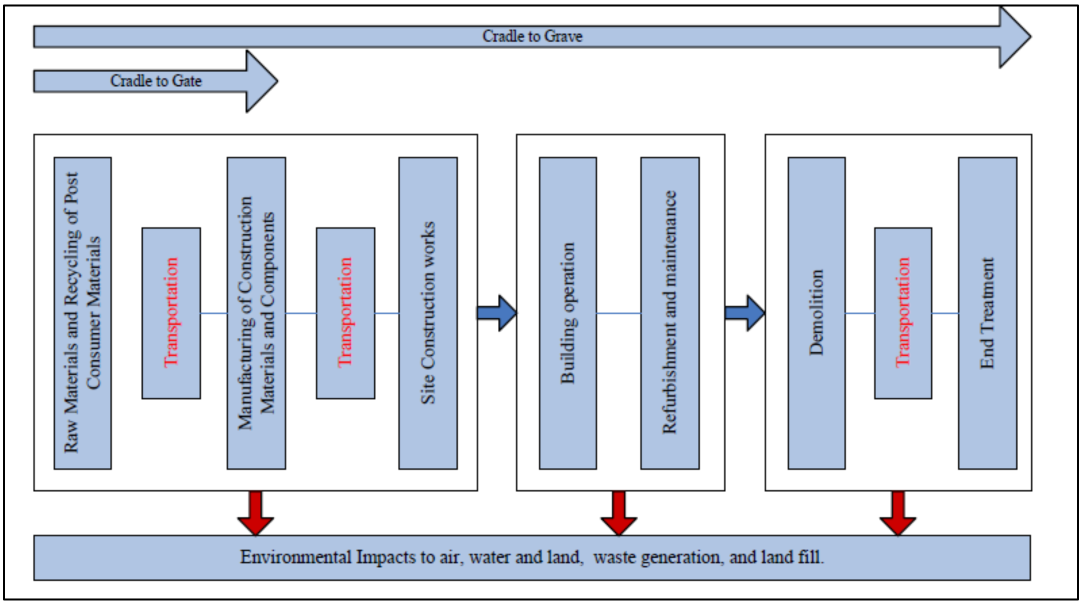


Figure 2.6. Flow diagram for building and/or construction [46]

Impact Assessment:

In impact assessment step, multiple processes are followed to examine the environmental impacts of buildings. Impact category selection, classification, expression and comparison of potential impacts, weighting and characterization are the processes applied during impact assessment stage [46].

The impact categories such as global warming, acidification, eutrophication, ozone depletion, water consumption, photochemical ozone depletion, resources consumption potential, ecotoxicity, carcinogens and air emissions can be differed for each building LCA case regarding goal and scope definition [46].

In order to measure the environmental impacts and the cost of buildings, LCA assessment tools are being developed for architectures, designers, engineers and researchers in accordance with the LCA approaches stipulated in ISO 14040 standards [49]. Building specific LCA tools are being established because general LCA tool might be time consuming for users. Architects, designers and researchers may conduct their LCA studies within a few days by the help of building specific LCA tools [43].

The list of building specific assessment tools are presented in Table 2.3. ATHENA and BEES are the most utilized building specific LCA tools among others [38].

Table 2.3. *Building Specific LCA Tools [38], [43]*

Name of Tool	Website
ATHENA	http://www.athenasmi.org/our-software-data/impact-estimator/
LEGEP-Life Cycle Assessment	https://legep.de/?lang=en
Envest 2.0	-
ECOSOFT	https://www.ibo.at/en/building-material-ecology/lifecycle-assessments/oekoindex-oi3/
BeCost	http://virtual.vtt.fi/virtual/proj6/environ/ohjelmat_e.html
Buildings for Environmental and Economic Sustainability (BEES)	https://www.nist.gov/services-resources/software/bees
EQUER	http://www.buildup.eu/en/learn/tools/equer-life-cycle-simulation-tool-buildings
EcoEffect	http://www.ecoeffect.se/
ECO-BAT 4.0	http://www.eco-bat.ch/index.php?option=com_content&view=frontpage&Itemid=1&lang=en
ECO-QUANTUM	-
OGIP	-
GREENCALC	https://www.dgbc.nl/

Table 2.3. *Building Specific LCA Tools [38], [43] - continued*

Name of Tool	Website
One-Click LCA	https://www.oneclicklca.com/

In addition to the building specific LCA tools; GaBi, SimaPro, OpenLCA, EIO-LCA, Boustead Model, Umberto NXT LCA Software, TEAM 5.2, Eco-it, Ecopro, Ecoscan, Euklid, KCL Eco, LCAit, Miet, Pems, Team and Wisard are one of the generic LCA tools that are applicable to building LCA [38] [43].

Interpretation:

This is the final step of LCA that the result of study is analyzed, results are obtained and reported, restrictions are explained and suggestions are made regarding the discoveries achieved from LCA and/or LCI studies. In this final step, the results of study are interpreted and clarified in compliance with goal and scope definition step of LCA study [46].

In literature, there are large number of studies that apply LCA methodology into buildings to evaluate the environmental performance of buildings and building components such as construction materials. For example, Guggemos and Horvath conducted a LCA study in 2005 [50] to assess the environmental impacts (such as energy use and emission) of two typical office buildings for construction phase and overall life cycle. Among these two typical office buildings, one has structural steel frame and the other has cast-in-place concrete frame. The purpose of selecting and comparing these two structural materials was that both steel frame and concrete frame are commonly used materials for commercial buildings. In order to assess the environmental impacts of buildings, they used process-based LCA and economic input-output analysis-based LCA methods by establishing Construction Environmental Decision Support Tool. Based on the construction phase comparison results, they reported that concrete frame contributes more energy use, more transportation impacts, longer equipment use, and more emission such as CO_2, CO, NO_2, SO_2 and PM_{10}. Besides, steel frame causes to more Volatile Organic Carbon (VOC) and heavy metal emission than concrete frame. In addition, they stated that construction phase impacts of materials are vanished and use phase impacts becomes dominant when comparison is conducted for overall life cycle of buildings over 50-year time period.

Asadollahfardi et al [51] applied LCA methods by using SimaPro 7.1 Software in compliance with International Organization of Standardization's (ISO) 14040 and evaluated the global warming impacts and acidification potential of the construction materials of the building located in Tehran, Iran. They reported that major building materials like concrete, steel, PVC window frames, ceramic tile and brick have significant environmental impact with a 79.4%, 2.96%, 0.92%, 1.45% and 7%, respectively. Also, concrete, steel, PVC window frames, ceramic tile and brick were found to cause to contribution global warming potential with a 43%, 19%, 13%, 5.38% and 8%, respectively. Moreover, in terms of acidification, they postulated that concrete, steel, PVC window frames, ceramic tile and brick have contribution with a 21%, 22%, 22%, 6%, and 7%, respectively. They concluded that PVC, steel and ceramic tile have significant environmental burden because of low mass distribution whereas wood materials have less environmental impact and less contribution than other construction materials. They also reported that the transportation of the materials has significant environmental burden.

All in all, LCA is very important and effective tool to assess and quantify the environmental burden and cost of the building and building's components and therefore, it can be concluded that LCA methodology is very helpful for sustainability development [46].

2.4. Concrete and its Constitutes with Their Environmental Impacts

Construction industry is responsible for high amount of raw material and energy consumption, waste generation, GHG emission. Therefore, it is important to improve the sustainability development for this industry, which accounts for 24% of global raw material extraction and 50% of global anthropogenic GHG emission. In the EU, buildings are responsible for 50% of total energy demand and 50% of total CO_2 emission during their whole service life. In addition to the natural resources depletion and environmental impacts (i.e. soil, air and water pollution, and waste generation), construction activities are also harmful for ecosystem, landscape, human health and welfare [52].

Concrete is the most commonly used construction material with 25 gigatonnes (Gt) consumption amount per year which represents 3.8 tons of concrete per capita annually. Concrete production contributes more than 5% of global CO_2 emission annually mostly due to the cement clinker production [53]. In order to produce concrete, 42% of aggregates have been producing annually and construction industry generates about 850 million tons of waste in every year which accounts for 31% of total waste generation in Europe [54].

Concrete basically contains cement, aggregate, fresh water and admixtures by mass. Most of emissions are due to cement production that accounts for approximately 7% of global CO_2 emission. Nearly 4 GJ energy is required to produce one ton of cement and one ton of cement clinker production leads to one ton of CO_2 emission in to the atmosphere. Also, quarrying of raw materials damages the landscape and causes to top soil loss. In every year, about 11 million tons of raw materials such as sand and gravel and about one trillion liter of fresh water are being consumed globally for concrete production [55].

Therefore, it is significant to quantify and assess the environmental impacts of concrete manufacturing by considering whole process [53]. As of today, a lot of sustainable solutions have been recommended, investigated and applied. In order to achieve more green and sustainable concrete mixtures, cement content of concrete is replaced partially with supplementary cementitious materials such fly ash, blast furnace slag, silica fume, limestone powder, natural pozzolan and steel slag. Also, natural aggregates are replaced with recycled aggregates such as construction and demolition wastes [5]. In order to evaluate the environmental impacts and optimize the material and energy flows of these green concrete mixtures and to compare the results with traditional concrete a significant amount of LCA studies have been conducted [52].

Marinkovic et al. conducted a case study in 2010 [8] by applying LCA methodology to compare the environmental impacts of two types of ready-mixed concrete in which one type is made from natural aggregate and the other is recycled aggregate concrete. They analysed the extraction of raw material, transportation and production of aggregate and cement as part of the LCA study. However, the construction phase, service phase and demolition phase were not included in the scope of their study to compare the environmental impacts of different concretes since the both concrete types have similar compressive strength and durability. They reported that environmental impacts of cement and aggregate production are slightly higher for recycled aggregate than natural aggregate depending on the transport distance for energy use, global warming, eutrophication, acidification and photochemical oxidation impact categories. However, transport scenario 1 in which transport distance of recycled aggregate is smaller than natural aggregate showed that the environmental impact of recycled aggregate and natural aggregate is nearly same for selected impact categories and significant gains can be achieved for waste recycling and minimization of resource depletion.

In order to evaluate and compare the environmental impacts of green and conventional concretes properly, Van Den Heede and De Belie [7] reviewed the available literature studies conducted for traditional and green concretes production stages via applying LCA methodology. They concluded that goal and scope definition, inventory analysis and impact analysis may significantly change the LCA results in the interpretation phase. In this context, their study indicates that the functional unit selection to calculate the environmental impacts of concretes has considerable influence on the outcome of the LCA study. They recommended that the functional unit should compromise the relevant concrete characteristics such as compressive strength, workability, service life and durability. In addition, input first hand data and economic allocation for cementitious materials were recommended since data inventory can significantly change the LCA results. They reported that environmental impacts of concrete made with blast furnace slag and fly ash are higher than traditional cement. Finally, they stated that impact assessment should cover more than impacts on climate change and should be specific to the problem.

In order to compare the environmental impacts of recycled concrete mixtures with conventional concrete, Knoeri et al. [10] analysed 12 concrete mixtures composed of different amount of cement and recycled aggregate with two types of cements. Their study indicated that recycled concrete options have less environmental impacts by 30% at endpoints compared to the conventional concrete in case transport distance and additional cement requirement are limited for recycled concrete. They reported that this gain is achieved through steel recycling and avoidance of disposal requirement for construction and demolition wastes.

In 2014, Gursel et al. [53] reviews the strengths and weaknesses of conducted concrete LCA studies and offers three important recommendations need to be elaborated in future cement and concrete LCA studies. The first one is about lack of holistic assessment of environmental impacts in concrete LCAs. It was noted that most of these LCA studies focus on GHG emissions and energy use, however, another important environmental and public health issues resulting from admixtures and commonly used supplementary cementitious materials such as slag and fly ash should also been considered. So, in their study the importance of the holistic approach is emphasized to understand the environmental and public health impacts of concrete production. Their second point was about the lack of application of regional and technological variations in concrete LCA studies. They recommended that cement and concrete LCA studies should consider local applications rather than national average approaches. Finally, their third dimension remarks the neglecting of LCA parts that are considered insignificant based on assumptions or past studies. They claimed that each unit and system included in concrete production are very important regarding energy use and environmental impacts. Therefore, the assumptions and deemed parts can be very significant for LCA results.

Turk et al. [56] evaluated the environmental impacts of different green concrete mixtures prepared from foundry sand, steel slag, fly ash and recycled aggregate by applying LCA methodology. They indicated that the supplementary cementitious materials reduce environmental impacts of traditional concrete up to 75% for fly ash scenario, 85% for foundry sand scenario and in between 65% and 95% for steel slag scenario. In addition, they revealed that environmental impact of traditional concrete is reduced approximately 88% by replacing natural aggregate with recycled aggregate. they stated that this significant reduction in environmental impacts is achieved by avoiding landfilling for cementitious materials and waste concrete. They also conducted a sensitivity analysis for transportation of alternative materials and recycled aggregates and showed that the results for alternative cementitious materials are not sensitive to transport but recycled aggregate scenario is sensitive to the transport and delivery distance and the impacts resulting from delivery distance (more than 100 km) become more significant for environmental impacts of recycled concretes.

Celik et al. [57] performed LCA study for two types of concrete mixtures including fly ash and ground limestone powder. Direct and supply chain global warming potential emissions for concrete mixtures were calculated by using “GreenConcrete LCA” tool developed by some co-authors (Gursel and Horvath) of the study. In their study, raw material extraction, cement manufacturing, extraction of aggregates, processing of aggregates, superplasticisers production, transportation of raw materials and products, extraction and handling of limestone, preparation and processing of fly ash and concrete batching were included. Their environmental assessment results for concrete mixtures indicate that GHG emission and other analysed air pollutants such as NO_x, PM_{10} and SO_2 emissions are equal or lower than emissions resulting from traditional concrete in all cases. However, CO emission results for concrete including fly ash were slightly higher than typical concrete due to preparation stage before mixing into concrete. In addition, GWP emissions for fly ash were found to be 5-10 folds greater than limestone powder for the same amount due to the fuel utilization in treatment stage for fly ash. In their study, not only environmental impacts but also mechanical properties of the green concrete mixtures were analysed.

The above-mentioned studies and other related studies that reveal the environmental impacts of green concrete mixtures by means of LCA are summarized in Table 2.4 in alphabetical order. It should be keep in mind that these literature studies were selected and presented by considering objective and scope of the studies, relevance to this study, the number of citations, type of utilized alternative concrete components, impact assessment methodology and outcomes of the studies.

Table 2.4. *Summary of the Literature LCA Studies on Concrete Manufacturing*

Reference Source	**Geography**	**Scope of LCA**	**System Boundary**	**Alternative Concrete Components**	**Impact Assessment Method**
Celik et al. [57]	U.S.	LCA	Cradle to gate	Fly ash and Limestone	-
Chen et al. (2010b) [9]	Europe	LCA	Cradle to gate	Blast furnace slag and fly ash	CML
Colangelo et al. [13]	Italy	LCA	Cradle to gate	Incinerator ashes, blast furnace slag, marble sludge and CDW	Eco-indicator 99
Garcia-Segura et al. [12]	Spain	LCI	Cradle to grave	Fly ash and blast furnace slag	-
Habert et al. [58]	France	LCA	Cradle to grave	Traditional vs. Geopolymer concrete constitute of fly ash, GGBFS, metakaolin	CML 2001

Table 2.4. *Summary of the Literature LCA Studies on Concrete Manufacturing - continued*

Reference Source	Geography	Scope of LCA	System Boundary	Alternative Concrete Components	Impact Assessment Method
Knoeri et el. [10]	Switzerland	LCA	Cradle to gate	Recycled concrete	Eco-indicator 99 and Ecological Scarcity 2006
Marinkovic et al. [5]	Serbia	LCA	Cradle to gate	Fly ash and recycled aggregate	CML baseline
Marinkovic et al. [8]	Serbia	LCA	Cradle to gate	Recycled aggregate concrete	CML
Schepper et al. [54]	Belgium	LCA	Cradle to cradle	Recycled concrete	CML 2002
Turk et al. [11]	Europe	LCA	Cradle to gate	Fly ash, foundry sand, steel slag and recycled	CML 2001
Van den Heede and De Belie [7]	Belgium	LCI and LCA	Cradle to gate	Fly ash and blast furnace slag	CML 2002 and Eco-indicator 99

The concrete constituents and alternative cementitious materials are detailed in following sub-sections with regards to LCA perspective.

2.4.1. Cement

Although, the history of cement usage date back 2,000 years ago, industrial manufacturing of cement was started in the middle of 1800s [59]. The global cement production amount was about 4,6 million tonnes in 2015 that is equal to 626 kg/per capita. This production amount has increased approximately by 34 times within 65-years [60]. The estimated cement production amount for 2050 is in between 3700 and 4400 megatons [61]. The output growth is mostly seen in developing countries and regions such as China, India, Middle East and Northern Africa [59]. However, this high amount cement production and increasing cement demand in construction industry cause anthropogenic emissions such as GHG. Cement production is responsible of 6% - 10% of global GHG emission, nearly 2.6 gigatonnes of CO_2 emission and 12% - 15% of industrial energy use [60], [61]. According to the several LCA studies conducted for cement production, 800 kg of CO_2 is emitted to produce one-ton cement. Therefore, it is important to be seek and adopted new sustainable cement production approaches since 50% reduction in CO_2 emission is required cement industry as stated by IPCC mitigation scenario [60].

Cement is a type of hydraulic binder and key component for concrete and mortar production. As of today, there are 27 types of commonly used cements and these are grouped into five as follows: CEM I Portland cement; CEM II Portland-composite cement; CEM III Blast furnace cement; CEM IV Pozzolanic cement; CEM V Composite cement. In addition, cements are distinguished into three categories depend on their strength such as ordinary, high and very high [62].

In order to manufacture cement, first, clinker is produced and then, clinker is milled with gypsum and other substances. Quarrying of raw materials is the first step for clinker production. Raw materials such as limestone that contribute $CaCO_3$ content are extracted from quarries. Then, these extracted raw materials are crushed into 10 cm in crushers. These crushed raw materials are mixed and ground together in raw meal grinding process that is very important step for cement quality. In order to recover thermal energy, increase the efficiency of process and use less fuel, these mixed and milled raw materials are preheated before reaching rotary kiln. In preheating processes, a number of cyclones are presented in which raw material mixtures are passed through. The number of cyclone may be changed depending on the moisture content of the raw materials. Preheating process is followed by precalcining. Limestone is converted to lime in precalcining stage that is responsible from almost 60% of total CO_2 emission generated during cement production [62]. The chemical reaction occurred in this stage is as below:

$CaCO_3 \longrightarrow CaO + CO_2$ [60]

After precalcining, precalcined raw material mixtures or raw meals enter the kiln at around 1000^0C and then fuel is thrown into the kiln to ensure the materials temperature reaches 1450^0C. Then, raw meal starts melting into clinker with the help of high temperature [62]. Although there are different types of kilns such as wet rotary kiln, semi-wet rotary kiln, semidry rotary kiln and shaft kiln, dry kilns are used mostly and more than 90% of cement clinker has been produced in dry kiln in Europe [59] [62]. Then, the clinker is discharged at the end of kiln and cooled by air. After clinker has produced, gypsum is added into clinker at the rate of 4-5% and this mixture is ground in cement mill. The final homogenized product is stored into silos [62].

A representative process flow diagram for cement manufacturing with inputs and outputs is given in Figure 2.7.

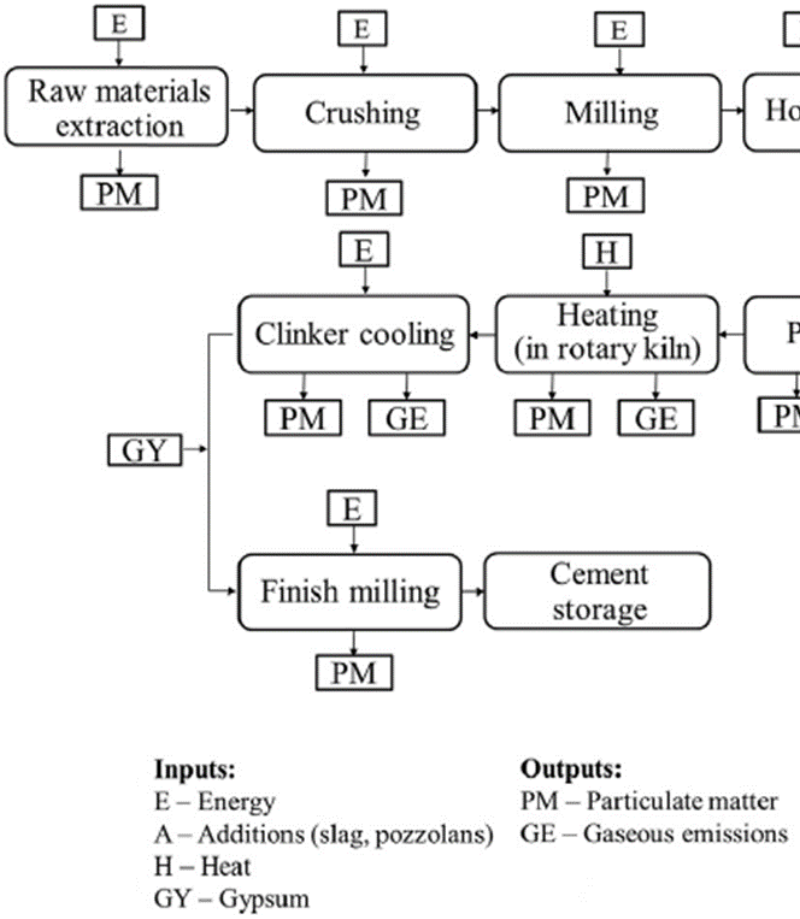


Figure 2.7. Representative process flow diagram for cement production [61]

Cement production may cause global, regional and local environmental impacts. The conducted LCA studies have revealed the significant environmental impacts of process stages of cement manufacturing. Raw material extraction is responsible from 20% of total GHG emission, and the remaining 80% emission is resulted from precalcining and fuel combustion [59]. Efficiency of kiln is very important by considering direct energy bound (DEB) emissions resulting from fuel combustion in the kiln. Generic heat consumption for cement kiln is about 3.1 GJ/ton clinker that emits nearly 0.31 kg DEB-CO_2 [7]. In order to reduce the emissions, cements made from alternative clinkers such as Belite-rich Portland cement clinkers, Belitic clinkers containing ye'elimite, hydraulic calcium silicate clinkers manufactured by hydrothermal processing, magnesium-based cements and carbonation-hardening cements can be considered [60]. Utilization of alternative fuels such as tyres, animal residue, sludge, waste oil and carbon neutral biomass rather than conventional fuels are important solution to reduce CO_2 emission [7], [59].

SO_2 and NO_x emissions which cause acid rains are the regional scale environmental impacts of cement manufacturing. SO_2 is generated as a result of fuel combustion and processing of raw material mixtures n the kiln. In addition, NO_x (NO and NO_2) is emitted due to utilized fuel for clinker production and energy consumption for entire operation of cement plants [7].

On the local scale, cement kiln dust (CKD), emission of metals and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and chromium found into cement are the main environmental concerns. CKD emission is generated during clinker production and is very hazardous for both public health and environment. The mean production amount of CKD is about 15-20% per kg clinker. Since the size of CKD particulates is in between 0.05 and 5 μm, CKD is very harmful for respiratory system. In order to reduce the environmental and health risks of CKD, mineral carbonation can be applied. Emission of metals and PCDD/Fs are another significant concern on the local scale. After emission, the impacts of these pollutants can be direct via air or indirect via soil and groundwater [7].

Chromium found in cement is another concern for cement manufacturing on local scale. As chromium such as Cr(VI) is not stable and soluble wen hydrated, it can be very harmful for human health especially interfering with the unprotected skin [7].

In order to eliminate and/or minimise the above-mentioned global, regional and local impacts of cement manufacturing, mitigation strategies such as improvement in energy efficiency, utilization of alternative fuels, clinker substitution by mineral additions and supplementary cementitious materials, applying carbon capture and use (CCU) and usage of alternative clinkers are applied in cement industry [60].

2.4.2. Aggregates

Concrete industry uses nearly 20 billion tonnes raw materials throughout the world especially in developing countries such as China, India and Brazil and three billion tonnes of aggregate are produced in EU countries, in every year. Therefore, concrete industry can be considered as one of the biggest consumer since concrete consists of approximately 55-80% natural (coarse and fine) aggregate by volume [8] [63].

In order to produce coarse aggregates such as granite, first, rocks from quarries are blasted with explosives to obtain medium size rocks. Then, these are removed by excavators and haulers to the crushing and screening part. At the final stage, the graded products are moved into the stockpiles. According to the study conducted by Flower and Sanjayan [64] at two coarse aggregate quarries by using fuel, electricity, explosives and transportation from quarries to the batching plants data, the CO_2 emission per tonne of granite and basalt is 0.0459 tCO_2-e/tonne and 0.0357 tCO_2-e/tonne, respectively. They claimed that the crushing process can be considered as the most important part of the coarse aggregate production since electricity has the highest contribution to CO_2 emission. In addition, they stated that blasting, excavation and hauling activities contribute less than 25% and explosives contribute less than 0.25% to total emission. In order to reduce these environmental emissions, they recommended the followings: improvements in placements of explosives to reduce electricity amount used in crushing and regular maintenance of crushing equipment and machinery.

The fine aggregates such as raw sand are stripped by excavators, and then loaded to haulers. After that, the sand is washed out and pumped to the grading plant to be filtered by electric vibrating screens. According to the study conducted by Flower and Sanjayan [64] at one fine aggregates quarry, 0.0139 tCO_2-e/tonne is emitting while the production of fine aggregate. The difference for emissions amounts in between coarse aggregate production and fine aggregate production was attributed mainly to the lack of crushing stage in fine aggregate production.

By considering above-mentioned environmental impacts and emissions arising from coarse and fine aggregate production, it is necessary to develop more sustainable solutions without affecting the quality of concrete.

The generation of CDW resulting from rehabilitation works, demolition works, reconstruction, new construction and natural hazards is increasing continuously. The annual CDW production by different countries is approximately as follows: 15.5 million tons in Australia; 30 million tons in USA; 14 million tons in Hong Kong; 750 thousand tons in Japan; 15.33 million tons in Iran. These wastes are generally disposed at landfill and cause many concerns for environment, public health and economy since concrete, asphalt, ceramic brick and other materials including toxic materials are the main sources for CDW. The European Directive 2008/98/CE states that at least 70% of non-hazardous CDW should be recycled until 2020. CDW can be reused in many applications such as concrete and brick production, road construction and mortar production [65] [66].

As a result of urban transformation projects, a great quantity of CDW has been producing. The estimated annual production amount for Turkey is about 5 million tons [67]. Therefore, it is important to manage CDW generated as a result of urban transformation projects. In this context, Integrated Decontamination and Rehabilitation of Buildings, Structures and Materials in Urban Renewal ("IRMA") Project was conducted in 2004 within the European Commission's Fifth Framework Programme "Energy, Environment and Sustainable Development" for nine European countries. The main objective of the project is to develop a management model for sustainable urban transformation to protect environment from contaminated and hazardous substances and to increase utilization of recycled CDW. This model states that maximum amount of recycled CDW will be used as aggregate and filling material in concrete to construct new structures and temporary roads [68].

Therefore, using CDW as recycled aggregate substituted for coarse aggregate is one of the important solutions that may result in less raw material extraction and consumption, less energy consumption, less emission, less waste generation, less landfill requirement and improved public health [66]. In addition, dredged sand and mining wastes can be used in concrete production as fine aggregates. However, using recycled aggregate in concrete production may result in some mechanical and structural changes because recycled aggregate is more porous than natural aggregate and therefore, water requirement would be higher to produce fresh concrete. As Mehta [55] states, using fly ash, water-reducing admixtures and recycled and natural aggregate mixtures can be a solution for these concerns.

Cradle-to-grave LCA of aggregates and conceptual LCA model for natural and recycled aggregate production are presented in Figure 2.8 and Figure 2.9, respectively.

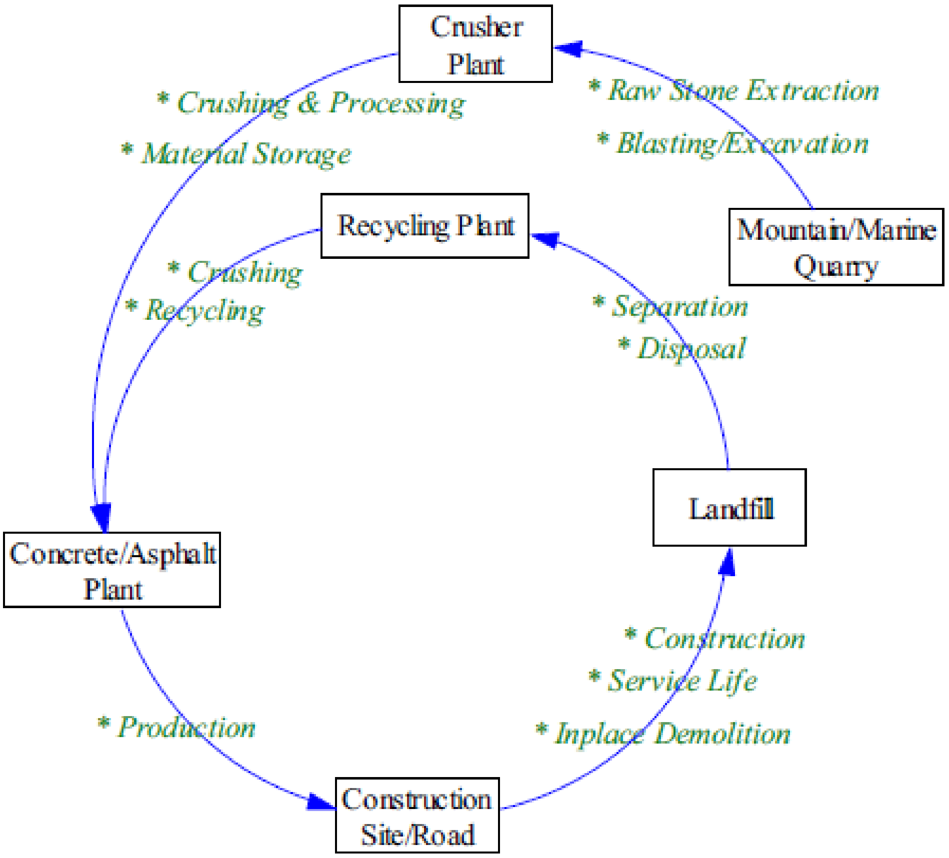


Figure 2.8. Cradle to grave LCA for aggregates [66]

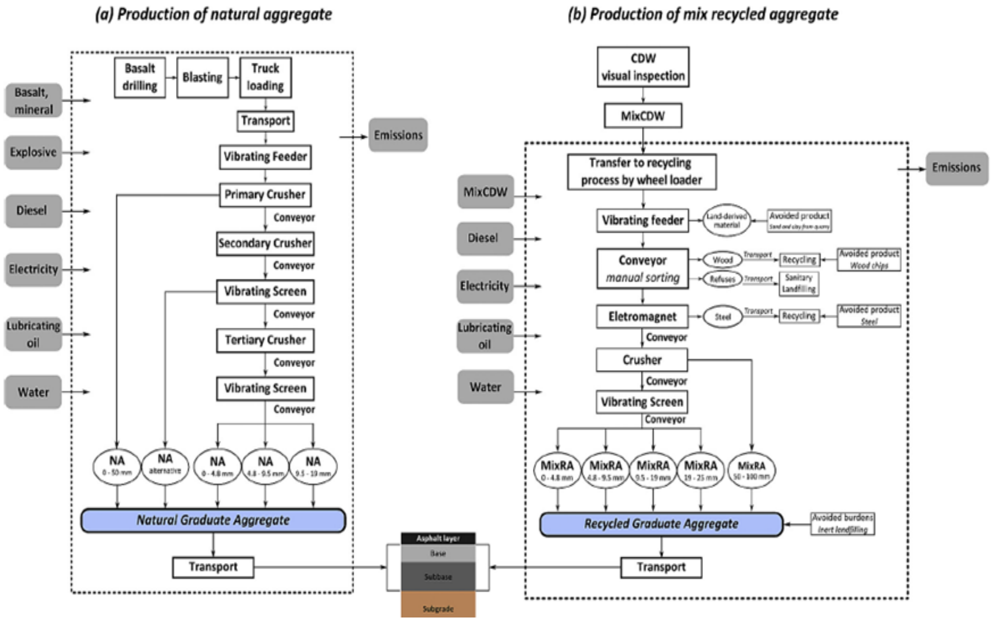


Figure 2.9. Conceptual diagram for natural and recycled aggregates [69]

2.4.3. Water

Although fresh water is abundant and much more accessible for concrete industry, potable water is recommended to be used in mixing and curing process as it does not include any organic substances, alkalies and chlorides. However, water scarcity and water quality are one of the biggest problems faced with due to increasing demand in agricultural activities, industries and urban needs.

Concrete industry is one of the largest sector utilize water resources. Approximately 284 L of water is required to produce 1 m^3 concrete and nearly 100 L/m^3 wash-water is consumed by ready-mixed concrete trucks. Also, approximately one trillion L mixing water is utilized annually by concrete industry. In order to reduce this water demand in concrete industry the following solutions may be applied: achieving better aggregate grading; increasing usage of admixtures; utilizing more recycled industrial water such as blue water rather than using surface water and/or groundwater [7] [55].

2.4.4. Admixtures

Admixtures are liquid or powdered agents which are added less than %5 by weight of cementitious mixture to the concrete during mixing process. Concrete admixtures are mainly used to improve the physical and chemical properties and quality of concrete by increasing its performance, strength and sustainability [70]. General information about five concrete admixtures such as water reducing agents (plasticisers), superplasticisers, set retarders, accelerators, air entraining agents and water-resisting admixtures is provided as follows:

Water Reducing Agents (Plasticisers): Water reducing agents are used to enhance workability (i.e. slump or compacting factor) of concrete mixtures at lower water – cement ratio without significantly affecting setting characteristics.

Water reducing agents are composed of three main chemicals namely lignosulfonate, hydroxycarboxylic acid and hydroxylated polymers [71].

Superplasticisers: Superplasticisers are high range water reducing agents that allow to producing high strength concrete having proper rheology. In addition, it is possible to achieve less porous concrete having higher load bearing capacity as the water demand is reduced through using superplasticisers. Superplasticisers help to reduce water consumption up to 40% and binder utilization up to 50% without altering strength of the concrete [72].

Although, SNF (sulfonated naphthalene formaldehyde), SMF (sulfonated melamine formaldehyde) and polyacrylates are the main raw materials used in superplasticisers, triethanolamine, tributyl phosphate and hydroxycarboxylic acid salts or lignosulfonates might also be used in small quantities.

Superplasticisers may affect properties of concrete through varying air content of fresh concrete (air entrainment), increasing workability and altering setting time. Superplasticisers have no any negative impact on compressive strength and stiffness of concrete [71].

Set Retarders: Retarders are the admixtures that prolong the elapsed time while transition of plastic concrete to the hardened concrete. Set retarders are used to compensate the negative impacts of warm weather such as reduction in setting time and to extend the initial setting time in case difficult situation observed in placement of cement compositions and/or in transferring of mixture to the field. In addition, set retarders help to extend the time while pumping the cement and concrete mixtures, and avoid the cement and concrete mixtures to be thickened early [73].

Accelerators: Accelerators are used to increase the rate of hardening and reduce the setting time of cement and concrete mixes [71]. Soluble calcium salts of chloride, nitrate, nitrite, sodium, thiocyanates and amines are substances that are used mostly as accelerators. However, usage of chloride salts should be avoided due to corrosive effects even they are very effective admixtures [72].

Air entraining agents: Air entraining agents are types of admixtures produce uniform small air bubbles, which entrain an amount of air, added into water while concrete mixing process [71]. These agents could stem from either natural sources or hydrocarbon derived surfactants. Air entraining agents enable to reduce CO_2 consumption resulting from mortar production which is an application that accounts for about a third of world cement production. Air entraining agents help to increase workability, produce low strength concrete, achieve favourable flow, increase in aggressive liquids resistances, protect steel reinforcement, maintenance compressive strength and increase in freeze-thaw [71] [72].

Water-resisting admixtures: Water-resisting admixtures are used to decrease the capillary suction of hardened concrete. Primarily salts of higher fatty acids in aqueous form are raw materials for water resisting agents, and defoaming agents and emulsifying agents are also used in small quantities. Water resisting agents contain active materials at a rate of 20-50% by mass [70].

Although admixtures are used in very small amount according to cement content while concrete production, their environment impacts should also be considered. The LCI data that covers raw material supply, transport and manufacturing product stage for inputs and outputs of admixtures as stated in Environmental Product Declaration (EPD) published by European Federation of Concrete Admixtures Associations Ltd. (“EFCA”) are given in Table 2.5.

Table 2.5. *LCI Data for Admixtures [70], [74]–[78]*

Parameter	**Unit**	**Water-Reducing Agents**	**Set Retarders**	**Hardening Accelerator**	**Set Accelerator**	**Air-entraining Agents**	**Water-resisting Admixtures**
GWP	[kg CO_2 Eq.]	1.88E+0	1.31E+0	2.28E+0	1.33E+0	5.27E-1	2.67E+0
ODP	[kg CFC11-Eq.]	2.30E-10	3.50E-10	1.74E-10	1.80E-10	7.56E-11	4.26E-10
AP	[kg SO_2-Eq.]	2.92E-3	1.04E-2	6.60E-3	2.56E-3	1.30E-3	8.29E-3
EP	[kg $(PO_4)^{3-}$-Eq.]	1.03E-3	5.32E-4	1.54E-3	3.95E-4	1.43E-4	9.55E-4
POCP	[kg ethane-Eq.]	3.12E-4	6.73E-4	4.84E-4	3.64E-4	3.45E-4	9.62E-4
ADP	[kg Sb-Eq.]	1.10E-6	5.87E-6	7.11E-6	5.31E-7	3.66E-7	7.20E-5
ADP (fossil_fuel)	[MJ]	2.91E+1	2.51+1	3.07E+1	2.80E+1	1.33E+1	5.70E+1

Table 2.5. *LCI Data for Admixtures [70], [74]–[78] - continued*

Parameter	**Unit**	**Water-Reducing Agents**	**Set Retarders**	**Hardening Accelerator**	**Set Accelerator**	**Air-entraining Agents**	**Water-resisting Admixtures**
Renewable primary energy as energy carrier	[MJ]	1.51E+0	1.97E+0	8.25E+0	1.02E+0	8.14E-1	7.23E+0
Renewable primary energy resources as material utilization	[MJ]	0.0	0.0	2.60E-1	0.0	0.0	0.0
Total use of renewable primary energy resources	[MJ]	1.51E+0	1.97E+0	8.51E+0	1.02E+0	8.14E-1	7.23E+0

Table 2.5. *LCI Data for Admixtures [70], [74]–[78] - continued*

Parameter	**Unit**	**Water-Reducing Agents**	**Set Retarders**	**Hardening Accelerator**	**Set Accelerator**	**Air-entraining Agents**	**Water-resisting Admixtures**
Non-renewable primary energy as energy carrier	[MJ]	2.66E+1	2.84E+1	3.30E+1	2.21E+1	1.42E+1	6.08E+1
Non-renewable primary energy as material utilization	[MJ]	4.82E+0	0.0	1.16E+0	7.61E+0	0.0	0.0
Total use of non-renewable primary energy resources	[MJ]	3.14E+1	2.84E+1	3.42E+1	2.97E+1	1.42E+1	6.08E+1

Table 2.5. *LCI Data for Admixtures [70], [74]–[78] - continued*

Parameter	**Unit**	**Water-Reducing Agents**	**Set Retarders**	**Hardening Accelerator**	**Set Accelerator**	**Air-entraining Agents**	**Water-resisting Admixtures**
Use of secondary material	[kg]	0.0	0.0	0.0	0.0	0.0	0.0
Use of renewable secondary fuels	[MJ]	0.0	0.0	0.0	0.0	0.0	6.17E-4
Use of non-renewable secondary fuels	[MJ]	0.0	0.0	0.0	0.0	0.0	5.89E-3
Use of net fresh water	[m^3]	6.04E-3	5.75E-3	4.47E-2	7.73E-3	4.13E-3	1.68E-2
Hazardous waste disposed	[kg]	5.17E-6	5.51E-6	1.32E-5	2.44E-5	2.47E-6	8.14E-6
Non-hazardous waste disposed	[kg]	2.56E-2	1.66E+0	9.79E-1	2.29E-2	1.95E-2	2.53E-1

Table 2.5. *LCI Data for Admixtures [70], [74]–[78] - continued*

Parameter	**Unit**	**Water-Reducing Agents**	**Set Retarders**	**Hardening Accelerator**	**Set Accelerator**	**Air-entraining Agents**	**Water-resisting Admixtures**
Radioactive waste disposed	[kg]	9.00E-4	1.29E-3	1.42E-3	6.68E-4	3.68E-4	1.50E-3
Components for re-use	[kg]	0.0	0.0	0.0	0.0	0.0	0.0
Materials for recycling	[kg]	0.0	0.0	0.0	0.0	0.0	0.0
Materials for energy recovery	[kg]	0.0	0.0	0.0	0.0	0.0	0.0
Exported electrical energy	[MJ]	0.0	0.0	0.0	0.0	0.0	0.0
Exported thermal energy	[MJ]	0.0	0.0	0.0	0.0	0.0	0.0

2.4.5. Supplementary Cementitious Materials

Portland cement has been used as binder in concrete over 175 years and global production amount of Portland cement is approximately 3 Gt/year. However, 10 EJ of energy which accounts nearly 3% of global energy use is consumed annually to produce Portland cement. Moreover, 0.87 tons of CO_2 is emitted to produce one tonne of cement. These environmental impacts force the cement industry to seek for new alternatives that can be used as cementitious material without significantly changing the mechanical properties of concrete. In this context, variety of materials and by-products of industries have been used as supplementary cementitious materials such as fly ash, ground granulated blast furnace slag, silica fume, limestone powder and pozzolans [79]. These cementitious materials are detailed in following sub-sections.

2.4.5.1. Fly Ash

Fly ash, which has pozzolanic properties, is a by-product generated while combustion of coal in thermal power plants. Fly ash is produced at nearly 1400^0C in the furnace and the shape of fly ash can be wide-ranging, but it is mostly spherical particles. The American Society for Testing and Materials (“ASTM”) groups the fly ash into three classes: Class C, Class F and Class N. Class C fly ash is generated as a result of lignite and/or subbituminous coal burning and as name implies, Class F fly ash has more than 10% calcium content which makes it very pozzolanic and favourable cementitious substance. The combustion of anthracite and/or bituminous coal produces Class F fly ash having less than 10% calcium content and pozzolanic property. Finally, Class N fly ash is composed of natural pozzolans such as volcanic ash. Class F fly ash is mainly composed of silica (SiO_2) and alumina (Al_2O_3), however, the main components of the Class C fly as are calcium oxide (CaO) and magnesium oxide (MgO).

Although there is several usage of fly ash such as soil amendment, zeolites, geopolymer, concrete and waste stabilization, the utilization of fly ash in construction sector to produce cement and concrete is the most common application since it has economically and environmentally benefits and it improves the strength and durability of concrete. In the main, fly ash is replaced with the Portland cement up to 35% to produce concrete. However, this can be extent up to 70% in some applications such as pavement and walls [80].

The compressive strength of concrete can be increased in curing stage by fly ash replacement since fly ash has pozzolanic properties. In addition, fly ash can increase workability and long-term compressive strength of concrete. Fly ash helps to reduce shrinkage by 30% and permeable void volume by 6-11%, in case 50% and 40% replacement, respectively. Moreover, fly ash replacement reduces the sorptivity and chloride permeability of concrete [81].

The environmental and economic benefits of fly ash utilization as cementitious materials is very remarkable since replacing cement with fly ash helps to reduce greenhouse gas emissions by 15% and in case one ton cement is replaced with fly ash, one ton CO_2 emission reduction is achieved [56] [80]. In the EU, 71% of generated fly ash was used in 2003 and 59% of produced fly ash was used in 2004 to produce cement and concrete. Besides reduction in greenhouse gas emission, usage of fly ash as cementitious material also helps to reduce the landfill requirement. About 9.4 Mt of unused fly ash was stored in landfill in Australia in 2011 [80]. In addition, China produced nearly 700 Mt of fly ash in 2014 [82].

2.4.5.2. Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag ("GGBFS") is a by-product of iron processing that is generated in blast furnace by physical separation of cast iron and other oxides. GGBFS has been used in construction industry as supplementary cementitious materials since it contains high calcium silicate and it has an amorphous structure and pozzolanic properties [83]. As stated in some studies in the literature, the optimum replacement range for GGBFS is 25% at 0.3 water-binder ratio and 1:1.5 cement-sand ratio [84].

Although some studies reported that GGBFS cause corrosion in concrete, laboratory studies prove that usage of GGBFS has several advantages for fresh and hardening concrete production as following: avoiding thermal cracks; enhancing durability and compressive strength; reducing chloride iron permeability; increasing steel corrosion resistance [83] [84].

Although the availability of blast furnace slag has decreased to 8% in 2014, there is approximately 330 Mt/year blast furnace slag globally. As of 2018, higher than 90% of blast furnace slag has been used as cementitious material to produce cement and/or concrete [60]. Therefore, replacement the GGBFS with cement gives an opportunity to reduce energy consumption, landfilling and greenhouse gas emission especially in CO_2 up to 22% [56].

2.4.5.3. Silica Fume

Silica fume is a by-product resulting from silicon and/or ferro-silicon manufacturing. It is composed of micro silica dioxide (SiO_2) and produced in electric arc furnaces at high temperature more than 2000^0C. Silica fume is used as cementitious material to produce high strength concrete due to its pozzolanic property. Since the silica fume fill the gaps between cement and aggregates, it has been used as filler material. The recommended replacement ratio for silica fume is 10% by weight of cement [85]. In addition to the compressive strength, silica fume also improves pozzolanic property, and increase porosity, carrying capacity, durability and resistance of the concrete. However, silica fume may reduce the workability of concrete and increase chloride corrosion in marine environment [84].

2.4.5.4. Limestone Powder

Limestone powder is mineral admixture that is produced by grinding limestone. Limestone powder is mainly composed of calcium carbonate ($CaCO_3$). Silicon dioxide (SiO_2), iron oxide (Fe_3O_4), magnesium oxide (MgO) and aluminium oxide (Al_2O_3) are other components that found in limestone powder. As stated in EN 197-1-2000 Standard, recommended replacement ratio for limestone powder is in between 5% and 35% by weight of Portland cement. However, C150-04 Standard allows only 5% replacement for limestone powder. Limestone powder improves workability of concrete, stimulates early hydration of cement, increase early compressive strength, increase concrete durability and reduce diffusion of chloride ions. In addition, utilization of limestone powder as cementitious materials helps to reduce the CO_2 emission since cement requirement for concrete production is decreased [86].

2.4.5.5. Pozzolans

Natural pozzolans are kind of the supplementary cementitious materials which are very reactive with lime in the presence of water. Minerals and/or organics are the sources of natural pozzolans such as volcanic tuff, volcanic ash, pumice, rice husk ash and scoria. Aluminium oxide (Al_2O_3), silica dioxide (SiO_2) and calcium oxide (CaO) as well as iron (III) oxide (Fe_2O_3) are the predominant compounds that found in naturally pozzolans [87]. Apart from natural pozzolans, there are also artificial pozzolans which are wastes and/or by-products of industries. Silicon-manganese slag, copper slag, coal combustion bottom ash and fluid catalyst are one of the artificial pozzolans generated in industrial processes. In addition, sugar cane ash, activated paper sludge, rice husks and bamboo leaves are the some examples for artificial pozzolans from agro-industrial waste [88].

The mechanical properties such as strength and durability of the concrete and blended cement containing either natural or industrial pozzolans can be equal to commercial Portland cement and concrete if the pozzolan substitution range is in between 25% and 60% [89].

The utilization of pozzolans as supplementary materials helps to reduce the fuel consumption and hence, lower CO_2, SO_2, NO_2 and CO emissions can be achieved [87]. In addition, the amount of required clinker to produce concrete and cement as well as amount of materials to be landfilled can be reduced by using pozzolans [89]. 75 Mt/year of pozzolans are being used as clinker substitutes as of 2018 [60]. Industrial pozzolans (i.e. by-products) are more favourable to use since exploitation of the natural pozzolans can damage the quarries and landscape [87].

CHAPTER 3

PROKON-EKON HEADQUARTER BUILDING

The Prokon-Ekon Headquarter Building ("Prokon-Ekon") which is LEED certificated green building located in Ankara, Turkey, is selected to conduct the research for comparison of environmental impacts of different concrete mixtures by using SimaPro version 8.4.1.0 LCA Software. Prokon-Ekon is used as an administrative office. This building, which is predominantly steel construction, was granted LEED v2009 New Construction ("NC") Platinum certificate with a score of 89 out of 110 and it is the second highest rated LEED Platinum building in Turkey. The general view of Prokon-Ekon is presented in Figure 3.1 and Figure 3.2.

Figure 3.1. General view of Prokon-Ekon Office Building

Figure 3.2. General view of Prokon-Ekon Office Building-II

There is a corbel structure in facade with 16 m. long 22 m. wide and 8 m. height. Three different materials such as window, aluminium composite panel and ceramic coating were used in facade. Gross floor area of Prokon-Ekon is 11,728 m^2 as a sum of basement area and upper floors. There are two basement floors, ground floor and five upper floors. Plant rooms, auditorium, recreational spaces and garage are included in the first basement floor, and archive rooms, garages and water depots are included in the second basement. The ground floor has a central double height space around which meeting rooms and modular offices are located. There is also dining room, cafeteria and offices on ground floor. Offices are located on first, second and third floors. In addition, general manager’s rooms and board room are located on fourth and fifth floor, respectively. In addition, every floor has lift entrance, toilets and fire-escape stairs. The general plan of Prokon-Ekon is presented in Figure 3.3.

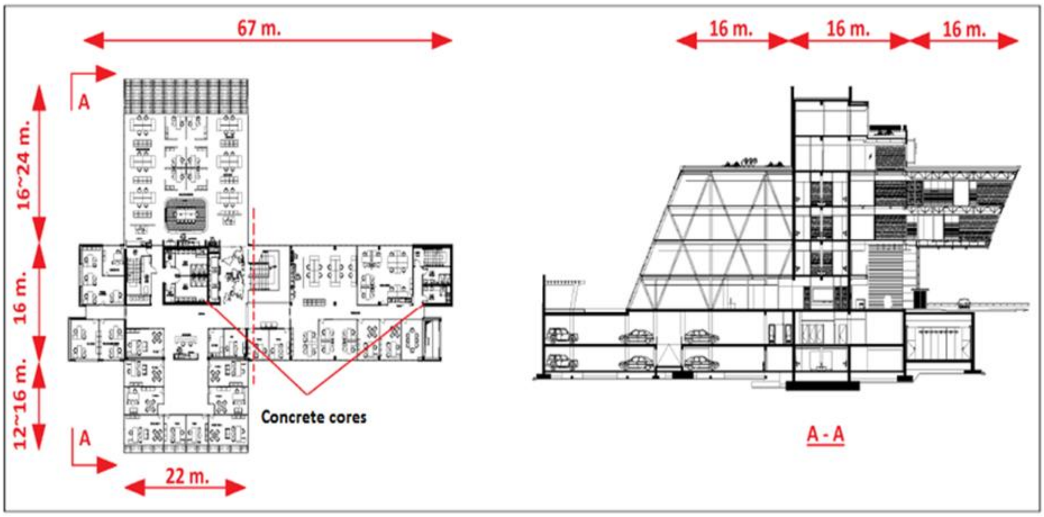


Figure 3.3. General plan of Prokon-Ekon Headquarter Building

Each rating system organized into five environmental categories under the LEED is detailed for the Prokon-Ekon with the ratings in the following sections.

<u>Sustainable Sites:</u>

Field including the steel construction factory of the Prokon-Ekon group of companies has been selected as the land of the new office building. The necessary landscape design was conducted for the site with planting.

Optimum numbers of services are ensured for the personnel and public transport is supported. In this context, reduction of CO_2 emission and fossil fuel consumption resulting from the use of individual cars is aimed.

Firm ground was tried to be used at minimum level except main entrance area of the building. Storm water are collected from roofs and vicinity, and used for garden irrigation purpose.

19 points out of 26 was granted for Sustainable Sites category under LEED v2009 NC.

Water Efficiency:

Water efficiency was considered as first priority during the design stage of Prokon-Ekon and 10 points out of 10 was granted for Water Efficiency category under LEED v2009 NC. The systems used for water efficiency are listed as below:

- Greywater systems,
- Storm water collection systems,
- Biological treatment system,
- Drinking water system,
- Pumps with invertor, and
- Economical water armatures.

Energy and Atmosphere:

The envelope of the building is designed to reach high levels of reduction in the heating and cooling demand. To make the building high performance one, firstly the energy performance of the building envelope has been improved. The strategic shading devices were incorporated on South West and North East side of the building so that undesired direct solar gain in summer months does not increase the cooling load.

As an insulation material, 10 cm. rock wool was used in the exterior walls and 16 cm. XPS was used in the roofs. In the facade, solar controlled and high performance double glazing windows with insulated aluminum frame were used.

The cooling and heating for the building will be provided by heat recovery Variable Refrigerant Volume (VRV) units which are fed by solar collectors, absorption chiller, cooling tower and condensing boiler depending on the season. To maximize the energy efficiency in heating and cooling, three pipes VRV system with heat recovery has been selected. In winter, which is heating season, the VRV devices are in heating mode, the heat is taken from the water circulating in the outdoor of VRV system units, and thermal storage tank temperature drops towards 20°C. In the summer, which is cooling season, in the night times cooling tower operates efficiently and charge thermal storage tank. Temperature in the circuits of outdoor units (temperature of the main storage tank) of the VRV system rises to 30ºC. At this situation, cooling tower starts to keep temperature of tank constant.

A cogeneration unit generating a rated electrical power of 70 kW and corresponding heating from exhaust and heating water to a range of 115 kW is also installed on site. Natural gas consumption is about 204 kW (21 Nm^3/h natural gas) resulting in an over-all efficiency of 90%. In addition to the cogeneration unit an absorption chiller was installed for the cold production in summer time. The purpose of the system is to offset the electrical energy demand and also supply heat and cold.

To provide energy efficiency of the air system, the CO_2 sensors and Variable Air Volume (VAV) boxes that operate depending on the sensors have been placed in the office spaces. In according to the contamination levels of the individual spaces, the air quantities are adjusted independently.

1.2 MW photovoltaic (PV) panels are installed within 14.000 m2 area and 650 kW part of this power is used for building.

Passive systems such as solar wall, solar tubes and thermal storage which decrease annual energy consumptions were adopted into Prokon-Ekon.

The lighting intensity in each space was optimized by counting the number of fixtures in reflected ceiling plan. There are timer controls in lighting operation and also dimming and daylight sensors were considered.

31 points out of 35 was granted for Energy and Atmosphere category under LEED v2009 NC.

Materials and Resources:

Temporary waste storage area was established during the construction phase in accordance with the Waste Management Plan prepared for the Prokon-Ekon and recyclable wastes such as glasses, aluminum and iron was stored in this designated area.

In order to protect the natural resources, at a rate of 33.75% recycled materials was used, where applicable. Construction materials having certain certification such as Floorscore and Cradle to Cradle and containing low level VOC were tried to be selected.

All generated wastes are separated regarding types appropriately and nearly 80% of wastes are recycled. Recycle bins have been placed in each floor for the collection of packaging wastes. Waste cabinets which are designed by engineering firm are installed within the open offices.

6 points out of 14 was granted for Materials and Resources category under LEED v2009 NC.

Indoor Environmental Quality:

The air flow rates are increased as per LEED v2009 NC requirements for human health and more comfortable environment. On the other hand, this application was increased energy consumption. In this context, the following applications were applied to reduce this increment:

- Demand based ventilation control has been carried out. Measuring the indoor air quality via CO_2 sensors, the fan velocities are adjusted.
- Measuring the outside air quantity and CO_2 levels, internal CO_2 levels will be set for under 900 ppm.
- Water-source heat pumps have been used in Air Handling Units ("AHU") for air climatization. Thus, temperature regime same as with the heating and cooling VRV system has been used. This system yields reduction annual energy consumption.
- The AHU's for the offices is the one consuming highest energy. In order to reduce the energy consumption, the outside air has been delivered to the air handling unit

with a pre-heating process using solar wall in heating season. Thus, the energy consumption has been reduced in heating season.

- In the air handling units for offices, evaporative humidification which consumes 10-15 times less energy in compare with electric steam-humidifiers has been used.
- Smoking is forbidden in indoor environment.
- Materials with less VOC content was tried to be selected.

13 points out of 15 was granted for Indoor Environmental Quality category under LEED v2009 NC.

Apart from these environmental categories there are two additional categories providing opportunities for up to 10 bonus points namely Innovation in Design (6 points) and Regional Priority (4 points). 10 points out of 10 was granted for these two categories under LEED v2009 NC.

CHAPTER 4

METHODOLOGY

4.1. Utilized LCA Software – SimaPro 8.4.1.0

As LCA software, SimaPro version 8.4.1.0 was used for the study to analyze and compare the environmental impacts of selected different concrete mixtures as per ISO 14040 / 14044 requirements. SimaPro, which is developed by PRé Consultants and launched in 1990, is detailed LCA tool which provides a certain number of impact assessment methods for users by covering over 10,000 Ecoinvent dataset processes as well as details of life cycle analyses [90]. Characterization, damage assessment, normalization and weighting are the basic impact assessment steps that are available under SimaPro. As stated in the ISO standards, damage assessment, normalization and weighting are the optional steps and one can choose the optional steps as on or off while editing the methods [21]. Under the head of Inventory, SimaPro has main titles such as process, product stage, system description, waste types and parameters. Material, energy, transport, processing, use, waste scenario and waste treatment are the sub-categories of the process. Also, assembly, life cycle, disposal scenario, disassembly and reuse are the sub-categories for product stage. The key elements of SimaPro are presented in Table 4.1.

Table 4.1. *General Characteristics of SimaPro 8.4.1.0 LCA Software*

Key Elements	General Characteristics of PRé - SimaPro
Level of analysis	Product analysis tool
LCA stages	Cradle to grave, gate to gate
Data locations	Global

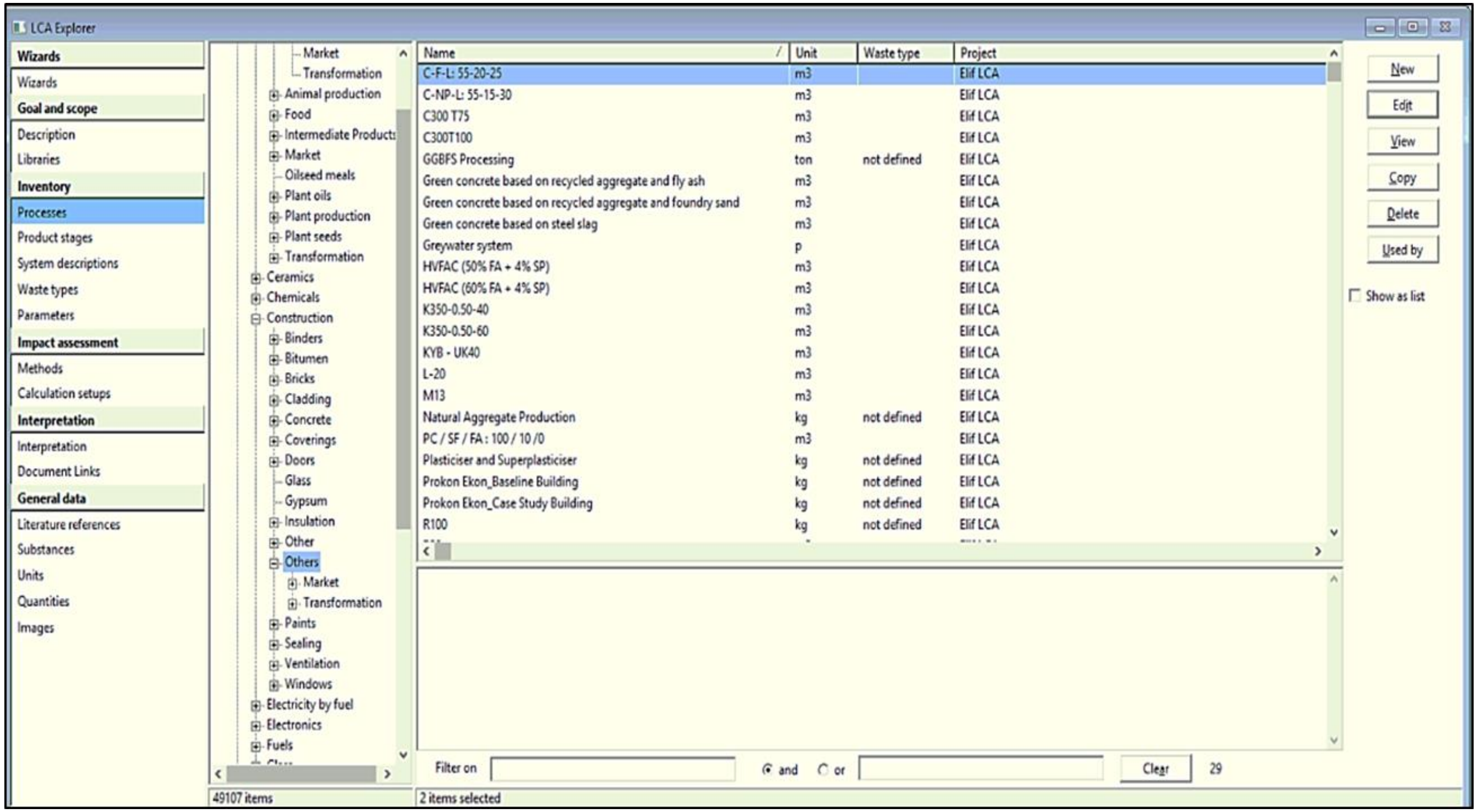
Table 4.1. *General Characteristics of SimaPro 8.4.1.0 LCA Software - continued*

Key Elements	**General Characteristics of PRé - SimaPro**
LCI libraries	• Agri-footprint – economic allocation • Agri-footprint – gross energy allocation • Agri-footprint – mass allocation • Ecoinvent v3 – allocation, default – system • Ecoinvent v3 – allocation, default – unit • Ecoinvent v3 – allocation, recycled content – system • Ecoinvent v3 – allocation, recycled content – unit • Ecoinvent v3 – consequential – system • Ecoinvent v3 – consequential – unit • ELCD • EU&DK Input Output Database • Industry data 2.0 • Methods • Swiss Input Output Database • USLCI
LCIA methods	• BEES+ • TRACI 2.1 • CML-1A (baseline and non-baseline) • Ecological Scarcity 2013 • EDIP 2003 • EPD 2013 • EPS (2015d and 2015dx) • ILCD 2011 Midpoint+ • IMPACT 2002+ • ReCiPe 2016 • Cumulative Energy Demand • Ecosystem Damage Potential • Greenhouse Gas Protocol • IPCC 2013 GWP 100a • IPCC 2016 GWP 20a • Selected LCI Results • Selected LCI Results, additional • USEtox 2 (recommended + interim)

Table 4.1. *General Characteristics of SimaPro 8.4.1.0 LCA Software - continued*

Key Elements	**General Characteristics of PRé - SimaPro**
LCIA methods	• USEtox (recommended only) • CML 1992 • CML 2 baseline • CML 2001 (all impact categories) • Eco-Indicator 95 • Eco-Indicator 99 • Ecological Footprint • Ecopoints 97 (CH) • EDIP / UMIP 97 • IPCC 2001 GWP

In the scope of this study, control concrete mix and other concrete mixtures, recycled aggregate production and GGBFS processing were defined under the "Construction" within the "Material" sub-title where LCA model of Prokon-Ekon Headquarter Building was also defined. The study page indicating created folder under "Construction" is presented in Figure 4.1.



Name	Unit	Waste type	Project
C-F-L: 55-20-25	m3		Elif LCA
C-NP-L: 55-15-30	m3		Elif LCA
C300 T75	m3		Elif LCA
C300T100	m3		Elif LCA
GGBFS Processing	ton	not defined	Elif LCA
Green concrete based on recycled aggregate and fly ash	m3		Elif LCA
Green concrete based on recycled aggregate and foundry sand	m3		Elif LCA
Green concrete based on steel slag	m3		Elif LCA
Greywater system	p		Elif LCA
HVFAC (50% FA + 4% SP)	m3		Elif LCA
HVFAC (60% FA + 4% SP)	m3		Elif LCA
K350-0.50-40	m3		Elif LCA
K350-0.50-60	m3		Elif LCA
KYB - UK40	m3		Elif LCA
L-20	m3		Elif LCA
M13	m3		Elif LCA
Natural Aggregate Production	kg	not defined	Elif LCA
PC / SF / FA : 100 / 10 /0	m3		Elif LCA
Plasticiser and Superplasticiser	kg	not defined	Elif LCA
Prokon Ekon_Baseline Building	kg	not defined	Elif LCA
Prokon Ekon_Case Study Building	kg	not defined	Elif LCA
R100	kg	not defined	Elif LCA

Figure 4.1. Created folder under “Construction” sub-category in SimaPro

Control concrete mix, green concrete mixtures, recycled aggregate production and GGBFS processing were defined as product under the "Outputs to technosphere: Products and co-products" with pertinent mass and volume units and amounts.

The environmental impacts of industrial by-products utilized as supplementary cementitious materials in the concrete mixtures were considered as avoided products and their environmental impacts were diminished. Therefore, fly ash, steel slag, GGBFS, foundry sand and silica fume were introduced into "Outputs to technosphere: avoided products" by considering landfill requirements. In addition, land-derived materials, wood chips, steel and inert landfilling were considered as avoided products and burden for recycled aggregate production [69]. Therefore, these are defined under "Outputs to technosphere: avoided products".

Inputs for products were entered under the titles of "Inputs from nature", "Inputs from technosphere: materials/fuels" and "Inputs from technosphere: electricity/heat". Inputs for materials that are obtained directly from nature such as water used for GGBFS processing, groundwater used in recycled aggregate production, natural aggregate and granite used in the concrete mixtures were entered to the software under the "Inputs from nature". In addition, Portland cement, tap water, plasticiser, perlite, limestone (as filler) and fine and coarse aggregates (other than recycled aggregate) were defined under the "Inputs from technosphere: materials/fuels". Since recycled aggregate production and GGBFS processing were defined under the "Materials" sub-title, these were also introduced under the "Inputs from technosphere: materials/fuels" while entering these data for concrete mixtures. Energy inputs such as electricity, natural gas, diesel consumption and also transport for recycled aggregate production were defined under "Inputs from technosphere: electricity/heat" as they have energy units.

In SimaPro, outputs of the units and products can be determined under following sub-compartments: "Emissions to air"; "Emissions to water"; "Emissions to soil"; Final Waste flows"; "Non-material emissions"; "Social issues"; "Economic issues" and

"Outputs to technosphere: Waste and emissions to treatment". Outputs for recycled aggregate production such as CO_2, CO, CH_4, NO_x, NMVOC, particulates matters, SO, SO_2, VOC and NO_x, and particulates emitted while GGBFS processing were entered into the "Emissions to air". Finally, solid waste composed of concrete and paste generated at ready-mixed concrete plants is defined under the "Outputs to technosphere: Waste and emission to treatment". In the application of concrete mixtures into the case building LCA model, disposal scenario was determined for the concrete and outputs for the case building regarding concrete were identified under the" Outputs to technosphere: waste and emission to treatment" for both landfilling and recycling options.

4.2. LCA Analysis for Different Concrete Mixtures

4.2.1. Goal and Scope Definition

The goal of the study is to quantify and assess the environmental impacts of different types of concrete mixtures and corresponding commercial concrete on whole life cycle of Prokon-Ekon Headquarter Building and to compare the environmental impacts pertaining to different cementitious materials by applying LCA approach. In the scope of this study, 21 different concrete mixtures were designated in order to determine how utilization of supplementary cementitious materials and/or recycled aggregate can affect the environmental impacts of concrete production. Then, each of these concrete mixtures was applied to the Prokon Ekon Headquarter Building LCA model to examine and quantify the environmental impacts of different concrete mixtures on whole-life cycle of case green building.

The main questions that are tried to be elucidated are as follows: "Which concrete mixture and/or supplementary cementitious material has lower impacts for the selected impact categories" and "What is the impact difference between commercial and green concrete on whole-life cycle of Prokon Ekon Headquarter Building".

As a result of this LCA study, decision makers, LCA practitioners, building contractors, designers, engineers, architects, researchers and public can be informed about which concrete mixture should be chosen and which supplementary cementitious material has more environmentally friendly. In addition, the impacts of concrete type on whole-life of buildings can be assessed during the design stage by considering the results of the LCA study.

Mean 28-day compressive cylinder strength and cube strength of the concrete used in Prokon-Ekon Headquarter Building is 35 MPa and 45 MPa (C35/45 type), respectively. Having similar compressive strength and functional requirements is essential to compare the environmental impacts of different concrete mixtures [8]. In this context, concrete types having C35/45 properties were selected by reviewing the literature. Selected concrete mixtures are differed according to the type of used alternative cementitious materials such as natural pozzolan, fly ash, limestone powder, ground granulated blast furnace slag, silica fume, foundry sand and recycled aggregate.

The system boundary was assigned as cradle-to-gate for concrete mixture scenarios and expanded to cradle-to-grave by including Prokon-Ekon Headquarter Building LCA model. The system boundary for concrete mixtures and building is presented in Figure 4.2.

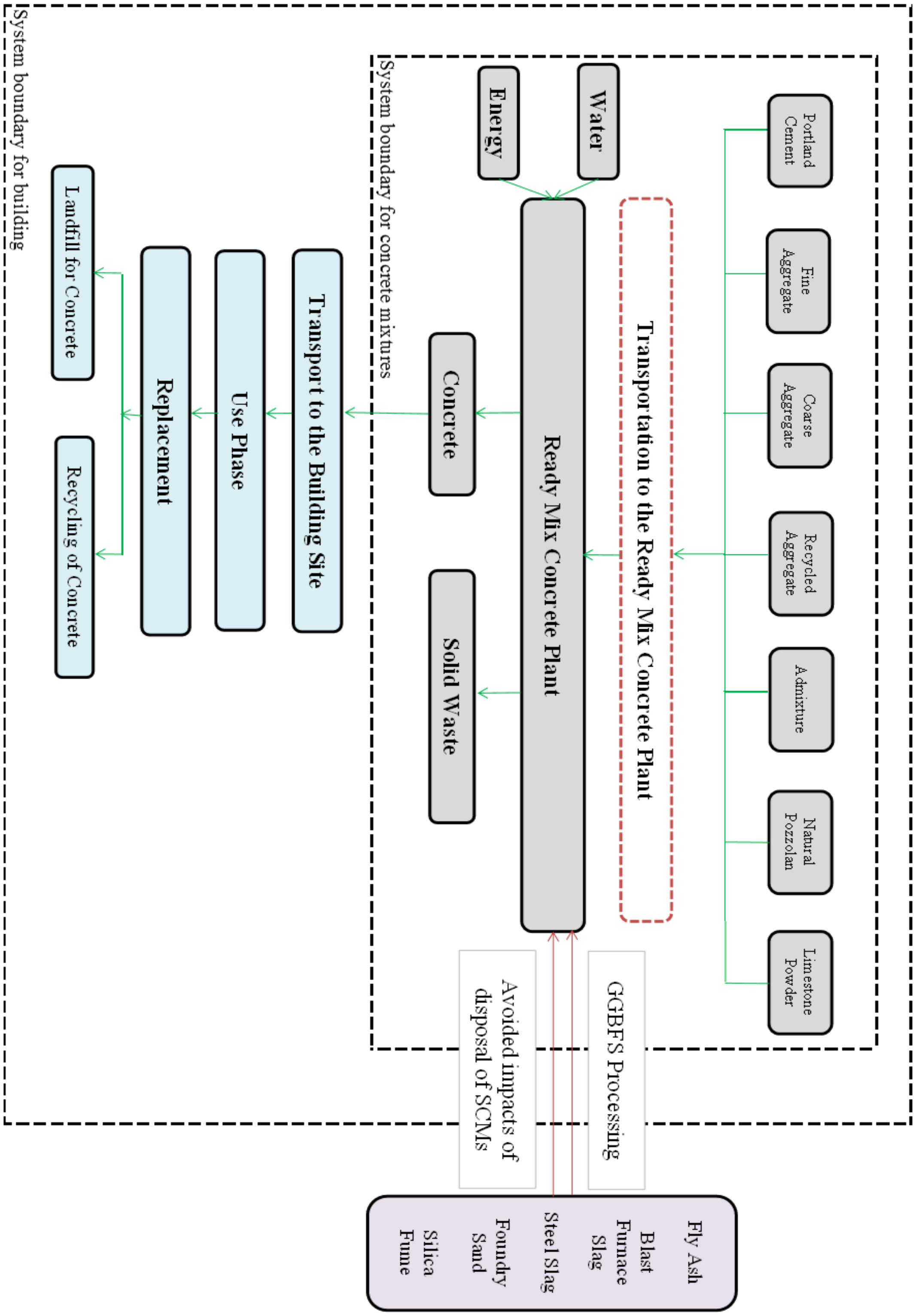


Figure 4.2. Sytem description of the LCA study

Upstream processes such as raw material extraction, processing and transportation from the supplier to the manufacturing plant for Portland cement, tap water, plasticiser, perlite, fine and coarse aggregates are included into the selected data since only consequential system model, system processes and market activities were selected from the database. Accordingly, energy such as electricity, diesel and natural gas used in the ready mix concrete plant operations were involved into the system boundary. The upstream processes for electricity, diesel and natural gas production are included into the selected data.

System boundaries also include the upstream processes for the production of recycled aggregates. These data were adopted from literature study and introduced into the SimaPro, manually.

Environmental burdens for production of industry by-products such as fly ash, blast furnace slag, steel slag, foundry sand and silica fume were excluded by system expansion since further processing is not required for these SCMs before concrete manufacturing and allocation is not applied in the scope of study as per ISO 14044 [7] [10] [56] [91]. In addition, landfill requirement for these materials were considered as avoided process and introduced into the system model for concrete mixtures. Process for GGBFS was also included into system boundary as several processes such as quenching, granulation dewatering and grinding are necessary for blast furnace slag before utilized in ready mixed concrete plant. The avoided impacts belonging to the landfill of SCMs and process for preparation of GGBFS are indicated by red arrows in the system description of the study as can be seen in Figure 4.2.

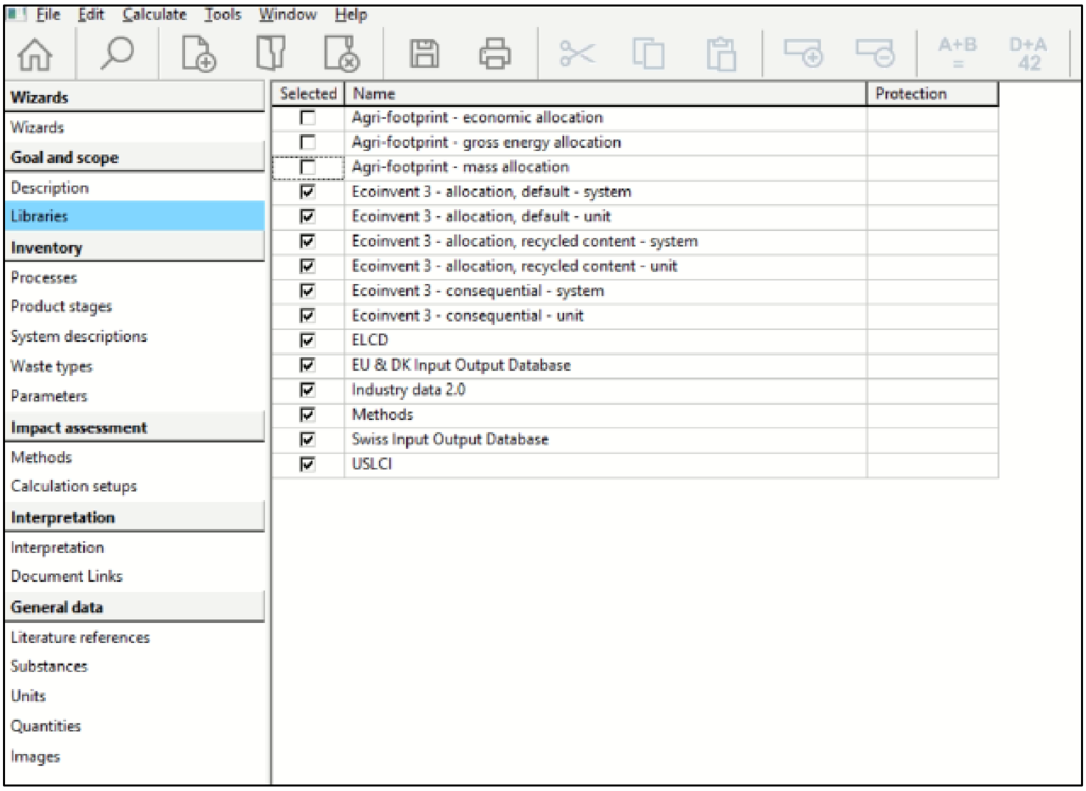
Transportation of input materials from the supplier to the ready mix concrete plant was excluded from the system boundary since locations and suppliers are different for selected concrete mixtures, and transportation distances were considered as comparable for each concrete scenario. In Figure 4.2, red dashed lines represent the assumption for excluded transportation for inputs.

Solid waste generated from ready mix concrete plant is also considered as output for concrete production.

Raw material supply and concrete manufacturing stages were considered within the scope of the concrete mixtures LCA. Therefore, system boundary of the concrete scenarios is cradle-to-gate.

In the scope of research, each designated concrete mixture and control concrete mix were also introduced into the LCA model conducted for Prokon-Ekon Headquarter Building. System boundary for this case study building is cradle-to-grave and comprised of following stages: raw material extraction and processing; transport to the manufacturer; manufacturing; transport to the building site; use or application of the installed product; replacement; and recycling and landfill.

The selected databases from the SimaPro 8.4.1.0 library are presented in Figure 4.3. As can be seen in the figure, all libraries were selected except Agri-footprinting which is specific to agriculture. Although, Ecoinvent v3 database was used primarily, other databases were also used for the missing data.



Selected	Name	Protection
☐	Agri-footprint - economic allocation	
☐	Agri-footprint - gross energy allocation	
☐	Agri-footprint - mass allocation	
☑	Ecoinvent 3 - allocation, default - system	
☑	Ecoinvent 3 - allocation, default - unit	
☑	Ecoinvent 3 - allocation, recycled content - system	
☑	Ecoinvent 3 - allocation, recycled content - unit	
☑	Ecoinvent 3 - consequential - system	
☑	Ecoinvent 3 - consequential - unit	
☑	ELCD	
☑	EU & DK Input Output Database	
☑	Industry data 2.0	
☑	Methods	
☑	Swiss Input Output Database	
☑	USLCI	

Figure 4.3. Selected databases from SimaPro 8.4.1.0

In order to compare the environmental performance of each concrete mixture and control concrete mix based on an equivalent unit, the functional unit should be defined. In this context, functional unit is expressed as unit volume of concrete and is determined as 1 m^3 for all concrete mixture scenarios. In addition, the functional unit is determined as 1 m^2 for the Prokon-Ekon Headquarter Building having 11,728 m^2 areas and lifespan of the case study building is selected as 60 years in accordance with the LEED.

Data quality is another subject for scope definition and data type to be used in the study should be defined in a systematic manner to identify the sufficiency of the data to be used in the study. In the previous versions of SimaPro, DQI requirements were exist to indicate the source of data. Time, geography, type of technology, allocation and system boundaries could be specified through SimaPro. However, DQI fields under the goal and scope section is invisible and no longer shown in the version of

SimaPro 8.4. Information about time, geography, technology and system boundaries is specified in the software for each data and can be seen in the comment box through clicking on the selected data.

4.2.2. Data Inventory

In the data inventory step, all collected data for each concrete mixture with all relevant inputs (energy, fuel, water, material etc.) and outputs (waste, air emissions etc.) are quantified and presented. Data to be used in concrete mixture scenarios were selected through literature search by considering 28-days compressive strengths of 35 MPa. Detailed inventory for the selected concrete mixtures is presented in Table 4.2. The data belonging to the Prokon-Ekon Headquarter Building was granted from Ms Merve Aygenç, LEED Accredited Professional (AP) of the building. In addition, the Prokon-Ekon Headquarter Building located in Kahramankazan, Ankara was visited on December 27th, 2018. Ms Tuba Yücel, the Project Manager of Prokon Engineering and Consultancy Co., provided some technical information about building such as AutoCAD files, presentations, layout plan as well as photographs taking from both inside and outside of the building.

Geographical locations for each activity are specified in the Ecoinvent v3 database. The location names are presented by using several abbreviations, for instance, Europe (RER), Switzerland (CH), China (CN), United States (US), India (IN), Australia (AU), Germany (DE), Turkey (TR), Global (GLO) and Rest of World (RoW) [92].

Global, namely GLO, is an average reference activities constituted by using all countries data in the world and is presented in Ecoinvent v3 to ensure the completeness for every activity [92]. On the other hand, RoW indicates the locations for which are not included in the Ecoinvent. In other words, RoW can be defined as GLO dataset minus all other defined location's dataset [93]. Therefore, global average data is selected for the study as possible since the study geographies for the concrete mixtures are wide range of such as US, Saudi Arabian, Canada, China, Spain, India and Turkey.

Table 4.2 *Mix Proportions for the Concrete Mixtures Considered*

Mix	Ref.	Concrete		Binder				Water	Aggregate						Admixtures				
		Specimen	28-day Strength	Portland Cement		SCM			Fine		Coarse		Recycled		Plasticizer		Superplasticizer		
		Shape	(MPa)	Type	(kg)	Type	(kg)	(kg)	Type	(kg)	Type	(kg)	Type	(kg)	Type	(kg)	Type	(kg)	%
1	[94]	Cylinder	35.00	PC42.5	310.0	SF	31.0	238.7	NRS	661.3	CS	1122.5					-	-	-
2	[56]	-	37.40	PC42.5	320.0	SS	106.0	190.0	NRS	885.5	CS	885.5			-	2.0			
3		-	35.50	PC42.5	240.0	FA	80.0	199.0	NRS	906.5	Basalt	362.5	RA	544.0	-	2.0			
4		-	34.30	PC42.5	280.0	-	-	180.0	NRS FS	688.0 289.0	Basalt	400.0	RA	577.0	-	2.0			
5	[95]	Cylinder	37.80	CEMI42.5N	200.0	FA	200.0	112.0	Sand	800.0	Graded CL	1199.0					P	16.0	4
6		Cylinder	34.20	CEMI42.5N	158.0	FA	236.0	122.0	Sand	788.0	Graded CL	1182.0					P	15.76	4
7	[96]	Cylinder	34.40	CEMI42.5N	296.0	NP	74.0	236.0	Sea sand CS sand	406.0 428.0	CS	853.0					-	5.92	2
8		Cylinder	34.00	CEMI42.5N	299.0	NP	99.0	242.0	Sea sand CS sand	394.0 416.0	CS	828.0					-	5.98	2
9	[97]	Cube	45.26	CEMI42.5	300.0	FA	200.0	190.0	NRS	910.0	NRS NRS	450.0 285.0					P	8.9	1.78
10	[86]	Cube	44.10	GB42.5	280.0	LP	70.0	125.0	NRS	826.0	CL	1094.0					P	5.6	2
11	[98]	Cube	46.50	PC42.5	210.0	GGBFS	140.0	175.0	NRS	915.0	Basalt	915.0					G 51	-	-
12		Cube	45.10	PC42.5	140.0	GGBFS	210.0	175.0	NRS	912.5	Basalt	912.5					G 51	-	-
13	[57]	Cylinder	36.30	ASTM Type I/II	248.0	FA GLP	90.20 112.75	157.83	Quartzitic sand	901.9	PG Basalt	270.57 631.33					ADVA 140	6.04	1.34
14		Cylinder	38.00	ASTM Type I/II	249.7	NP GLP	136.2 68.1	158.9	Quartzitic sand	908.0	PG Basalt	272.4 635.6					P	6.08	1.22
15	[99]	Cube	44.90	ASTM Type I	180.0	FA SF	202.5 67.5	198.0	NRS CL sand	565.0 223.0	RG	828.0					PE	4.8	
16	[100]	Cylinder	35.00	ASTM Type I	187.5	FA GGBFS	93.75 93.75	71.25	Local sand	880.0	CL	649.0	RA	216.0			-	3.75	2
17	[101]	Cylinder	38.26	CEM I 52.5R	325.0	-	-	162.0	LS	683.2	-	-	RA	1123.4			G 313C	4.49	1.38
18		Cylinder	38.79	CEM I 52.5R	300.0	-	-	165.0	LS	765.1	NCA	905.2	RA	265.7			G 313C	2.37	0.79
19	[102]	Cube	45.30	ASTM Type I	410.0	-	-	225.0	RS	642.0	CG	840.0	RA	204.0			-	8.2	2
20		Cube	48.10	ASTM Type I	307.5	FA	205.0	225.0	RS	526.0	CG	496.0	RA	482.0			-	6.15	2
21		Cube	45.30	ASTM Type I	307.5	FA	205.0	225.0	RS	526.0	-	-	RA	963.0			-	6.15	2

Unit processes of human activities are differentiated in the Ecoinvent v3 database as market activities, transforming activities, treatment activities, import and export activities and production and supply mixes. Transforming activities and marketing activities are one the basic types of activities. There are almost 6000 transform activities and 3000 market activities defined in Ecoinvent v3. As the name implies, transforming activities transform the inputs into the different outputs. On the other hand, market activity does not transform the inputs. It links the output of transforming activities to another as an input. Market activities include transport, losses, imports and exports [93]. In addition, in the website of SimaPro Help Centre it is recommended that market process should be used in case specific supplier of products is unknown [103]. Therefore, market activities were selected from the Ecoinvent v3 database for the inputs in the scope of the research. Figure 4.4 indicates those intermediate exchange processes applied through market activity.

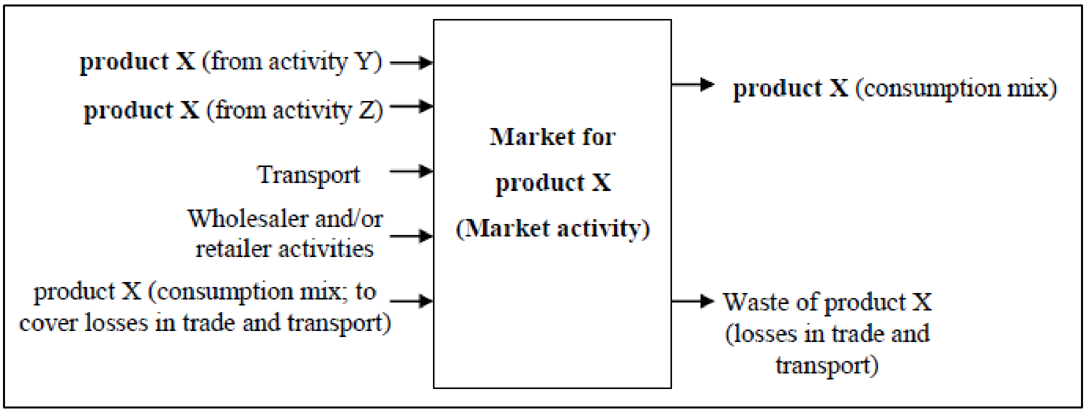


Figure 4.4. Market activity in Ecoinvent v3 [93]

Two class of system models are available under Ecoinvent v3: Allocation, ecoinvent default (short name: "Allocation, default") and Substitution, consequential, long-term (short name: "Consequential"). In allocation system model, which is a system model with partitioning, all activities supplied from the markets are linked into the system model through attributional linking. On the other hand, consequential linking is applied in the consequential system model and by-products are treated by substitution.

Therefore, consequential model can be called as system model with substitution or system expansion. Consequences of long-term decisions are reflected in this model. In the study, consequential system model was selected from the Ecoinvent v3 database since the aim of this model is to provide decision support [93].

In Ecoinvent v3, each process or activity is given with two options: unit process and system process. Unit process contains emissions and resource inputs, and all upstream processes are included automatically by selecting this version. In other respect, system process behaves like a black box and overall LCA results are provided through all inputs and outputs of different processes. Therefore, system process was selected from the Ecoinvent v3 database considering its simple process tree, no uncertainty information and fast calculation [90]. However, it should be keep in mind that unit processes were preferred for the LCA model of Prokon-Ekon Headquarter Building which is being concurrently conducted by Ms Merve Aygenç through her MSc thesis study. Therefore, unit processes were selected from Ecoinvent v3 database for the disposal scenario of the case study building regarding concrete LCA to provide consistent and comparable results.

Products and processes for concrete mixtures and control concrete mix are taken from SimaPro 8.4.1.0 database which are readily available in the software. However, data for recycled aggregate production and GGBFS do not exist in any database of SimaPro 8.4.1.0; thus, they were introduced to the software manually with all input and outputs.

Data inventory for all inputs and outputs to produce 1 m^3 concrete mixtures is detailed in the following sub-topics with the assumptions.

4.2.2.1. Data Inventory for Cement

The cement used in the concrete mixtures is Portland cement and cement strength classes are different for some mixtures. The types of utilized Portland cements are as follows: PC 42.5, CEM I 42.5N, CEM I 52.5R, ASTM Type I/II and GB 42.5. Therefore, Portland cement is selected from the SimaPro 8.4.1.0 as binder for each concrete mixture. Portland cement for GLO is not available under Ecoinvent v3.

Therefore, Europe without Switzerland option including transport distances generated by using global transport distance model was selected from the database.

4.2.2.2. Data Inventory for Supplementary Cementitious Materials

Natural pozzolan, fly ash, limestone powder, GGBFS and silica fume are the products and co-products that were used in concrete mixtures as supplementary cementitious material.

Natural pozzolan is not included into any database of SimaPro 8.4.1.0. Therefore, perlite was selected from the Ecoinvent v3 instead of natural pozzolan since perlite can also be used as mineral admixture for concrete manufacturing if it has adequate pozzolanic property [104]. Perlite should be grinded before used in concrete as admixture. Bond work index (W_i) required to grind the perlite was taken as 12.77 kWh/ton, which is same as the quartz's W_i value, since perlite and quartz have similar Mohs hardness [105]–[107].

Fly ash, GGBFS and silica fume are the industrial by-products that can be substituted for Portland cement while concrete production. Therefore, upstream processes for fly ash, silica fume and blast furnace slag are excluded from the system boundary and landfill requirement for these materials were considered as avoided process and introduced into the system model for concrete mixtures.

Blast furnace slag needs to be treated before concrete production to get binding properties. Processes to treat blast furnace slag and/or to prepare GGBFS are respectively: slag quenching and granulation; dewatering; grinding; and storage. In the GGBFS processing, water, electricity, natural gas and fuel are consumed for the most part. In addition, particulate matter emitted while GGBFS processing was also taken into consideration as output data. Table 4.3 indicates the data inventory including total inputs and outputs for the one ton GGBFS processing [4].

Table 4.3. *Inputs and Outputs for GGBFS Processing, adapted from [4]*

Parameter	Unit	Processes	Amount (per ton of slag)
Inputs			
Electricity	kWh	Quenching, dewatering, crushing, grinding, storage silos	9.47E+01
Natural gas	m^3	Dewatering and grinding	8.96E+00
Water	m^3	Quenching, grinding and storage silos	9.19E-01
Diesel	L	Dewatering and grinding	1.26E+00
Outputs			
Particulate matters	kg	Quenching, dewatering, grinding, storage piles and storage silos	2.19E-01

Limestone powder does not exist within the SimaPro 8.4.1.0 and instead limestone crushed for mill options were selected.

4.2.2.3. Data Inventory for Water

Potable water is generally advised for concrete production in batching, mixing, curing and wash-off. For this purpose fresh water such as groundwater and surface is utilized in the concrete industry [4] [7]. Therefore, tap water under the drinking water is selected from the software for water inputs. It was assumed that ready mixed concrete plant does not have any water recycling system.

4.2.2.4. Data Inventory for Electricity and Fuel Utilized in Ready-Mix Concrete Plants

Although amounts of energy used in ready mix concrete plants vary from one plant to another, generic data for fuel, natural gas and electricity consumption for ready mix concrete plant operations was adopted from the Life Cycle Inventory of Portland Cement Concrete prepared by Portland Cement Association (PCA) [91]. Typical fuel and energy consumption during plant operations to produce 35 MPa concrete is presented in Table 4.4. In this study, these consumption amounts were taken and applied to all concrete mixture scenarios as an input.

Table 4.4. *Energy Inputs for the Ready Mix Concrete Plant Operations, Adapted from [91]*

Input	**Unit**	**Amount (per m^3 of concrete)**	**Intended Use in Concrete Plant Operation**
Electricity	kWh	4.11E+00	Plant operations such as batching and mixing
Natural Gas	thousand m^3	2.93E-04	Industrial boilers for hot water and building heat
Middle distillates (Diesel Fuel)	L	4.35E-01	Forklifts, light trucks, loaders, boilers, vehicles, space heaters, generators, etc.

In the Ecoinvent v3, unit for diesel fuel is kg for the selected option. Therefore, density of diesel ($D_{density}$) is used to convert litre to kg. By taking the $D_{density}$ as 7.099 lb/gal (850.647807 kg/m^3), the equation used for conversion of litre to kg is as below [4]:

Equation 1: $\text{Diesel fuel (kg)} = D_{density}\,(\text{kg/m}^3) * \text{Diesel fuel (L)} * (1\ \text{m}^3 / 1000\ \text{L})$

$$\text{Diesel fuel (kg)} = 850.647807\ \text{kg/m}^3 * 4.35\text{E-}01\ \text{L} * (1\ \text{m}^3 / 1000\ \text{L})$$

$$\text{Diesel fuel (kg)} = 0.370\ \text{kg}$$

Electricity is assumed as medium voltage and market process [108]. In addition, natural gas has been selected as high pressure from Ecoinvent v3 database. The losses and transport are not included in the GLO data for diesel, thus, Europe without Switzerland option that covers inventory data for the distribution of petroleum product to the final consumer including all necessary transport was selected from the database.

4.2.2.5. Data Inventory for Solid Waste

Only small amount of solid waste including concrete and paste is generated at ready mix concrete plants since most of waste is recycled. According to the average data gathered from 43 ready mix concrete plants operating in US, the average solid waste generation amount is 24 kg per 1 m^3 production [91]. In the research, this solid waste amount is taken from outputs to technosphere sub-compartment as inert waste for each concrete mixture scenarios.

4.2.2.6. Data Inventory for Aggregates

4.2.2.6.1. Data Inventory for Fine and Coarse Aggregates

Type and particle size of fine and coarse aggregates used in concrete mixtures are not identical for each other.

Natural river sand, sea sand, sand, quartzitic sand, foundry sand, crushed stone sand and limestone sand are the fine aggregates used in the concrete mixtures. Natural river sand, sea sand and quartzitic sand are not available in the database. Therefore, these natural fine aggregates were substituted as sand by considering the similar particle size distribution. In addition, crushed stone sand and limestone sand do not exist within the software and instead crushed stone and limestone crushed for mill options were selected, respectively.

Foundry sand and steel slag, which were used in concrete mixtures as an aggregate, are an industrial by-products and further processing is not required. Therefore, the amount of utilized foundry sand and steel slag were considered as avoided burden in the scope of system expansion (i.e. consequential) model [7].

Coarse aggregates used in the selected concrete mixtures consist of crushed basalt stone, crushed limestone, crushed stone, natural river sand, pea gravel, river gravel, crushed granite and natural coarse aggregate. Natural river sand, pea gravel and river gravel are not present in the selected database. Thus, these natural coarse aggregates were selected as gravel, round [108].

As stated in the study conducted by Fang et al. [109], the crushing energy for 1 tonne granite having 12.56 mm – 17.76 mm particles size is in between 0.70 and 1.60 kWh. The particle size distribution is in between 4 mm and 20 mm for the granite used in the Mixture 18 (see Table 4.2). Therefore, the average value of 1 kWh/t is selected as crushing energy for granite.

Mixing ratio between fine aggregates and coarse aggregates are not stated for some concrete mixtures such as Mixture 2, 3, 4, 11 and 12 (see Table 4.2). For these concrete mixtures, the mass ratio between fine and coarse aggregates was assumed as 1:1. In other words, it was assumed that total aggregate amount consists of 50% fine aggregate and 50% coarse aggregate, by mass.

4.2.2.6.2. Data Inventory for Recycled Aggregates

Data for recycled aggregate production was adopted from the LCA study conducted by Rosadoet. Al [69] using SimaPro 8.0.2, and Ecoinvent v.3.01, EU & DK Input Output and US LCI databases. Only allocation data is available for the wood chips, thus, "Wood chips, dry, measured as dry mass (RoW), plywood production, for outdoor use, Allocation Rec, S" data was selected as avoided product. The data inventory for the production of 1.25 ton mixed recycled aggregate that was integrated into the SimaPro 8.4.1.0 is given in Table 4.5.

Table 4.5. *Data Inventory for Recycled Aggregate, adapted from [69]*

Consumptions	**Unit**	**Amount**
Electricity	kWh	1.77
Diesel	MJ	19.07
Lubricating Oil	kg	0.008
Water from Underground Well	L	0.8
Transport to the Customer	tkm	10
Sanitary Landfilling	t	0.0047
Refuse Transport to Sanitary Landfill	tkm	0.26
Wood Recycling	**Unit**	**Amount**
Electricity	kWh	0.168
Diesel	L	0.019
Lubricating oil	kg	0.0003
Steel Recycling	**Unit**	**Amount**
Hard Coal	kg	0.009
Natural Gas	m^3	0.025
Electricity	kWh	0.282
Transport to Steel Recycling Facility	tkm	0.43
Avoided Burdens	**Unit**	**Amount**
Inert Landfilling	t	1
Avoided Product	**Unit**	**Amount**
Land-derived material	t	0.22
Wood Chips	t	0.02
Steel	t	0.003
Emission to Air	**Unit**	**Amount**
CO_2, fossil	g	-8.4
CO_2, biogenic	g	133
CO, fossil	g	-262
CO, biogenic	g	10.1
CH_4, fossil	g	-38.4
CH_4, biogenic	g	112.3
NO	g	36

Table 4.5. *Data Inventory for Recycled Aggregate, adapted from [69] - continued*

Consumptions	Unit	Amount
NMVOC, non-methane volatile organic carbons	g	-17.4
PM < 2.5 µm	g	-9.3
PM > 10 µm	g	-6.8
PM > 2.5 µm and PM < 10 µm	g	-4.3
SO_2	g	-41.7
SO	g	4.9
VOC	g	2.3

4.2.2.7. Data Inventory for Plasticizers and Superplasticizers

Plasticisers or superplasticisers were used as an admixture in the experiments conducted for selected concrete mixtures. The type of plasticisers and superplasticisers are not same for each concrete mixture. In addition, not all type of these admixtures is available under SimaPro 8.4.1.0 database. Generic data for plasticisers based on sulfonated melamine formaldehyde is available under Ecoinvent v3. Therefore, in order to ease the comparison, this data was selected from the database while comprising the concrete mixtures.

For some concrete mixtures, i.e. Mixture 7, 8, 10, 16, 19, 20 and 21 (Table 4.2), admixture amount was not stated in the articles. Therefore, the amount of superplasticisers was assumed as 2% of by mass of cement weight [74].

4.2.2.8. Data Inventory for the Control Mix

In order to assess and compare the environmental performance of green concrete mixtures more appropriately, control concrete mix was created. The concrete mix ratio and characteristics for the conventional C35/45 concrete were adopted from the dissertation study conducted by Gürsel [4]. Type of fine and coarse aggregates was not mentioned by Gürsel; therefore, assumption was made for the aggregates used in the control mix. In this study, sand and basalt were considered as utilized fine and coarse aggregates, respectively. Mix design for the control concrete mix is detailed in Table 4.6.

Table 4.6. *Data Inventory for Control Mix, adapted from [4]*

Inputs for 1m^3 Control Mix	Unit	Amount
Portland cement	kg	366
Water	kg	169
Fine aggregates	kg	867
Coarse aggregates	kg	831
Superplasticizers	kg	6.22

4.2.2.9. Data Inventory for the Prokon-Ekon Headquarter Building

Data inventory for the case building was obtained from the LCA study being concurrently conducted by Ms Merve Aygenç using SimaPro 8.4.1.0 and CML-1A baseline impact assessment methodology. Transportation from the suppliers to the building construction area was also included in the scope of the LCA. As stated in the study, data inventory for the Prokon-Ekon Headquarter Building was provided by meeting and interviewing with the building authorities and reviewing invoices, construction progress documents, building simulation report, architectural project and mechanical equipment list. Table 4.7 indicates the used material type, quantity, service life and transport distances for the building.

Table 4.7. *Life Cycle Inventory of the Prokon-Ekon Headquarter Building*

Material Type	Quantity	Service Life (yr)	Transport Distance from Supplier (km)
Building Materials			
Concrete	3487 m^3	60	22
Steel mesh	18,200 kg	60	40
Reinforcing bar	325,480 kg	60	40
Steel sheet	68,700 kg	60	362

Table 4.7. *Life Cycle Inventory of the Prokon-Ekon Headquarter Building - continued*

Material Type	**Quantity**	**Service Life (yr)**	**Transport Distance from Supplier (km)**
Building Materials			
Aerated concrete block	3738 m^2 x 0.1 m	60	120
Steel profile	240,750 kg	60	362
Steel profile	232,970 kg	60	360
Aluminum facade	2926 m^2	40	50
Rock wool	5212 m^2 x 0.08 m	60	40
Gypsum board	5212 m^2 x 0.0125 m	60	40
Ceramic tile for external walls	1605 m^2	60	50
Roof membrane	1535 m^2	35	374
Carpet	1745 m^2	10	430
Granite	1620 m^2	60	26
Self-smoothing floor	4600 m^2	20	60
Parquet	760 m^2	40	40
Wood beam	1158 kg	60	40
Windows	2615 m^2	45	50
Coating	267 kg	25	374
Coating	285 kg	25	374
Coating	250 kg	25	374
Coating	285 kg	25	374
Coating	445 kg	10	374
Paint	215 kg	25	374
Coating	245 kg	25	374
Cement mortar	8853 kg	60	37
Mechanical Equipment			
Boiler	1 piece	16	394
Solar collector	50 m^2	20	394
Photovoltaic panels	3000 m^2	30	394

Table 4.7. *Life Cycle Inventory of the Prokon-Ekon Headquarter Building - continued*

Material Type	**Quantity**	**Service Life (yr)**	**Transport Distance from Supplier (km)**
Mechanical Equipment			
Circulation pump < 50 W	45 pieces	10	25
Circulation pump > 50 W	1 piece	10	25
Co-generation unit	1 piece	20	394
ABS Chiller	1 piece	25	25
Rainwater System			
Concrete	280 m^3	60	22
Ultrafiltration unit	1 piece	0.5	52
UV Lamp	3 pieces	5	52
Control device	2 pieces	10	52
Greywater System			
Stainless steel	10 m^3	60	28
Ultrafiltration unit	1 pieces	0.5	28
Air compressor	2 pieces	15	28
Potentiometer	2 pieces	10	28
Indoor Water Fixtures			
WC+ Reservoir	90 pieces	20	26
Faucet	61 pieces	20	26
Operational Use			

Source Type	**Amount for the year 2018**
Water	1,954 m^3
Electricity	850,397 kWh
Natural gas	46,787 m^3

In the LCA study of the Prokon-Ekon Headquarter Building, only aluminium, steel and iron were considered as recyclable building materials and remaining materials were assumed as inert waste that is directly disposed to the landfill. However, disposal scenario regarding concrete was also developed for the building in the scope of cradle-to-grave LCA approach. In the present case, aluminium, steel and iron and in large part of concrete were identified as recyclable concrete materials and remaining amount was assumed as inert waste end up with landfilling.

As in the cradle-to-grave LCA study conducted for recycled concretes by Colangelo et al. [13], 85% of the total concrete amount used in the case study building was assumed as recycled and remaining part was considered to be disposed directly to the landfill. Since waste concretes should be sorted before recycling, the option with sorting plant was selected from the Ecoinvent v3 database. Selected data for sorting includes energy consumption for dismantling, particulate matter emissions from dismantling and handling, machines for handling in sorting plant, electricity demand for sorting plant, transport to dismantling facilities and final disposal of waste material.

It should be noted that, system boundary for disposal ends up with sorting plant and landfilling, and recycling process for sorted concrete wastes was not included in the scope. In addition, reuse of recycled waste concretes as raw material for the concrete manufacturing was not included in the scope.

4.2.2.10. Data Inventory Summary

Details related to the selected database and processes used in the inventory of concrete mixtures, control concrete mix, recycled aggregate production, and GGBFS processing are presented in Table 4.8, Table 4.9 and Table 4.10, respectively.

Table 4.8. *LCI Data Inventory Summary for Concrete Mixtures*

Inputs for 1 m^3 Concrete Production	**Processes**	**Database**
Cement		
Portland cement	Cement, Portland {Europe w/out Switzerland}, market for, Consequential, S	Ecoinvent v3

Table 4.8. *LCI Data Inventory Summary for Concrete Mixtures- -continued*

Inputs for 1 m^3 Concrete Production	**Processes**	**Database**
Supplementary Cementitious Materials		
Perlite (substituted as natural pozzolan)	Perlite {GLO}, market for, Consequential, S	Ecoinvent v3
Limestone powder	Limestone, crushed, for mill {CH}, market for limestone, crushed, for mill, Consequential, S	Ecoinvent v3
GGBFS	128 Waste treatment, Landfill of waste, Slag/ash, EU27	EU & DK Input
Silica fume		
Fly ash		
Fine and Coarse Aggregates		
Natural river sand	Sand {GLO}, market for, Consequential, S	Ecoinvent v3
Sea sand		
Quartzitic sand		
Sand		
Limestone sand	Limestone, crushed, for mill {CH}, market for limestone, crushed, for mill, Consequential, S	Ecoinvent v3
Crushed limestone		
Crushed stone sand	Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System	Ecoinvent v3
Crushed stone		
Foundry sand	128 Waste treatment, Landfill of waste, Slag/ash, EU27	EU & DK Input
Steel slag		
Basalt	Basalt {GLO}, market for, Consequential, S	Ecoinvent v3
River sand (utilized as coarse aggregate)	Gravel, round {CH}, market for, Consequential, S	Ecoinvent v3
Pea gravel		
River gravel		
Granite	Granite, in ground	General data

Table 4.8. *LCI Data Inventory Summary for Concrete Mixtures- -continued*

Inputs for 1 m^3 Concrete Production	**Processes**	**Database**
Admixture		
Plasticiser	Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}, production, Consequential, System	Ecoinvent v3
Water		
Tap water	Tap water {GLO}, market group for, Consequential, S	Ecoinvent v3
Energy		
Electricity	Electricity, medium voltage {GLO}, market group for, Consequential, S	Ecoinvent v3
Natural Gas	Natural gas, high pressure {GLO}, market group for, Consequential, S	Ecoinvent v3
Middle distillates (Diesel Fuel)	Diesel {Europe w/out Switzerland}, market for, Consequential, S	Ecoinvent v3
Outputs for 1 m^3 Concrete Production	**Processes**	**Database**
Solid Waste	Inert waste, for final disposal {CH},market for inert waste, for final disposal, Consequential, S	Ecoinvent v3

Table 4.9. *LCI Data Inventory Summary for Recycled Aggregate Production*

Inputs for 1 tone Recycled Aggregate Production	**Processes**	**Database**
Electricity	Electricity, medium voltage {GLO}, market group for, Consequential, S	Ecoinvent v3
Diesel (wood recycling)	Diesel {Europe w/out Switzerland}, market for, Consequential, S	Ecoinvent v3
Diesel (used in building machine)	Diesel, burned in building machine {GLO}, market for, Consequential, S	Ecoinvent v3
Lubricating Oil	Lubricating oil {GLO}, market for, Consequential, S	Ecoinvent v3
Water from underground well	Water, groundwater consumption	General data
Transport to the Customer	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}, Consequential, S	Ecoinvent v3
Hard Coal	Hard coal {ROW}, market for, Consequential, S	Ecoinvent v3
Outputs for 1 m^3 Concrete Production	**Processes**	**Database**
Sanitary Landfilling	Municipal solid waste {ROW}, treatment of, sanitary landfill, Consequential, S	Ecoinvent v3
Avoided Burdens	**Processes**	**Database**
Inert Landfilling	128 Waste treatment, Landfill of waste, Slag/ash, EU27	EU & DK Input
Avoided Product	**Processes**	**Database**
Land-derived material	_17 Clay and soil from quarry, EU27	EU & DK Input
Wood Chips	Wood chips, dry, measured as dry mass (RoW), plywood production, for outdoor use, Allocation Rec, S	Ecoinvent v3
Steel	Steel, low-alloyed (RER), steel production converter, low-alloyed, Consequential, S	Ecoinvent v3

Table 4.10. *LCI Data Inventory Summary for GGBFS Processing*

Inputs for 1 ton GGBFS Processing	**Processes**	**Database**
Electricity	Electricity, medium voltage {GLO}, market group for, Consequential, S	Ecoinvent v3
Natural Gas	Natural gas, high pressure {GLO}, market group for, Consequential, S	Ecoinvent v3
Diesel Fuel	Diesel {Europe w/out Switzerland}, market for, Consequential, S	Ecoinvent v3
Water	Water, process, unspecified natural origin	General data
Outputs for 1 ton GGBFS Processing	**Processes**	**Database**
Particulate Matters	Particulates	General data

Data inventory summary for the Prokon-Ekon Headquarter Office Building with the selected processes and data from the database are presented in Table 4.11.

Table 4.11. *LCI Data Inventory Summary for the Case Study Building*

Inputs from technosphere: materials/fuels	**Processes**	**Database**
Building Materials		
Concrete	Concrete, 35MPa {GLO}| market for | Alloc, S	Ecoinvent v3
Steel mesh	Steel rebar, blast furnace and electric arc furnace route, production mix, at plant, GLO S	ELCD
Reinforcing bar	Reinforcing steel {GLO} market for, Alloc Def, U	Ecoinvent v3
Steel sheet	Galvanized steel sheet, at plant/RNA	USLCI
Aerated concrete block	Autoclaved aerated concrete block {GLO} market for, Alloc Rec, U	Ecoinvent v3
Steel profile	Steel, low-alloyed {GLO} market for, Alloc Def, U	Ecoinvent v3

Table 4.11. *LCI Data Inventory Summary for the Case Study Building - continued*

Inputs from technosphere: materials/fuels	**Processes**	**Database**
Building Materials		
Aluminum facade	Cladding, crossbar-pole, aluminum {GLO} market for, Alloc Def, U	Ecoinvent v3
Rock wool	Rock wool, fleece, production mix, at plant, density between 30 to 180 kg/m^3 RER S	ELCD
Gypsum board	Gypsum plasterboard {GLO} market for, Alloc Rec, U	Ecoinvent v3
Ceramic tile for external walls	Ceramic tine {GLO} market for, Alloc Rec, U	Ecoinvent v3
Roof membrane	Single-ply, white, polyester reinforced PVC roofing membrane, 1.219 mm/m^2/RNA	USLCI
Granite	Natural stone plate, cut {GLO} market for, Alloc Rec, U	Ecoinvent v3
Parquet	Prefinished engineered wood flooring, at engineered wood flooring plant, E/m^3/RNA	USLCI
Wood beam	Glue laminated timber, for indoor use {GLO} market for, Alloc Rec, U	Ecoinvent v3
Windows	Window frame, aluminum, U=1.6 W/m^{2}K{GLO} market for, Alloc Rec, U	Ecoinvent v3
	Glazing, triple, U<0.5 W/m^{2}K {GLO} market for, Alloc Rec, U	Ecoinvent v3
Coating	Acrylic varnish, without water, in 87.5% solution state {GLO} market for, Alloc Rec, U	Ecoinvent v3
Coating	Coating powder {GLO} market for, Alloc Rec, U	Ecoinvent v3
Coating	Acrylic filler {GLO} market for, Alloc Rec, U	Ecoinvent v3

Table 4.11. *LCI Data Inventory Summary for the Case Study Building - continued*

Inputs from technosphere: materials/fuels	**Processes**	**Database**
Building Materials		
Coating	Coating powder {GLO} market for, Alloc Rec, U	Ecoinvent v3
Coating	Coating powder {GLO} market for, Alloc Rec, U	Ecoinvent v3
Paint	Alkyd paint, white, without solvent, in 60% solution state {GLO} market for, Alloc Rec, U	Ecoinvent v3
Coating	Coating powder {GLO} market for, Alloc Rec, U	Ecoinvent v3
Cement mortar	Cement mortar {CH} market for cement mortar, Alloc Rec, U	Ecoinvent v3
Mechanical Equipment		
Boiler	Gas boiler {GLO} market for, Alloc Rec, U	Ecoinvent v3
Solar collector	Flat plate solar collector, Cu absorber {GLO} market, Alloc Rec, U	Ecoinvent v3
Photovoltaic panels	Photovoltaic cell, multi-Si wafer {GLO} market for, Alloc Rec, U	Ecoinvent v3
Circulation pump < 50 W	Pump, 40 kW {GLO} market for, Alloc Rec, U	Ecoinvent v3
Co-generation unit	Heat and Power co-generation unit, 50 kW electrical, common components for heat+electricity {GLO} market for, Alloc Rec, U	Ecoinvent v3
ABS Chiller	Absorption chiller, 100 kW {GLO} market for, Alloc Rec, U	Ecoinvent v3
Rainwater System		
Concrete	Concrete, 35 MPa {GLO} market for, Alloc Rec, U	Ecoinvent v3
Ultrafiltration unit	Ultrafiltration module {GLO} market for, Alloc Rec, U	Ecoinvent v3

Table 4.11. *LCI Data Inventory Summary for the Case Study Building - continued*

Inputs from technosphere: materials/fuels	**Processes**	**Database**
Building Materials		
UV Lamp	Backlight, for liquid crystal display {GLO} market for, Alloc Rec, U	Ecoinvent v3
Control device	Potentiometer, unspecified {GLO} market for, Alloc Rec, U	Ecoinvent v3
Greywater System		
Stainless steel	Steel, unalloyed {GLO} market for, Alloc Rec, U	Ecoinvent v3
Ultrafiltration unit	Ultrafiltration module {GLO} market for, Alloc Rec, U	Ecoinvent v3
Air compressor	Air compressor, screw-type compressor, 4 kW {GLO} market for, Alloc Rec, U	Ecoinvent v3
Control device	Potentiometer, unspecified {GLO} market for, Alloc Rec, U	Ecoinvent v3
Water Use		
Water use	Tap water {RER} market group for, Alloc Rec, U	Ecoinvent v3
Input from technosphere: electricity/heat	**Processes**	**Database**
Natural gas	Natural gas, high pressure {GR} import from RU, Alloc Rec, U	Ecoinvent v3
Electricity	Building can meet its own energy demand from the photovoltaic panels installed.	-
Transport of building materials	Transport, freight, lorry>32 metric ton, Euro6 {GLO} market for, Alloc Rec, U	Ecoinvent v3
Transport of building materials	Transport, freight, lorry>7.5-16 metric ton, Euro6 {GLO} market for, Alloc Rec, U	Ecoinvent v3

Table 4.11. *LCI Data Inventory Summary for the Case Study Building - continued*

Inputs from technosphere: materials/fuels	**Processes**	**Database**
Transport of building materials	Transport, freight, lorry>32 metric ton, Euro6 {GLO} market for, Alloc Rec, U	Ecoinvent v3
Waste Scenario		
Outputs to technosphere: Waste and emissions to treatment	**Processes**	**Database**
Aluminum	Aluminum (waste treatment) {GLO} recycling of aluminum, Alloc Def, U	Ecoinvent v3
Steel	Steel and iron (waste treatment) {GLO} recycling of steel and iron, Alloc Def, U	Ecoinvent v3
Concrete (sorting plant)	Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U	Ecoinvent v3
Concrete (landfill)	Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U	Ecoinvent v3
Other wastes	Inert waste, for final disposal {CH} market for inert waste, for final disposal, Alloc Rec, U	Ecoinvent v3

4.2.3. Impact Assessment

Following the data inventory, impact assessment was conducted to quantify the potential impacts of the designated different concrete mixtures based on the selected impact categories. SimaPro 8.4.1.0 has several important mid-point and end-point impact assessment methods such as CML, TRACI, IMPACT 2002+, ReCiPe, EPD, Eco-indicator 99 and BEES having different impact indicators.

In order to select most appropriate impact assessment methodology, similar literature studies have been reviewed. As a result of literature review, it was concluded that CML is one of the most recommended LCIA method especially for assessment the impacts of different concrete mixtures since CML method enables best practice for mid-point impact category indicators as per ISO 14040 and ISO 14044. [5] [7] [8] [56] [110]. In addition, CML-1A baseline method was used to calculate and evaluate the environmental impacts of Prokon-Ekon Headquarter Office Building. Therefore, CML-1A baseline methodology has been selected as LCIA method for the research.

CML methodology is "problem oriented" mid-point approach which was improved by Center of Environmental Science of Leiden. CML 1992, CML 2 baseline 2000 and CML 2001 methods are no longer supported by SimaPro 8.4.1.0 and these are placed within the "Superseded" list in the software. The details for these impact assessment methods can be found under the list. Therefore, CML-1A had been applied in the scope of impact assessment. The idea behind the method is presented in Figure 4.5.

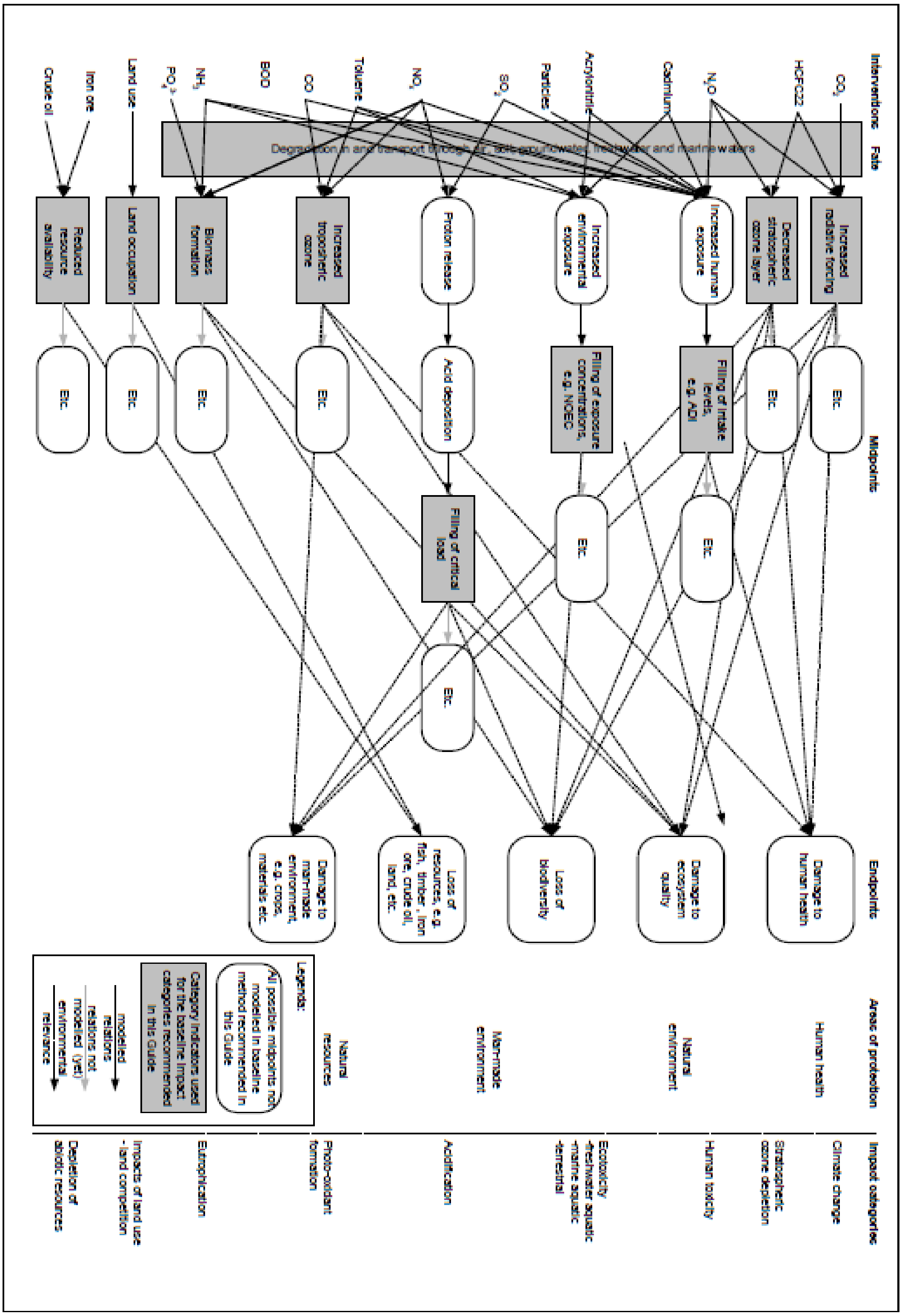


Figure 4.5. Working principle of CML method [111]

In the SimaPro 8.4.1.0, there are two versions of CML-1A method namely baseline and non-baseline. CML-1A baseline method is an updated version of CML 2 baseline 2000 and the latest update has been made in 2016 for the method.

The CML-1A baseline method has ten impact category indicators: depletion of abiotic resources; climate change; stratospheric ozone depletion; human toxicity; fresh-water aquatic ecotoxicity, marine ecotoxicity; terrestrial ecotoxicity; photo-oxidant formation; acidification; and eutrophication [112]. All of these impact categories were included while impact assessment for the study. Characterization, which is the obligatory step for LCIA, was applied by multiplying the defined characterization factors and inventory data, and then results were summed up. Finally, the impact category indicators were characterized at the mid-point level. Characterisation factors for CML-1A baseline method and their unit expressions are presented in Table 4.12.

Table 4.12. *Characterization Factors and Unit Expressions for CML-1A Baseline [112]*

Midpoint Impact Category Indicator	**Characterization Factor**	**Unit Expressions**	**Concerns**	**Regional Validity**
Depletion of abiotic resources	Abiotic Depletion Potential (ADP)	kg Sb eq	Human and ecosystem health	Global scale
Climate change	Global Warming Potential for time horizon 100 years (GWP 100)	kg CO_2 eq	Greenhouse gas emissions to the atmosphere	Global scale

Table 4.12. *Characterization Factors and Unit Expressions for CML-1A Baseline [112] - continued*

Midpoint Impact Category Indicator	**Characterization Factor**	**Unit Expressions**	**Concerns**	**Regional Validity**
Stratospheric ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	UV-B radiation that poses risks for human and animal health, ecosystems, cycles and materials	Global scale
Human toxicity	Human Toxicity Potential (HTP)	1,4-dichlorobenzene equivalents	Harmful impacts of toxic substances on human welfare	Local and Global scale
Fresh-water aquatic ecotoxicity	Fresh-water Aquatic Ecotoxicity Potential (FAETP)	1,4-dichlorobenzene equivalents	Harmful impacts on fresh water ecosystem	Regional and Local scale
Marine ecotoxicity	Marine Aquatic Ecotoxicity Potential (MAETP)	1,4-dichlorobenzene equivalents	Harmful impacts on marine ecosystem	Regional and Local scale
Terrestrial ecotoxicity	Terrestrial Ecotoxicity Potential (TETP)	1,4-dichlorobenzene equivalents	Harmful impacts on terrestrial ecosystem	Regional and Local scale

Table 4.12. *Characterization Factors and Unit Expressions for CML-1A Baseline [112] - continued*

Midpoint Impact Category Indicator	**Characterization Factor**	**Unit Expressions**	**Concerns**	**Regional Validity**
Photo-oxidant formation	Photochemical Ozone Creation Potential (POCP)	kg C_2H_4 eq	Formation of photo-oxidants that poses risks for human health and ecosystem	Local and continental scale
Acidification	Acidification Potential (AP)	kg SO_2 eq	Harmful impacts of acidification on soil, surface water, groundwater, ecosystem organisms and materials	Local and continental scale
Eutrophication	Eutrophication (EP)	kg PO_4 eq	Harmful impacts of excessive amount of nutrients that reach to the water, soil and air	Local and continental scale

Although, LCA results belonging to the concrete mixtures and building were assessed by considering the characterization results and impact contribution of the products, normalization step was also applied to ease the comparison of impact assessment results and to remove the impact category indicators having less contribution. Characterization and normalization results for the concrete mixtures and building are provided in APPENDIX A, APPENDIX B, APPENDIX C and APPENDIX D whereas characterization results and normalization results for actual case study building and building scenarios with designated concrete mixtures are presented in APPENDIX E and APPENDIX F, respectively. In normalisation step, impact category indicators were divided into "normal value" to demonstrate the impacts of inventory data on environment and/or human health. Normalization practices available in CML-1A baseline method are as follows: EU25; EU25+3, 2000; World, 1990; World, 1995; World, 2000; The Netherlands, 1997; and West Europe, 1995.

In this study, global data was tried to be selected from the related database, therefore, World, 2000 was chosen in the normalization.

4.2.4. Interpretation

The results of life cycle inventory and life cycle impact assessment were evaluated in a systematic way in the interpretation step. In addition, the suggestions were made by considering the goal and scope of the study. Characterization results were used while comparison and evaluation of the different concrete mixtures.

CHAPTER 5

RESULTS AND DISCUSSION

LCA results obtained from SimaPro 8.4.1.0 for the concrete mixtures and case study building are presented in the following sub-sections of Sec 5.1-Results part. Moreover, comparison and discussion in regarding these results were provided under Sec 5.2-Discussion part.

As stated in Section 4, CML-1A baseline impact assessment method was used to assess the environmental impacts of selected concrete mixtures and case study building. Characterization and normalization results were considered while evaluating the outputs of processes. Units are different for each mid-point category and comparison might be confusing and difficult by just looking at the characterization results. Therefore, normalization results were also taken into consideration to ease the comparison of mid-point impact categories with each other. Characterization results and normalizations results are presented in APPENDIX A and APPENDIX C, and APPENDIX B and APPENDIX D, respectively for each concrete mixture. In addition, total of characterization and normalization results of case study building and building scenarios with concrete mixtures are provided in APPENDIX E and APPENDIX F.

5.1. Results

5.1.1. Environmental Impacts of Concrete Mixtures

5.1.1.1. Mixture-1

Mixture-1, as stated in Table 4.2, consists of Portland cement, silica fume, water, natural fine aggregates and coarse aggregates [94]. Water to binder (w/b) ratio is 0.7 and superplasticisers were not used for this concrete mixture. Silica fume was added into the mixture by 10% of the cement weight. The 28-days compressive strength of the concrete is 35 MPa that was conducted by 150 x 300 mm cylindrical specimens. Further processing for the silica fume is not required before utilized in the concrete [94].

During the LCA runs, the impacts resulting from disposal of silica fume landfilling was considered as avoided impacts, as it is possible to reuse it as a raw material to form Mixture-1. LCA characterization results obtained for the Mixture-1 per mid-point impact categories are provided in Figure 5.1 and normalized impacts are given in APPENDIX B and APPENDIX D.

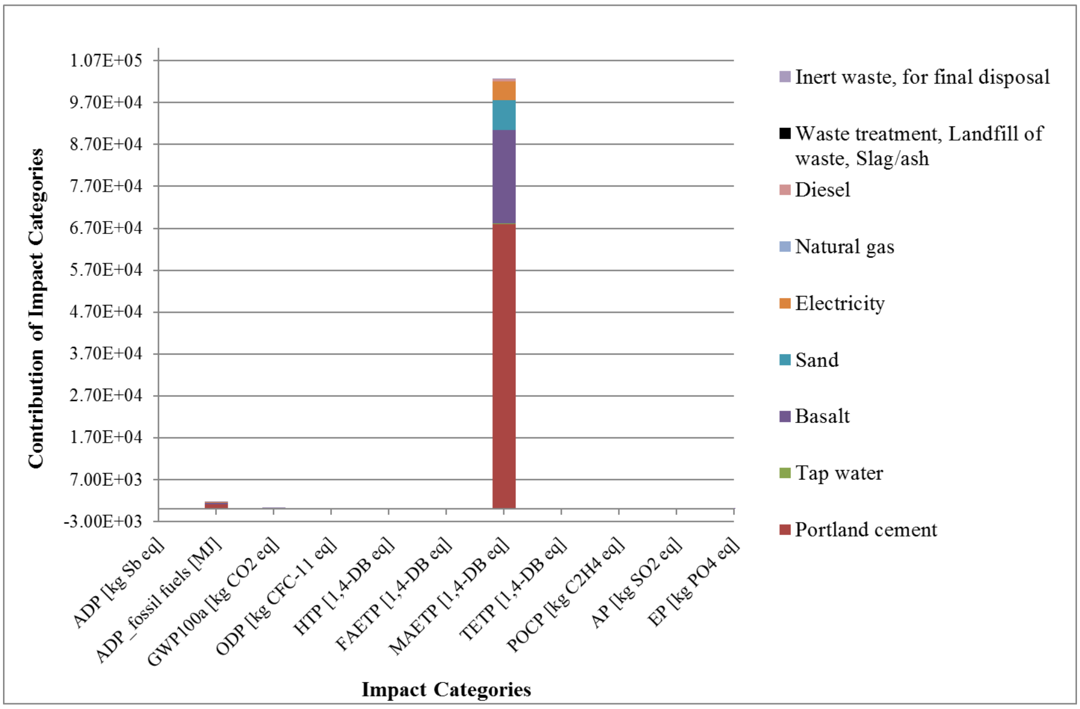


Figure 5.1. Characterization results of the Mixture-1 (Please see Table 4.12 for the definition of the impact categories)

From the Figure 5.1, it can be clearly seen that, Portland cement is the main contributor to each mid-point impact categories. The percentage contribution of Portland cement varies in between 68.22% (ADP) and 90.15% (for GWP) to the impact categories. Basalt and sand production follow the Portland cement production at the second and third highest rate, respectively. Results for landfill of silica fume as avoided product show negative contribution to the mid-point impacts. The production of 1 m^3 concrete Mixture-1 has the highest impact on MAETP (5.3E-10). HTP (1.89E-11) and FAETP (1.49E-11) have the second and third highest rate.

5.1.1.2. Mixture-2

For production of Mixture 2; Portland cement, natural aggregate, steel slag, water and plasticizer were considered (Table 4.2). Calculated w/b ratio is 0.48 and 28-days compressive strength of the Mixture-2 is 37.4 MPa.

Steel slag was replaced with the natural aggregate [11] and therefore disposal requirement for the steel slag was considered as avoided product, during the LCA run. Environmental impacts of the Mixture-2 obtained per mid-point impact categories are provided in Figure 5.2 and normalized impacts are given in APPENDIX B and APPENDIX D.

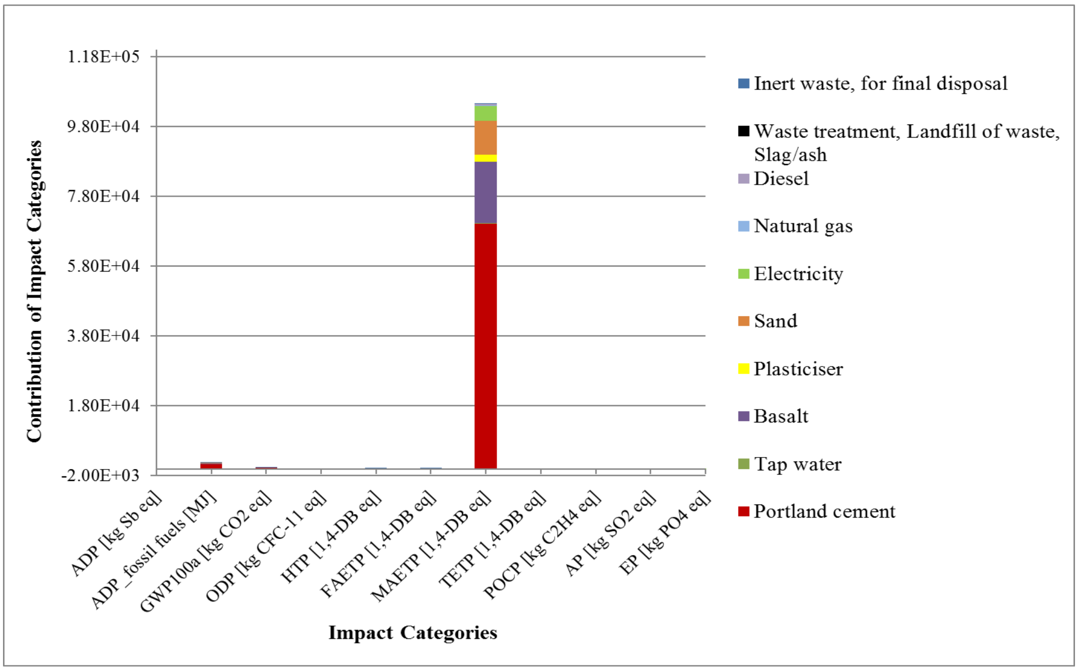


Figure 5.2. Characterization results of the Mixture-2 (Please see Table 4.12 for the definition of the impact categories)

As can be seen in Figure 5.2, the impacts resulting from 1 m^3 Mixture-2 production are mostly observed at the MAETP (5.40E-10), HTP (1.99E-11) and FAETP (1.52E-11). Regarding all mid-point impact categories, Portland cement has the highest contribution percentages that vary in between 90.104% (for GWP) and 62.52% (for ADP). Basalt has the second most contributor product for the Mixture-2 production while sand is in the third rank. Avoided disposal requirement for the steel slag has the negative or zero contribution to the mid-point impact categories.

5.1.1.3. Mixture-3

Portland cement, natural aggregate, water and plasticizer as well as fly ash and recycled aggregate were combined for the production of Mixture-3 (Table 4.2) [11]. Processing is not required for the fly ash before utilized in the concrete production. 28-days compressive strength of the Mixture-3 is 35.5 MPa and w/b is 0.81 [11].

During the LCA run, landfill requirements for the fly ash were taken as avoided process within the system boundary. Fly ash was replaced with the cement by weight as supplementary cementitious material. Environmental impacts of the Mixture-3 per mid-point impact categories are provided in Figure 5.3 and normalized impacts are given in APPENDIX B and APPENDIX D.

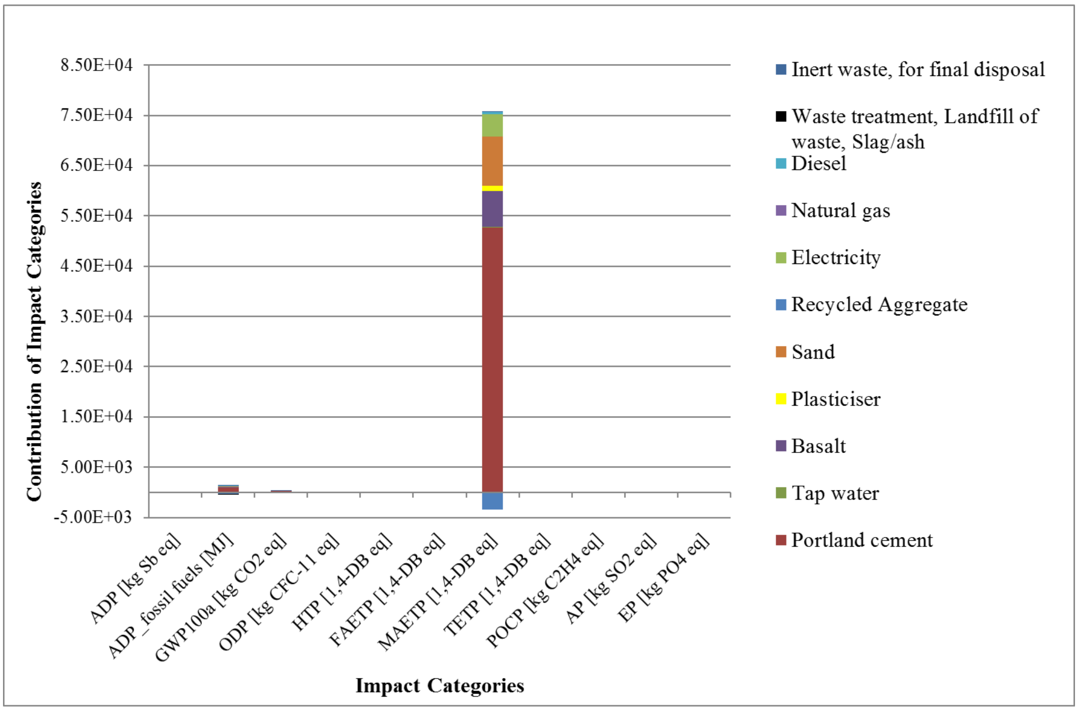


Figure 5.3. Characterization results of the Mixture-3 (Please see Table 4.12 for the definition of the impact categories)

As presented in Figure 5.3, Portland cement is the main impact contributor for each mid-point impact categories. Production of 1 m^3 Mixture-3 has the biggest impact on MAETP (3.80E-10). FAETP (1.15E-11) and HTP (9.33E-12) have the second and third rate, respectively. The percentage contribution of the Portland cement is in between 58.23% (for ADP) and 90.32% (for GWP). The total of reycled aggregate and avoided disposal for fly ash show the negative contribution. Negative contribution due to recycled aggregate is mostly occurred at the POCP (-58%), ADP (-52%) and HTP (-38%) mid-points.

5.1.1.4. Mixture-4

Mixture-4, having 28-day strength of 34.3 MPa and 0.74 w/b ratio, is composed of Portland cement, natural aggregate, water, plasticizer, foundry sand and recycled aggregate, as also indicated in Table 4.2 [11].

Foundry sand and recycled aggregate were substituted as natural aggregate [11] and therefore, landfill requirements for the foundry sand was considered as avoided process, during the LCA run. In addition, no additional data for treatment of foundry sand was included since further processing is not required before used in concrete production. Characterization results for the Mixture-4 are presented in Figure 5.4 and normalized impacts are given in APPENDIX B and APPENDIX D.

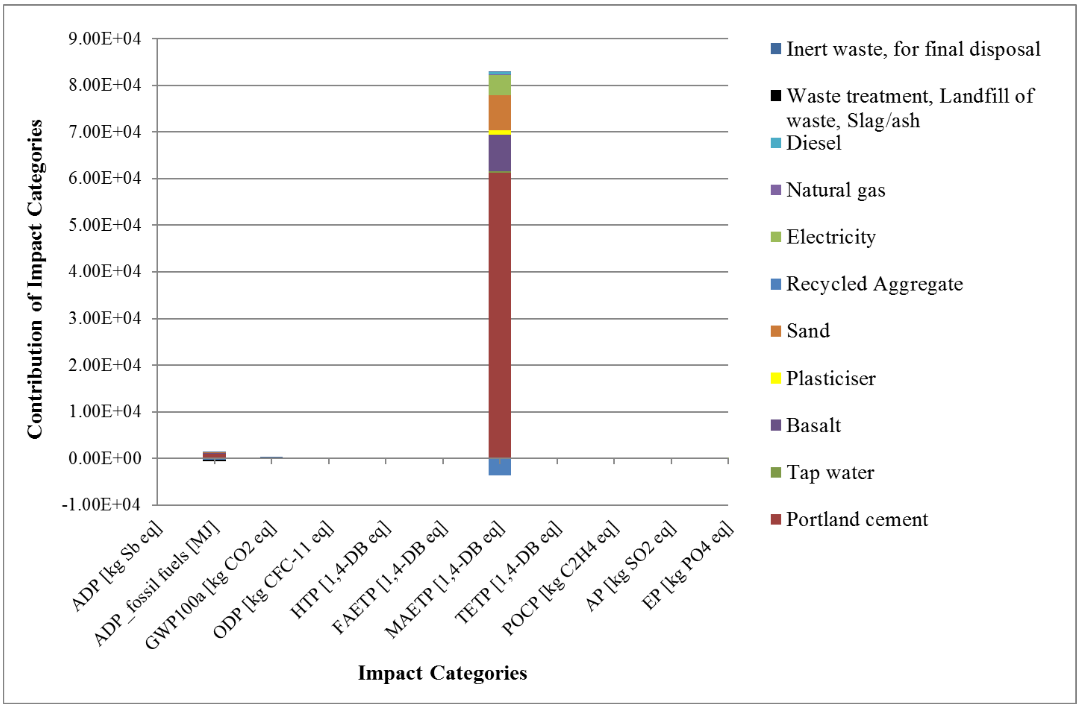


Figure 5.4. Characterization results of the Mixture-4 (Please see Table 4.12 for the definition of the impact categories)

As depicted in Figure 5.4, Portland cement is the main contributor for each mid point imapct category with the prcentage contribution of changing in between 66.16% (for ADP) and 92.72% (for GWP). Recycled aggregate and avoided disposal for treatment of foundry sand have the negative contribution in total. Negative contribution due to recycled aggregate is mostly occurred at the POCP (-57%), ADP (-54%) and HTP (-37%) mid-points. Production of 1 m^3 Mixture-4 has the highest impact on MAETP

(4.15E-10). The second most impact is observed on FAETP (1.27E-11). The impacts on HTP (1.03E-11) are in the third rank.

5.1.1.5. Mixture-5 and Mixture-6

Mixture-5 and Mixture-6 contain Portland cement, fly ash, water, superplasticisers, fine aggregates and coarse aggregates (Table 4.2) [95]. The proportions of the materials used in these two mixtures are different from each other. The fly ash replacement ratio with cement is 50% and 60% for the Mixture-5 and Mixture-6, respectively. On the other hand, the superplasticizer dosage is identical for the mixtures. The compressive strengths of the concretes were tested by cylindrical specimens. According to the compressive strength results, 28-days compressive strength was 37.8 MPa for the Mixture-5 and 34.2 MPa for the Mixture-6 [95].

During the LCA run, landfill requirement for the fly ash were taken as avoided process within the system boundary, since the fly ash were used in concrete production instead of being disposed. Environmental impacts obtained for these two concrete mixtures are presented in in Figure 5.5 and Figure 5.6. In addition, normalized impacts are given in APPENDIX B and APPENDIX D.

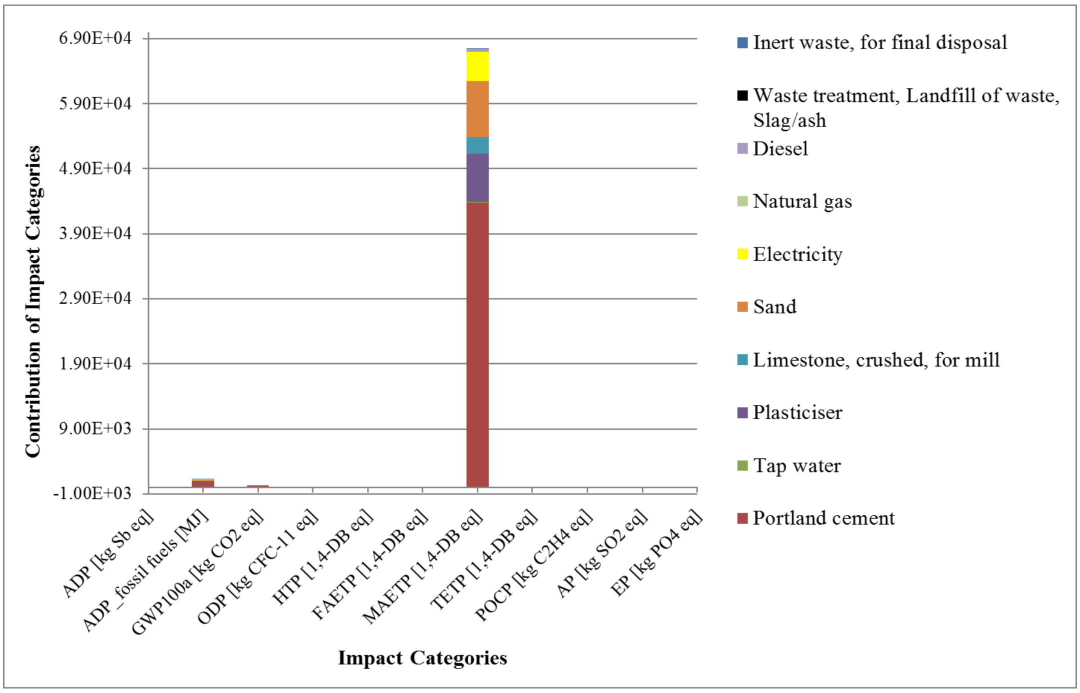


Figure 5.5. Characterization results of the Mixture-5 (Please see Table 4.12 for the definition of the impact categories)

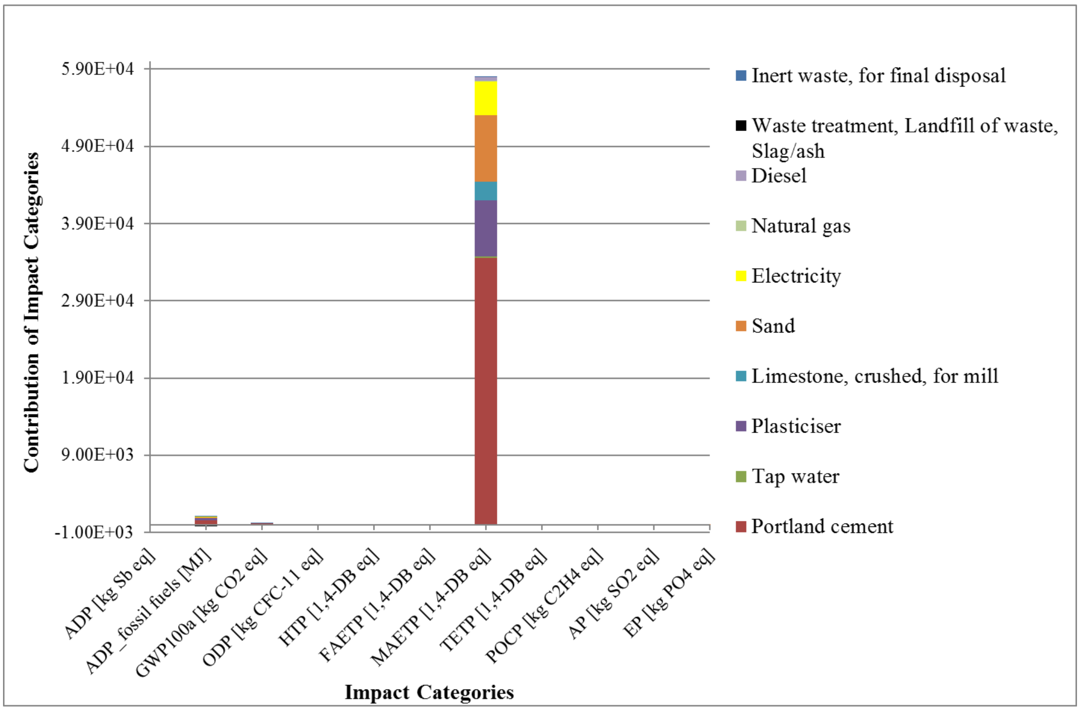


Figure 5.6. Characterization results of the Mixture-6 (Please see Table 4.12 for the definition of the impact categories)

As indicated in Figure 5.5 and Figure 5.6, the Portland cement has the highest impacts on mid-point impact categories for the 1 m^3 Mixture-5 and Mixture-6 production. Portland cement has significant impact on GWP with the percentage contribution of 83.49% and 80.19% for Mixture-5 and Mixture-6, respectively. The 1 m^3 concrete production has significantly impact on MAETP in which the mass contributions belonging to the Mixture-5 and Mixture-6 are 3.95E-10 and 3.45E-10, respectively. The avoided waste disposal considered for the fly ash has negative contribution to the total characterized results.

Since Portland cement, sand and admixture amount utilized in Mixture-5 are higher than the one Mixture-6, the environmental impacts of Mixture-5 are higher than the Mixture-6.

5.1.1.6. Mixture-7 and Mixture-8

Mixture-7 and Mixture-8 consist of Portland cement, natural pozzolan, water, crushed stone, sea sand and crushed stone sand (Table 4.2) [96]. As seen from Table 4.2, except natural pozzolan, all materials were included in similar amount for these two concrete mixtures. The 28-days of compressive strengths achieved by addition of natural pozzolan are 34.4 MPa and 34.0 MPa, respectively, for the Mixture-7 and Mixture-8 [96].

Characterization results obtained through the LCA run for the Mixture-7 and Mixture-8 are given in Figure 5.7 and Figure 5.8, respectively. Moreover, normalized impacts are given in APPENDIX B and APPENDIX D.

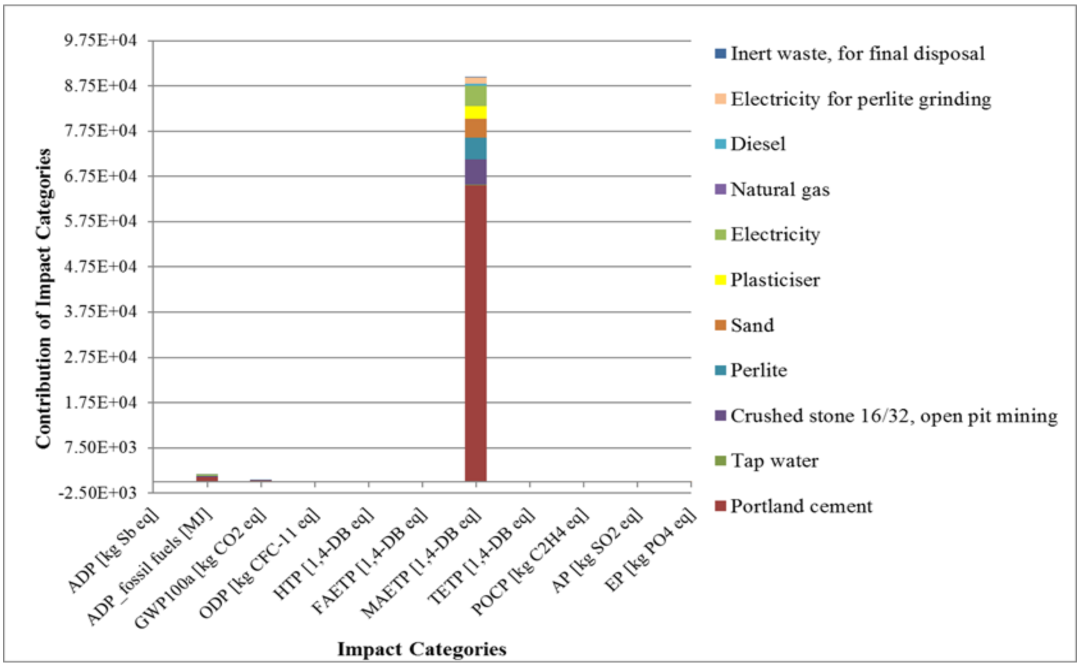


Figure 5.7. Characterization results of the Mixture-7 (Please see Table 4.12 for the definition of the impact categories)

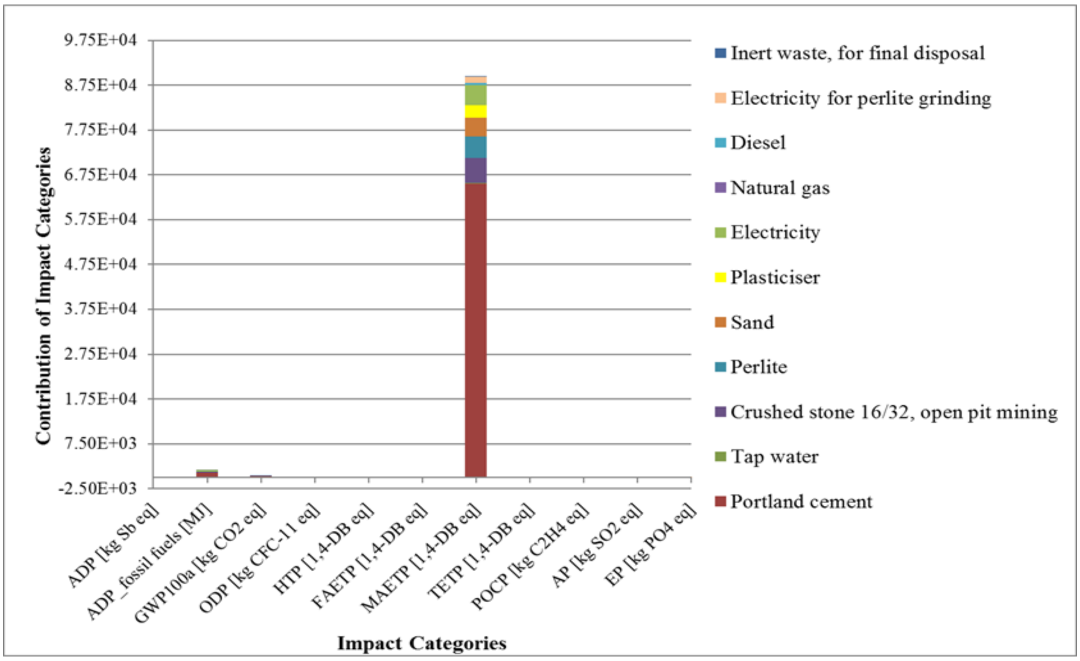


Figure 5.8. Characterization results of the Mixture-8 (Please see Table 4.12 for the definition of the impact categories)

From the Figure 5.7 and Figure 5.8, it can be inferred that Portland cement is the main contributor to each mid-point impact category for the production of 1 m^3 Mixture-7 and Mixture-8. In addition, impacts originating from crushed stone have the second rank. The percent contribution of the Portland cement is in between 58.1% (for ODP) and 87.43% (for GWP) for the Mixture-7 as well as 58.08% (for ODP) and 87.28% (for GWP) for the Mixture-8. Production of Mixture-7 and Mixture-8 has the leading impact on MAETP. The second and third highest impacts are observed on HTP and FAETP.

Although Portland cement percentages are similar, the perlite content used in the Mixture-8 is higher than the Mixture-7. Therefore, all of the characterization and normalization results for each mid-point impact categories are slightly higher for Mixture-8.

5.1.1.7. Mixture-9

Portland cement, superplasticizers, water, fine aggregate and coarse aggregate were combined to produce Mixture-9, which has 0.38 w/b ratio (Table 4.2) [97]. In addition, fly ash was inserted as cementitious material by 40% replacement with Portland cement. For the compressive strength test, cube specimens were used and as results of the tests, 28-days compressive strength of the mixture was specified as 45.26 MPa [97].

During the LCA run, additional process for the treatment of fly ash was not included since further processing is not required and impacts regarding disposal of fly ash was considered as avoided product. Characterization results obtained for the Mixture-9 are presented in Figure 5.9 and normalized impacts are given in APPENDIX B and APPENDIX D.

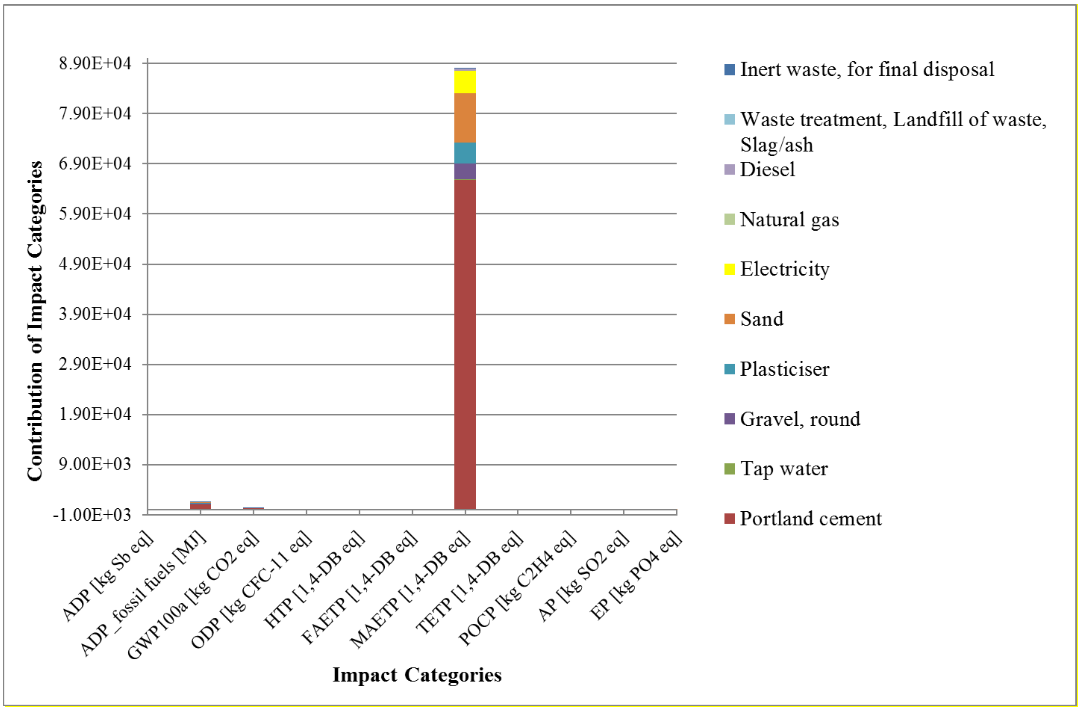


Figure 5.9. Characterization results of the Mixture-9 (Please see Table 4.12 for the definition of the impact categories)

As presented in Figure 5.9, the production of 1 m^3 Mixture-9 concrete has highest contribution to MAETP (4.80E-10) among other mid-point impact categories. The impacts are mostly due to the consumption of Portland cement, especially for the GWP impact category. The percent contribution of the Portland cement to GWP is 90.25%. In addition, sand production and admixture utilization are also important contributors to the mid-point impact categories, especially for ADP. Avoided landfill requirement for the fly ash has negative contribution in total.

5.1.1.8. Mixture-10

Mixture-10 consists of Portland cement, limestone powder, fine aggregates and coarse aggregates (Table 4.2) [86]. The amount of Portland cement was replaced with the limestone powder and replacement ratio of the limestone powder is 20%. Compressive strength of the mixture is 44.1 MPa that was measured by using cube specimens and w/b ratio was calculated as 0.36 [86].

Characterization results obtained through the LCA run for the Mixture-10 are provided in Figure 5.10 and normalized impacts are given in APPENDIX B and APPENDIX D.

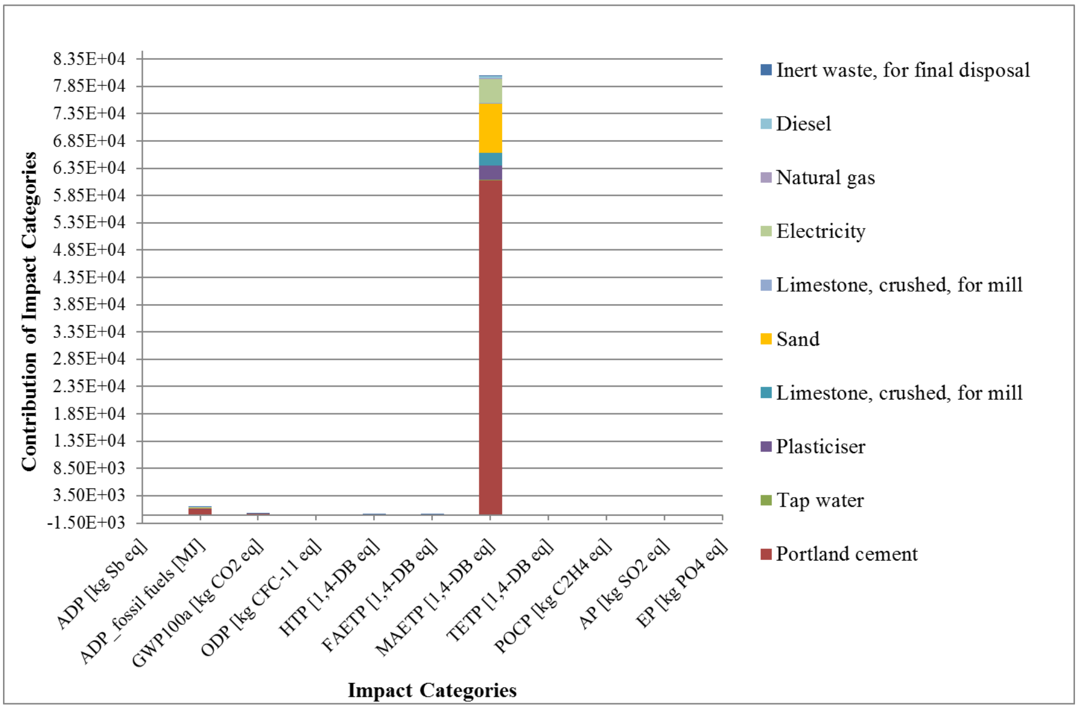


Figure 5.10. Characterization results of the Mixture-10 (Please see Table 4.12 for the definition of the impact categories)

According to the Figure 5.10, Portland cement has the highest impacts for each mid-point category. Sand and admixture usage have the second and third highest rate, respectively. The percent contribution of the Portland cement is in between 56.95% (for ADP) and 91.6% (for GWP) for the production of 1 m^3 Mixture-10. The highest impacts are observed for the MAETP (4.31E-10) mid-point impact category. The second most impact is observed on HTP (1.72E-11). The impacts on FAETP (1.23E-11) are in the third rank.

5.1.1.9. Mixture-11 and Mixture-12

For the production of Mixture-11 and Mixture-12; Portland cement, GGBFS, water and aggregates were combined (Table 4.2) [98]. Plasticizers or superplasticisers were not added for the selected mixtures. Water - cement ratio is equal to 0.5 for each concrete and 28-days compressive strength of the Mixture-11 and Mixture-12 is 46.5 MPa and 45.1 MPa, respectively. Cube specimen having 5 *5 * 5 cm dimension were used. In the mixtures, Portland cement was replaced by GGBFS. The replacement ratio for the Mixture-11 is 40% and for the Mixture-12 is 60% [98].

During the LCA run, GGBFS processing were included within the system boundary since further processing is required for the blast furnace slag before used in concrete production. Mass contribution of impact categories of the Mixture-11 and Mixture-12 are presented in Figure 5.11 and Figure 5.12, respectively. In addition, normalized impacts are given in APPENDIX B and APPENDIX D

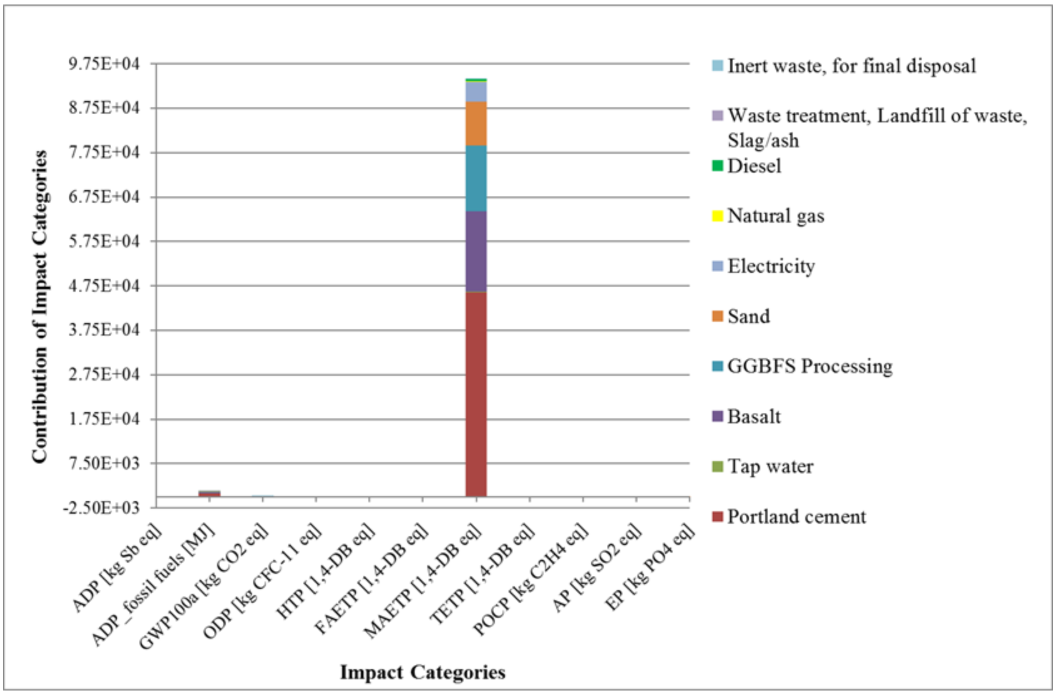


Figure 5.11. Characterization results of the Mixture-11 (Please see Table 4.12 for the definition of the impact categories)

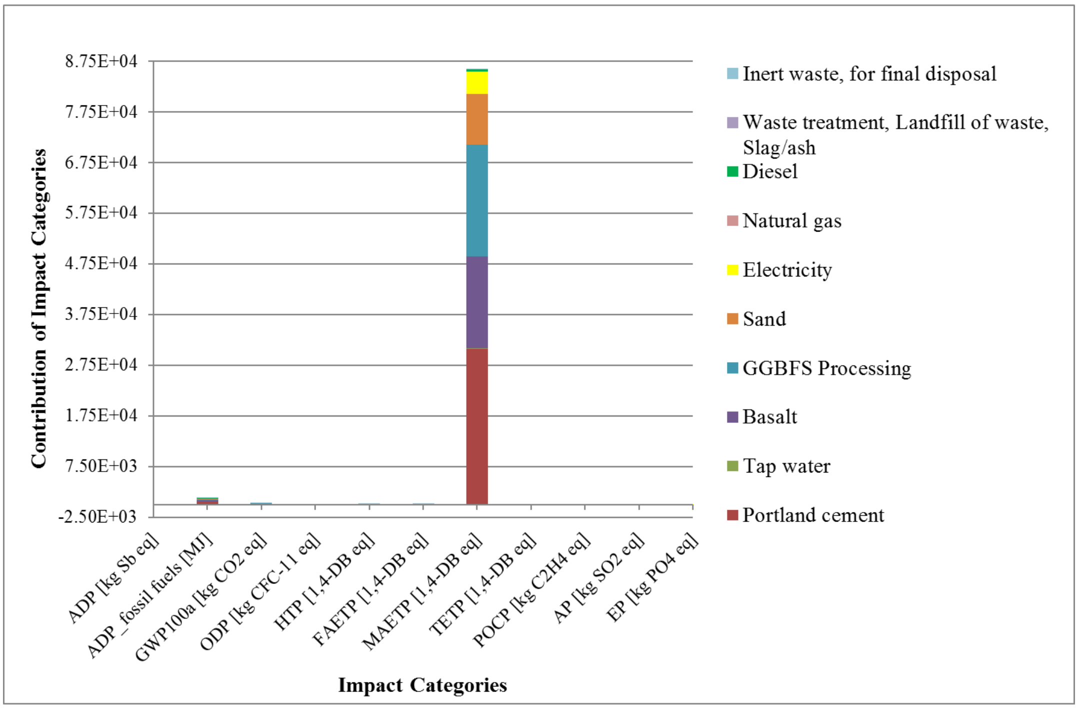


Figure 5.12. Characterization results of the Mixture-12 (Please see Table 4.12 for the definition of the impact categories)

As can be understood from Figure 5.11 and Figure 5.12, Portland cement has the highest impact share regarding all mid-point impact categories for both 1 m^3 Mixture-11 and Mixture-12 production. Percentage impact contribution of the Portland cement ranges from 35.63% (for MAETP) and 73.70% (for GWP) as against the other products utilized in the production of Mixture-12. However, the impact share of Portland cement is much higher in the Mixture-11 since the amount of used Portland cement is higher by comparison with Mixture-12. Within the Mixture-11, the percentage contribution of the Portland cement varies in between 48.89% (for MAETP) and 82.52% (for GWP). Apart from the Portland cement, the total of characterized impacts resulting from basalt production has the second biggest impacts as well as GGBFS processing has the third rate, for the Mixture-11. However, the case for Mixture-12 is opposite since the utilized slag amount is higher whereas utilized basalt amount were similar.

Production of these two mixtures impacts significantly on MAETP, HTP and FAETP, respectively.

5.1.1.10. Mixture-13

Mixture-13 was made of Portland cement, fly ash, limestone powder, fine aggregates, coarse aggregates, superplasticizer and water (Table 4.2) [57]. Portland cement was replaced by fly ash and limestone powder. The replacement ratio for fly ash and limestone powder is 20% and 25% by weight, respectively. The 28-days compressive strength of the concrete mixture is 36.3 MPa according to test conducted by cylindrical specimen having 75*150 mm dimensions. In addition, w/b ratio of the Mixture-13 was set as 0.35 [57].

During the LCA run, additional process for the treatment of fly ash was not included since further processing is not required and impacts regarding disposal of fly ash was considered as avoided product.

Characterization results of the Mixture-13 are presented in Figure 5.13 and normalized impacts are given in APPENDIX B and APPENDIX D.

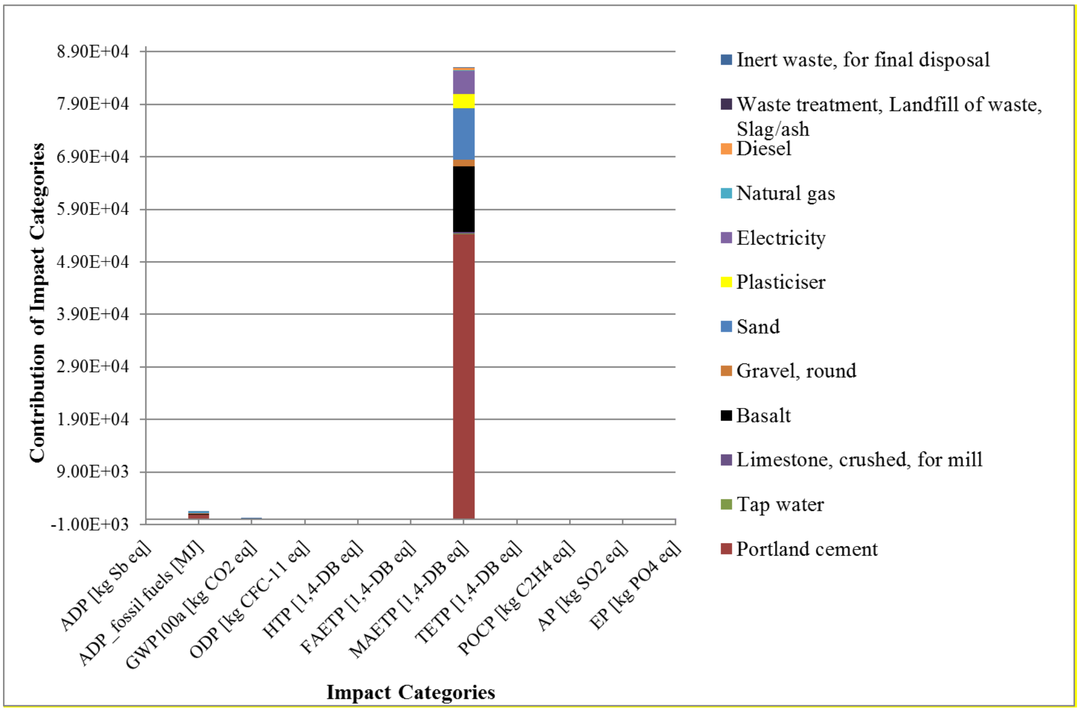


Figure 5.13. Characterization results of the Mixture-13 (Please see Table 4.12 for the definition of the impact categories)

As indicated in Figure 5.13, The production of 1 m^3 Mixture-13, has the highest impact on MAETP (4.61E-10), HTP (1.77E-11) and FAETP (1.28E-11). All of the impacts are mostly due to the Portland cement consumption. The impact percentage of the Portland cement changes in between 47.81% (for ADP) and 86.75% (for GWP). Sand has the second rank which is followed by basalt and admixture, respectively. Avoided disposal requirement for the fly ash has negative contribution in total.

5.1.1.11. Mixture-14

Portland cement, high volume natural pozzolan, fly ash, fine aggregate, coarse aggregate, water and superplasticizer were used to produce Mixture-14 (Table 4.2) [113]. Portland cement was replaced by high volume natural pozzolan and limestone filler. The cement replacement ratio for natural pozzolan is 30% by mass and for limestone filler is 15% by mass. 28-days compressive strength is equal to 38 MPa according to experiments conducted with 75*150 mm cylindrical specimens. In addition, w/b ratio of the Mixture-14 was set as 0.35 [113].

Characterization results obtained through the LCA run for the Mixture-14 are presented in Figure 5.14 and normalized impacts are given in APPENDIX B and APPENDIX D.

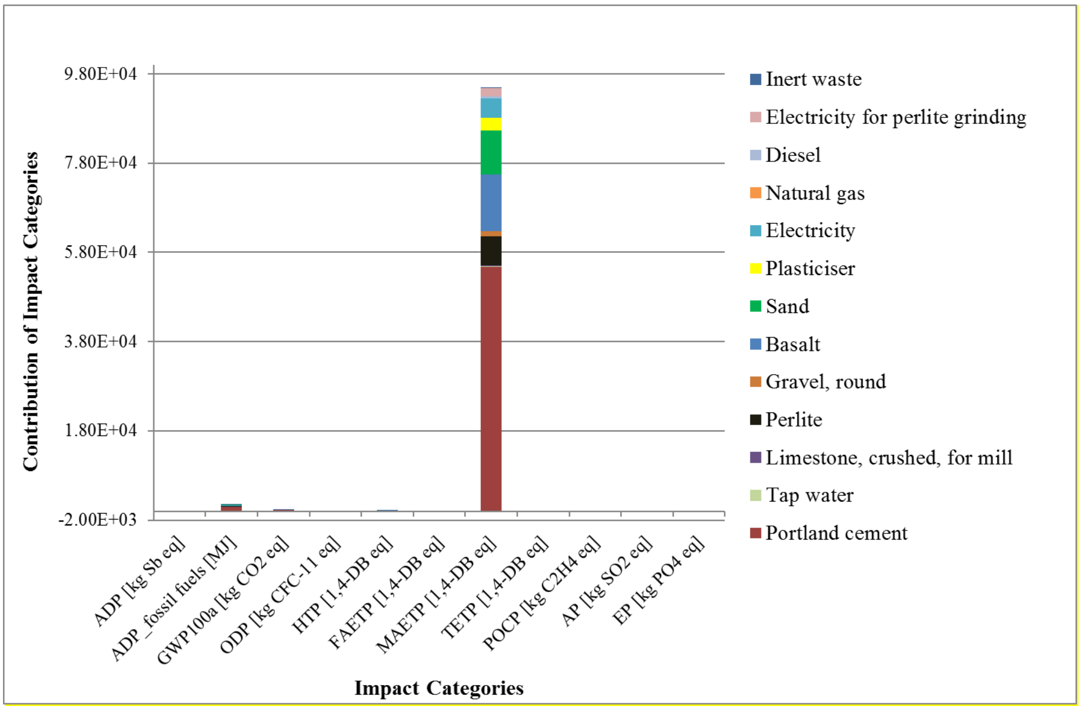


Figure 5.14. Characterization results of the Mixture-14 (Please see Table 4.12 for the definition of the impact categories)

As seen in Figure 5.14, the production of 1 m^3 Mixture-14 has the highest impacts on MAETP (5.08E-10). The second most impact is observed on HTP (1.96E-11). According to the characterization results, Portland cement is the main impact contributor especially for the GWP (84.12%). Productions of basalt, sand and perlite have the second, third and fourth rank within the characterized results, respectively.

5.1.1.12. Mixture-15

Fly ash and silica fume were used to produce Mixture-15, in addition to the Portland cement, water, fine aggregate, coarse aggregate and superplasticizer (Table 4.2) [99]. For compressive strength measurements, cube specimens having 150 mm dimensions were used and 28-days compressive strength was determined as 44.9 MPa. Portland cement was replaced with fly ash and silica fume by 45% and 15% ratio [99].

During the LCA run, additional process for the treatment of fly ash and silica fume was not included since further processing is not required and impacts regarding disposal of fly ash and silica fume was considered as avoided product. Characterization results obtained for the Mixture-15 are given in Figure 5.15 and normalized impacts are given in APPENDIX B and APPENDIX D.

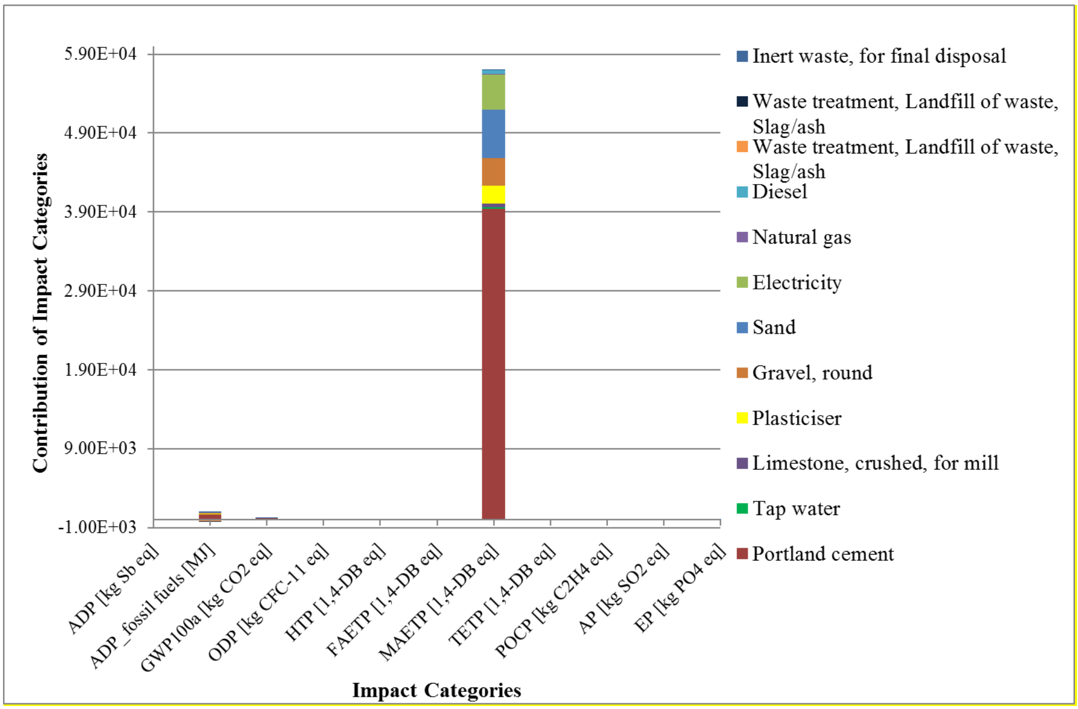


Figure 5.15. Characterization results of the Mixture-15 (Please see Table 4.12 for the definition of the impact categories)

As shown in Figure 5.15, Portland cement is one of the main contributors to all mid-point impact categories with percentage contributions changes in between 42.14% (for ADP) and 88.54% (for GWP). Following the Portland cement, sand has the second rank for the production of 1 m^3 Mixture-15. Gravel and admixture utilization have also significant impacts on mid-point impact categories as third and fourth rate. The highest impact was observed on the MAETP (3.08E-10) mid-point followed by HTP (1.26E-11) and FAETP (8.78E-12). The avoided products regarding disposal requirements for fly ash and silica fume have the negative contribution. Since the amount of fly ash is higher than the silica fume, negative contribution belonging to landfill of fly ash is higher than the silica fume.

5.1.1.13. Mixture-16

Portland cement, fly ash, GGBFS, fine aggregates, coarse aggregates, recycled aggregates, water and superplasticizer were used in the concrete Mixture-16 (Table 4.2) [100]. Compressive strength of the mixture at 28-days is 35 MPa and w/b ratio is 0.38. Replacement ratio for the natural coarse aggregate with the recycled aggregate is 25%. Similarly cement was replaced by both fly ash and GGBFS with 25% [100].

During performing the LCA run, additional process for the treatment of fly ash was not included, however, GGBFS processing were included since further processing is required for the blast furnace slag before used in concrete production. In addition, impacts regarding disposal of fly ash and GGBFS were considered as avoided product. Characterization results obtained for the Mixture-16 are given in Figure 5.16 and normalized impacts are given in APPENDIX B and APPENDIX D.

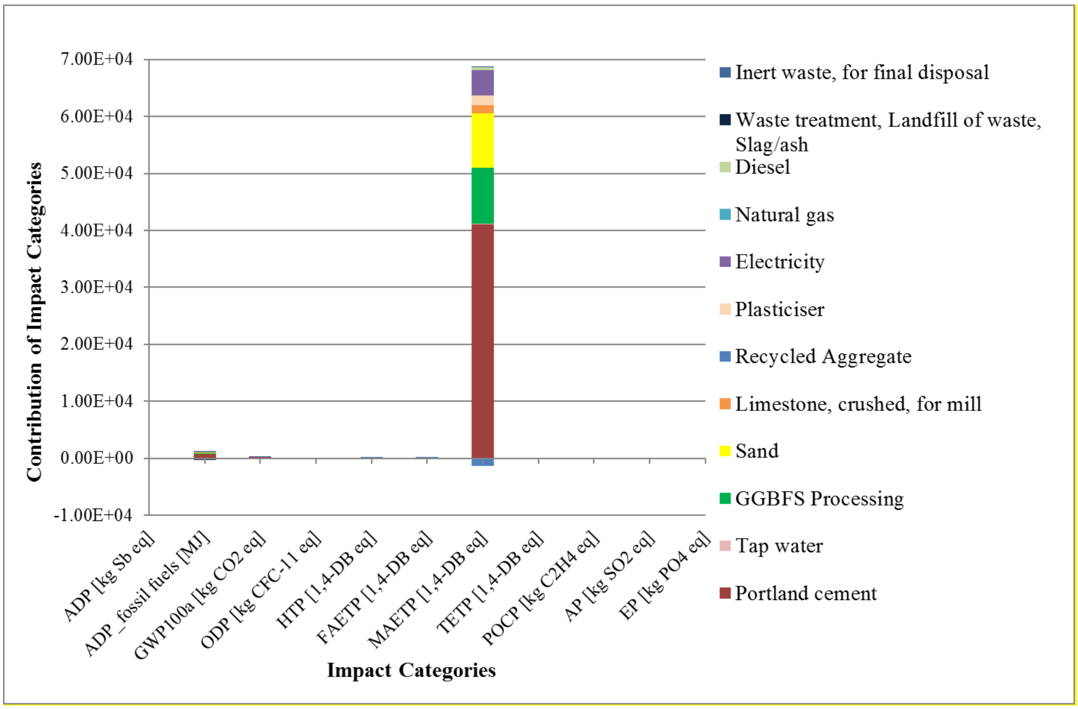


Figure 5.16. Characterization results of the Mixture-16 (Please see Table 4.12 for the definition of the impact categories)

Portland cement has the highest impact on each mid-point impact categories according to analysis results provided in Figure 5.16. The highest percentage impact contribution due to Portland cement is observed in the GWP (86.21%) impact category, whereas the least impact is occurred on the ADP (50.24%). Sand follows the Portland cement as the second most impact contributor product while GGBFS processing and plasticiser have the third and fourth rank, respectively. The total characterized environmental impact assessment results show negative contribution for the recycled aggregate and avoided landfill requirement for blast furnace slag and fly ash. As can be deduced from the Figure 5.16, 1 m^3 Mixture-16 production has the highest impact on MAETP (3.58E-10) in contrast to ODP (3.76E-14).

5.1.1.14. Mixture-17 and Mixture-18

Mixture-17 and Mixture-18 were made of Portland cement, water, superplasticizer, fine aggregates, coarse aggregates and recycled aggregates (Table 4.2) [101]. The only difference between Mixture-17 and Mixture-18 is the proportion of the recycled aggregate used in the 1m^3 concrete production. Mixture-17 consists of 100% recycled coarse aggregates, whereas Mixture-18 includes 25% recycled coarse aggregate. The 28-days compressive strength tested by cylinder specimens is 38.26 MPa and 38.79 MPa for the Mixture-17 and Mixture-18, respectively [101].

Environmental impacts obtained through the LCA run for the Mixture-17 and Mixture-18 are presented in Figure 5.17 and Figure 5.18, respectively. Further, normalized impacts are given in APPENDIX B and APPENDIX D.

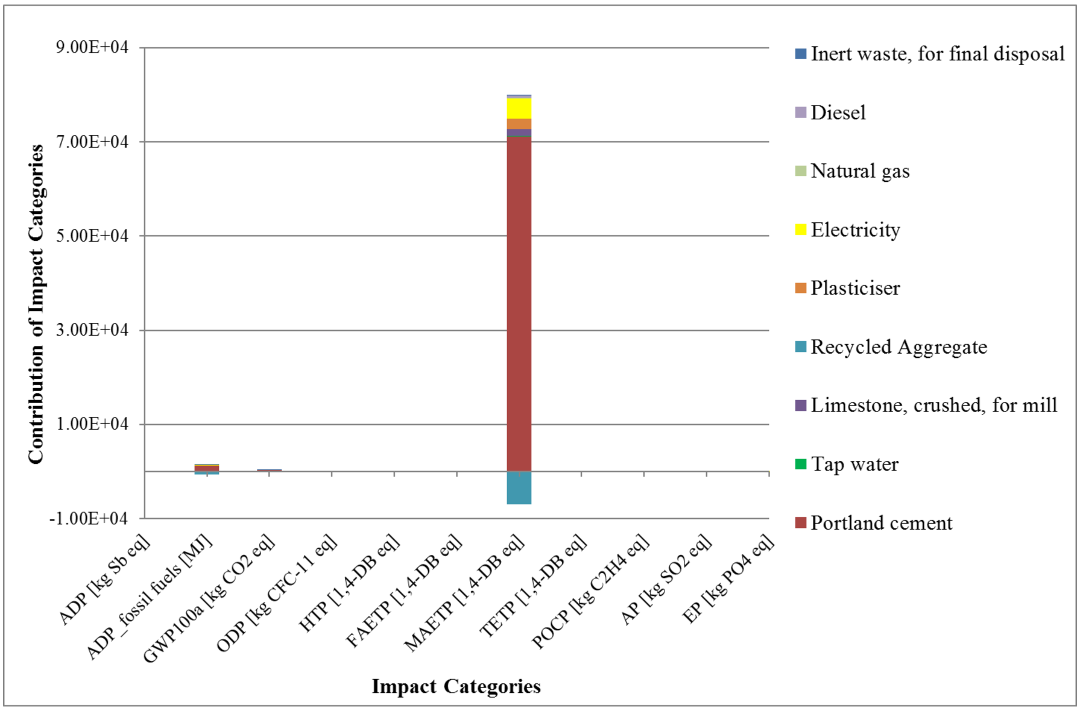


Figure 5.17. Characterization results of the Mixture-17 (Please see Table 4.12 for the definition of the impact categories)

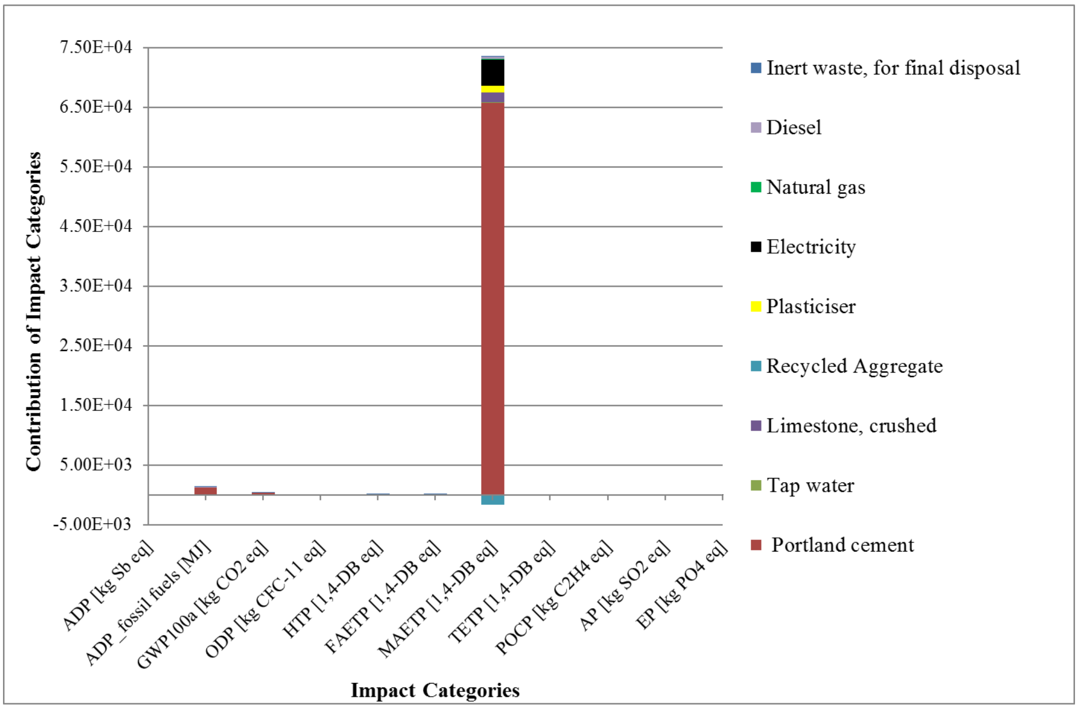


Figure 5.18. Characterization results of the Mixture-18 (Please see Table 4.12 for the definition of the impact categories)

As can be seen from Figure 5.17 and Figure 5.18, Portland cement is the main impact contributor to all mid-point impact categories for both 1 m^3 Mixture-17 and Mixture-18 production. Characterization results of the recycled aggregate have a negative sign for all impact categories, except FAETP. Although amount of utilized recycled aggregate is higher, LCIA results are slightly higher for Mixture-17 since the utilized Portland cement is higher than Mixture-18. As presented in APPENDIX D, production of the Mixture-17 and Mixture-18 has the highest impact on MAETP which is 3.89E-10 and 3.78E-10, respectively.

5.1.1.15. Mixture-19, Mixture-20 and Mixture-21

Mixture-19, Mixture-20 and Mixture-21 consist of Portland cement, water, superplasticizer, fine aggregates, coarse aggregates and recycled aggregates (Table 4.2) [102]. In addition to these materials, fly ash was utilized as 25% by mass addition of cement in the Mixture-20 and Mixture-21. The cube specimens having 10*10*10cm dimensions were used to determine the compressive strength of the concrete mixtures. According to the measurement results at 28 days, the compressive strengths of the Mixture-19, Mixture-20 and Mixture-21 are 45.3 MPa, 48.1 MPa and 45.3 MPa, respectively [102].

While performing the LCA run, additional process for the treatment of fly ash was not included and impacts regarding disposal of fly ash were considered as avoided product. Characterization results obtained for the Mixture-19, Mixture-20 and Mixture-21 are given in Figure 5.19, Figure 5.20 and Figure 5.21, respectively. In addition, normalized impacts are given in APPENDIX B and APPENDIX D.

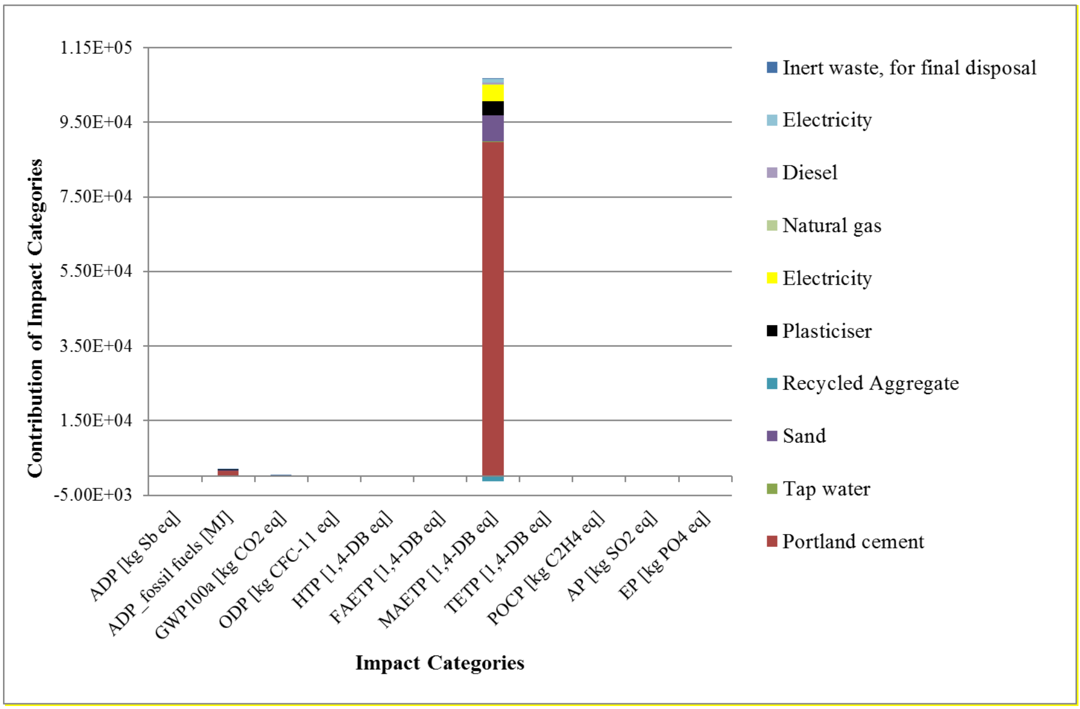


Figure 5.19. Characterization results of the Mixture-19 (Please see Table 4.12 for the definition of the impact categories)

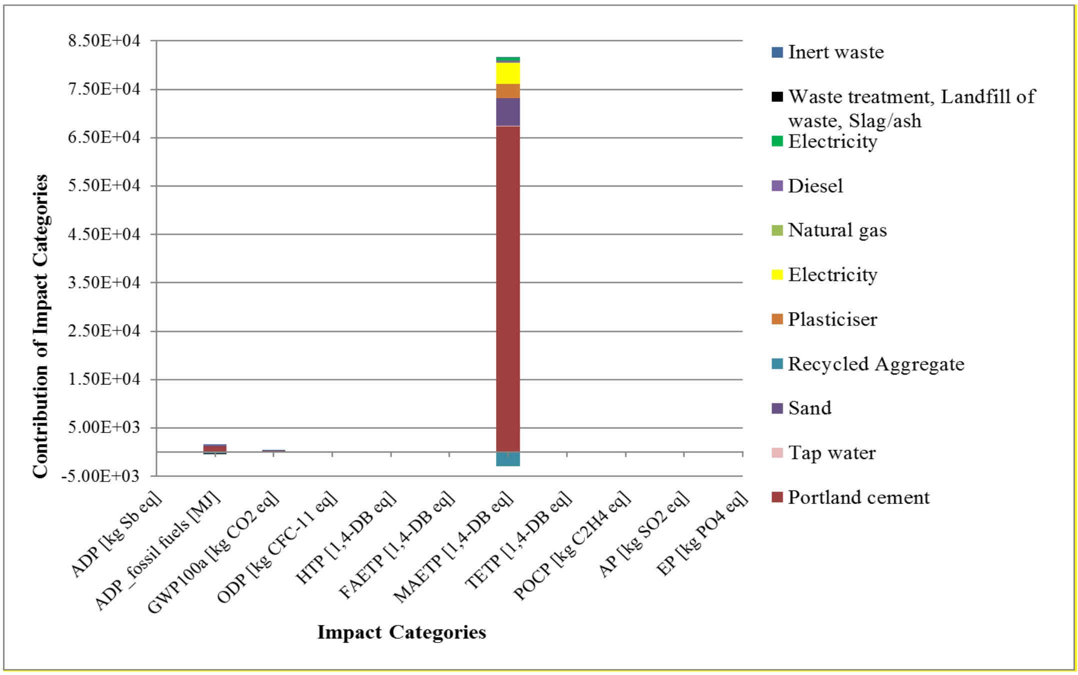


Figure 5.20. Characterization results of the Mixture-20 (Please see Table 4.12 for the definition of the impact categories)

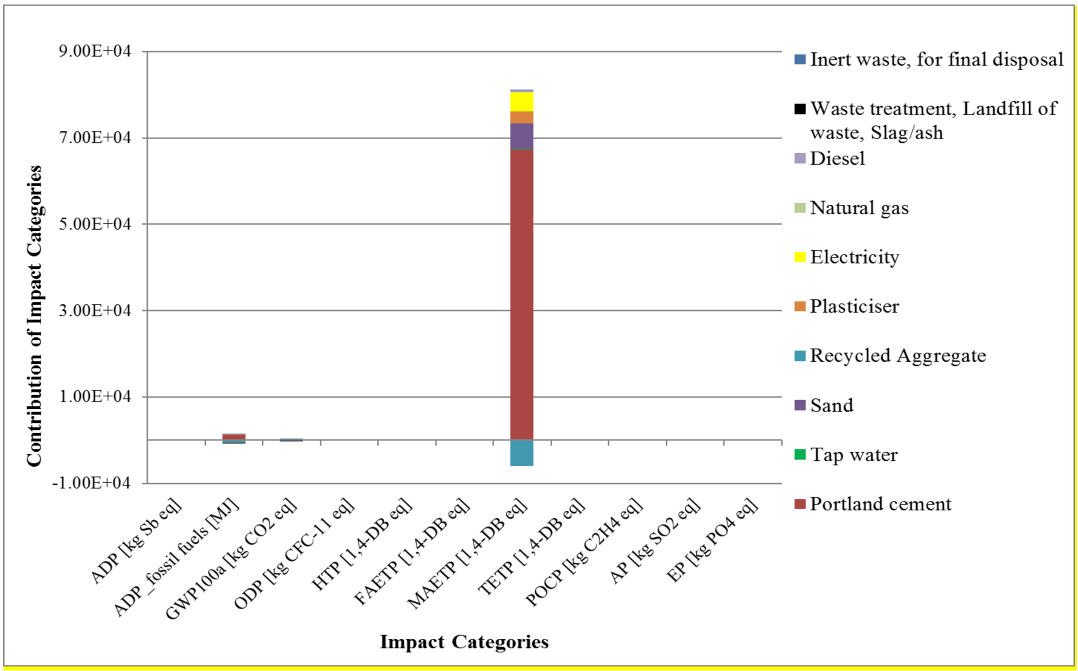


Figure 5.21. Characterization results of the Mixture-21 (Please see Table 4.12 for the definition of the impact categories)

For the production of 1 m^3 Mixture-19, Mixture-20 and Mixture-21, Portland cement is the main contributor to all mid-point impact categories. Sand and admixture utilization have the second and third rank as the impact contributor, respectively. For the Mixture-20 and Mixture-21, disposal requirement of the fly ash that was considered as avoided product shows negative results. In addition, recycled aggregate has negative results at the all mid-point impact categories, except FAETP. As can be seen in Figure 5.21, Mixture-21 has the minimum results at all impact category since the recycled aggregate amount used in the production of mixture is higher than the Mixture-19 and Mixture-20. Production of these three mixtures has the highest impact on MAETP, FAETP and HTP, whereas the least impacts are observed at the ODP, POCP and ADP.

5.1.2. Environmental Impacts of the Case Study Building

LCA results belonging to the Prokon-Ekon Headquarter Building are supposed to be provided soon in detail in the dissertation study being performed by Ms Aygenç. In the study, CML-1A baseline impact assessment method was also applied and only ADP (fossil fuel), GWP, ODP, POCP, AP and EP mid-point impact categories were examined. However, in this study, all mid-point impact categories are considered in the scope and additional disposal scenario was developed for the concrete. In the light of this adjustments, the results of case study building reanalysed. It should be keep in mind that this study focus on the cradle-to-grave LCA of the concrete production; therefore, impacts of other components included in the case study building LCA were categorized under main groups such as building materials, water use, energy consumption and transportation. Percentage impact contributions of the control mix, transportation, energy consumption, water consumption, other building materials and concrete disposal (both recycled and landfilled concrete) to the case study building are presented in Figure 5.22 in respect to all midpoint impact categories.

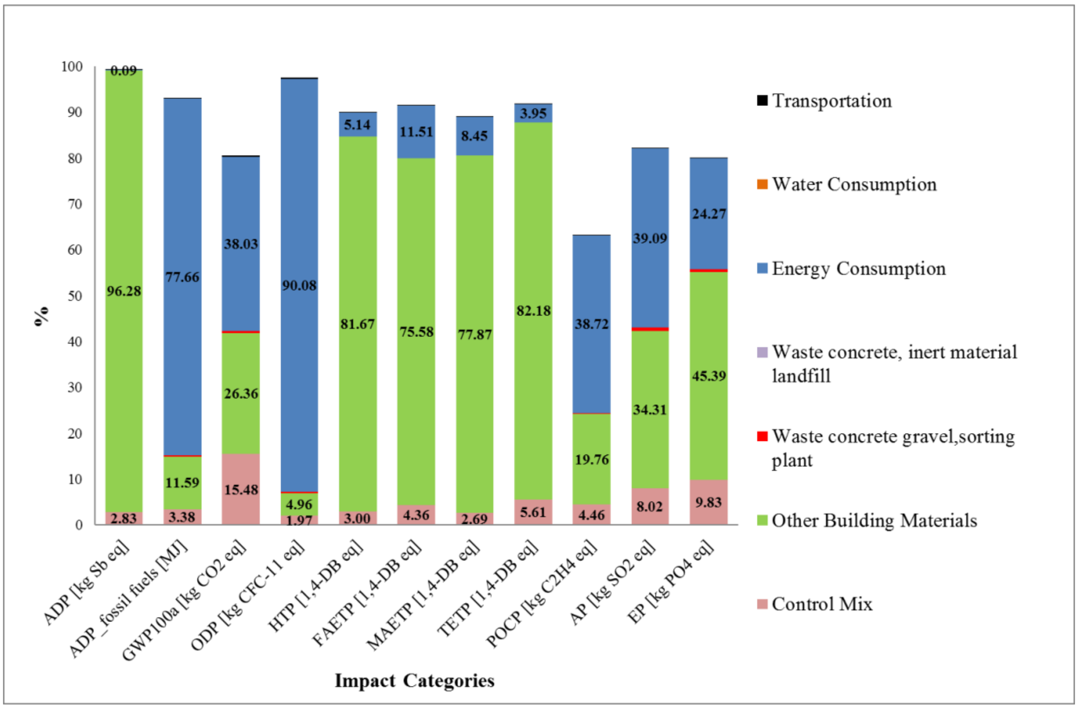


Figure 5.22. Characterization results of the case study building

As can be seen from Figure 5.22, control mix has considerable impacts on whole-life cycle of the case study building since building has several components such as natural gas consumption, steel, cladding, glazing and PV panel having significant impacts on mid-point impact categories. Highest percentage impact contribution originating from control mix is observed in the GWP (15.48%) impact category, and EP (9.83%) and AP (8.02%) have the second and third rank, respectively. On the other hand, least impact contribution is seen for the ODP, MAETP, HTP and ADP with 1.97%, 2.69%, 3.00% and 2.83%, respectively.

As can be understood from Figure 5.22, energy consumption causes the highest impacts on ADP (fossil fuels), GWP, ODP, POCP and AP impact categories with 77.66 %, 38.03%, 90.08%, 38.72% and 39.09% percentage contribution, respectively.

Water consumption, transportation and disposal of concrete have minor impacts on whole-life cycle of the case study building. As pointed out in Figure 5.22, concrete landfilling process has no impact on any impact category since infrastructure is excluded while analysing the impacts.

For the case study building and the building scenarios that were applied different concrete mixtures, characterization results in terms of mass contributions and normalization results are provided in APPENDIX E and APPENDIX F.

In the discussion part (Sec 5.2), results belonging to buildings that include different concrete mixtures are provided and evaluated.

5.2. Discussion

5.2.1. Comparison of the Concrete Mixtures Regarding Environmental Impacts

The subject concrete mixtures which consist of variable components in different amounts have been compared for each other in accordance with the impact categories included in the scope of CML-1A baseline methodology and discussions have been made according to these comparison graphs. The comparison graphs have been created by taking into consideration the characterization results (i.e. mass contribution to each impact categories) of the concrete mixtures.

As can be pointed out from the characterization (see APPENDIX A and APPENDIX C) and normalization results (see APPENDIX B and APPENDIX D) belonging to the concrete mixtures, MAETP is the prevailing impact category among others. These results are compatible with the literature LCA studies that apply CML baseline impact assessment method. As stated in an article written by Prado et al. [114], MAETP impact category has the highest share for the studies conducted for different industries including concrete manufacturing. Therefore, in several studies this impact category was excluded as it dominates the others. The reason behind this situation is CML-1A baseline method itself independently of the used normalization practices such as EU25 and World 2000,as also stated by Prado et al. [114]. For this reason, MAETP was excluded from the scope of discussion part for both concrete production and case study building scenarios.

The characterization results of the LCA studies carried out for different concrete mixtures are presented in between Figure 5.23 and Figure 5.32 for each mid-point impact category.

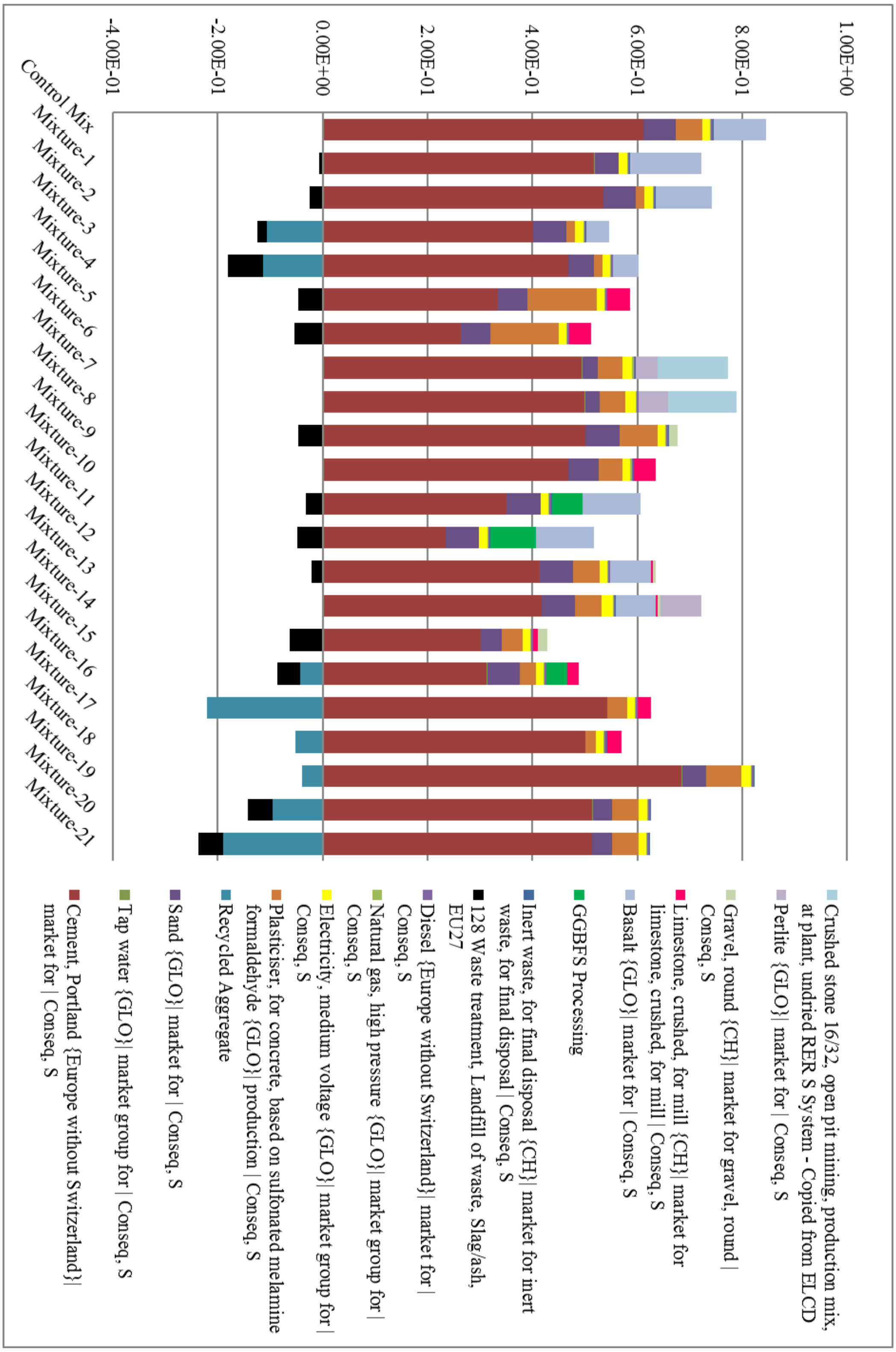


Figure 5.23. Characterization results of 1 m^3 concrete mixtures for AP [kg SO_2 eq]

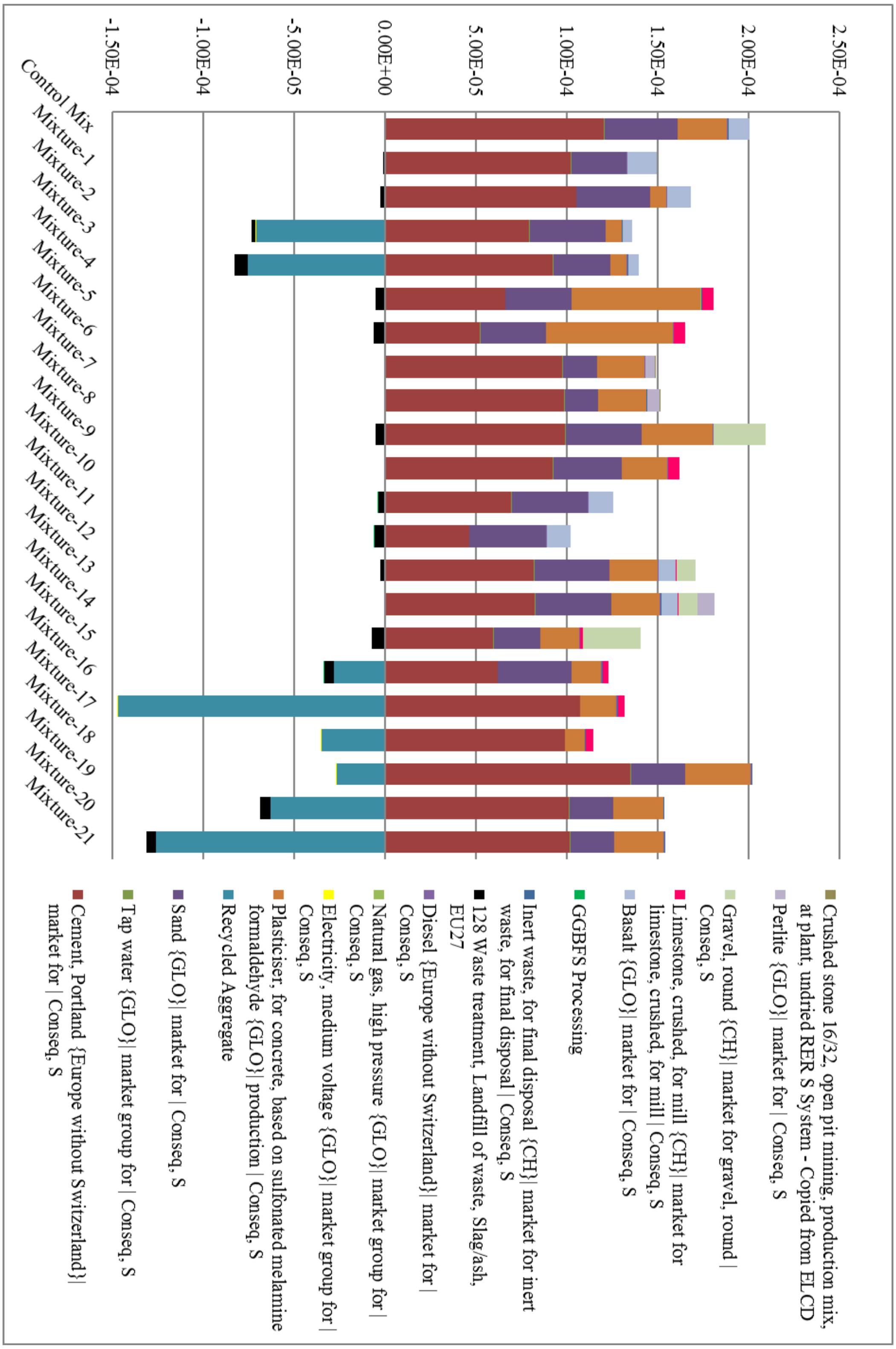


Figure 5.24. Characterization results of 1 m^3 concrete mixtures for ADP [kg Sb eq]

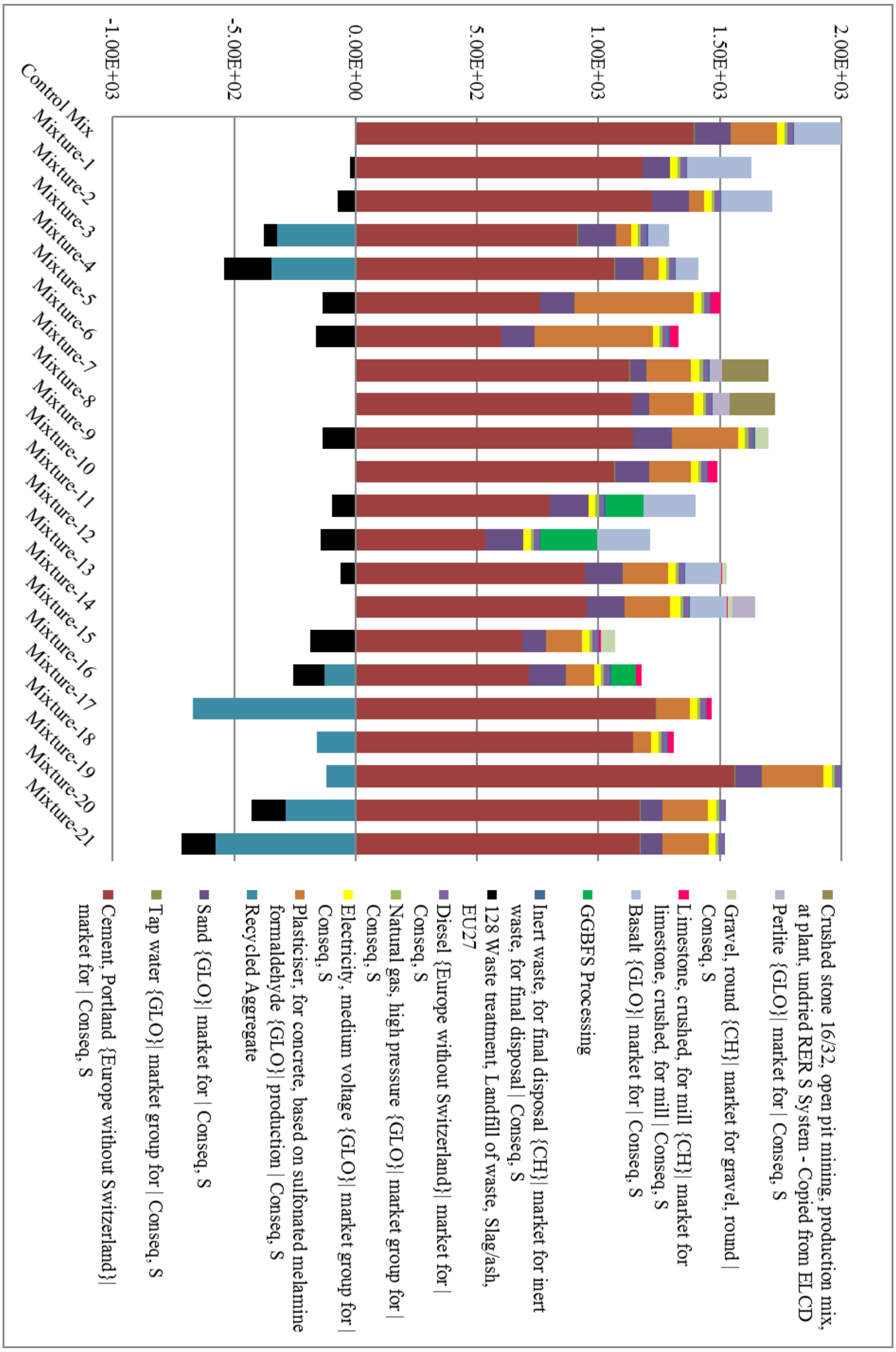


Figure 5.25. Characterization results of 1 m^3 concrete mixtures for ADP (Fossil Fuel) [MJ]

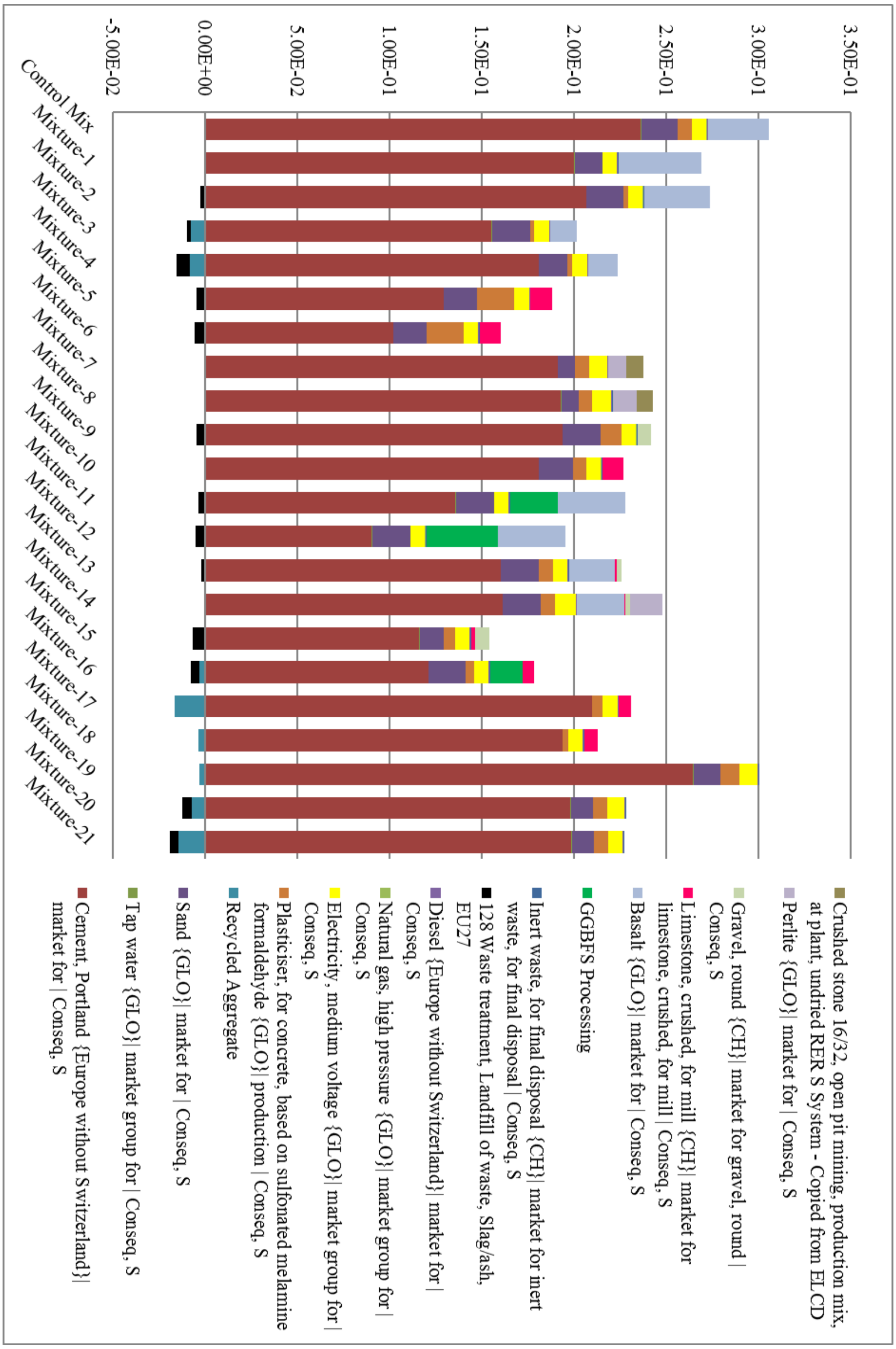


Figure 5.26. Characterization results of 1 m^3 concrete mixtures for EP [kg PO_4 eq]

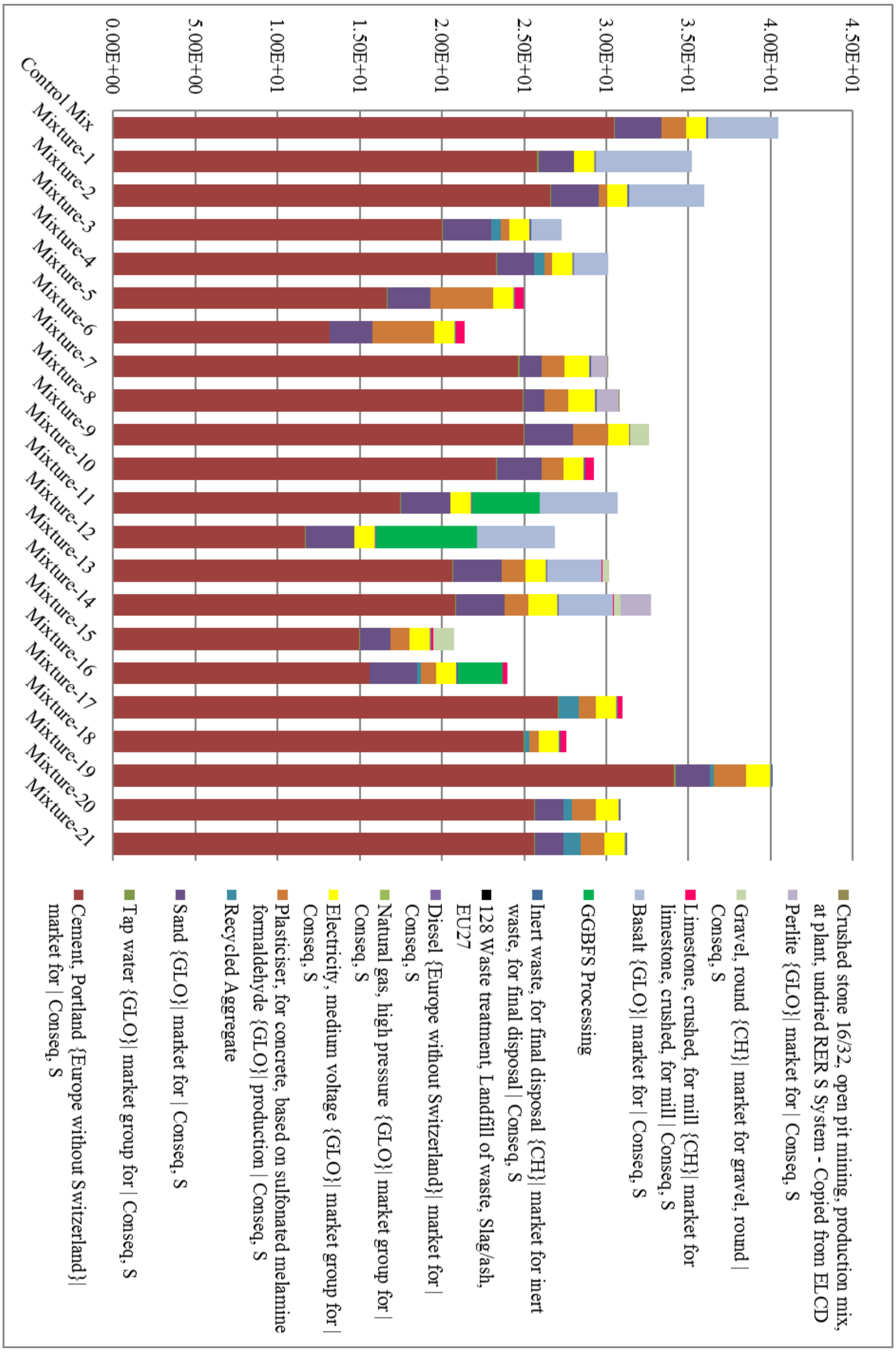


Figure 5.27. Characterization results of 1 m^3 concrete mixtures for FAETP [1,4-DB eq]

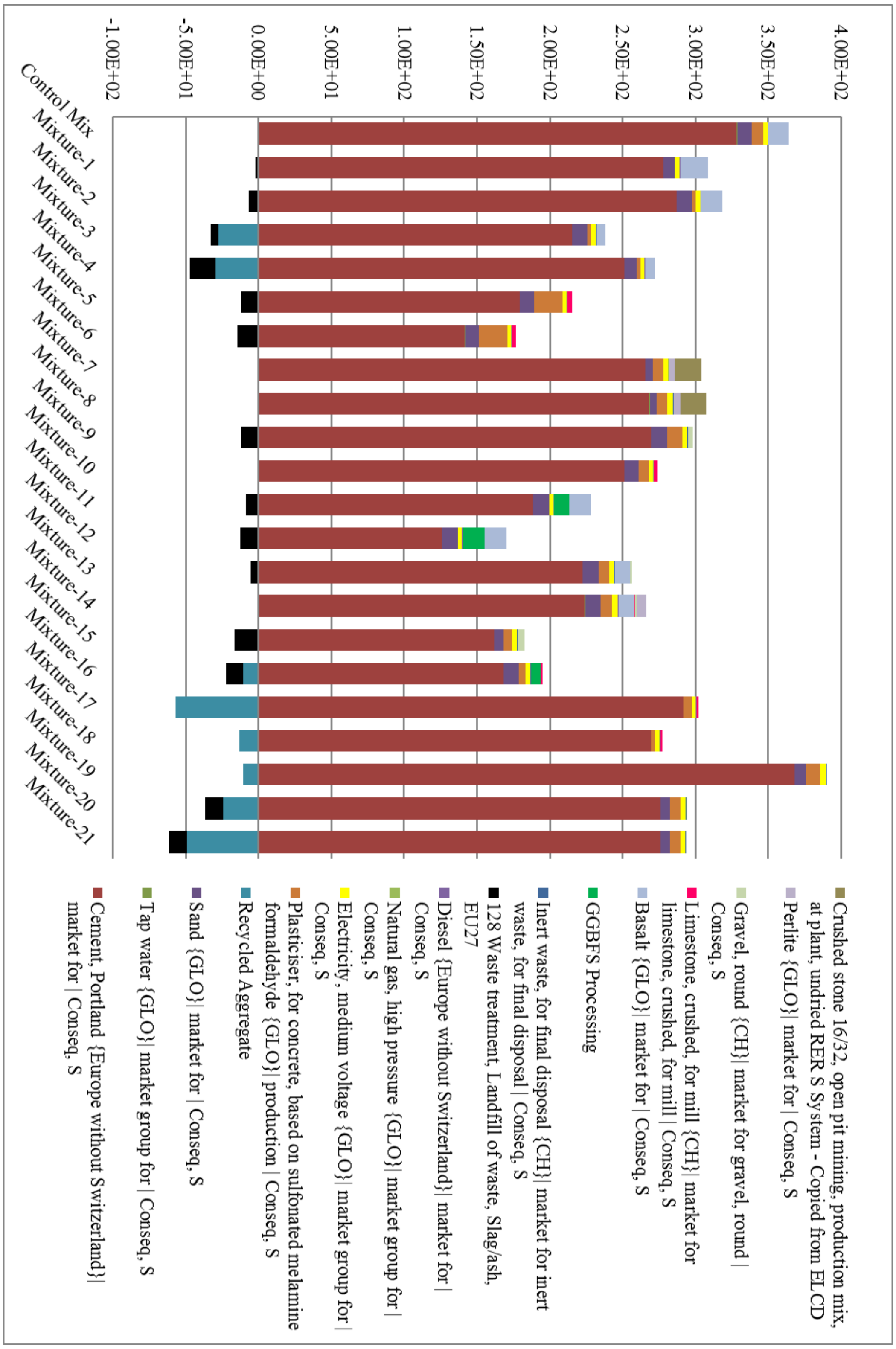


Figure 5.28. Characterization results of 1 m^3 concrete mixtures for GWP [kg CO^2 eq]

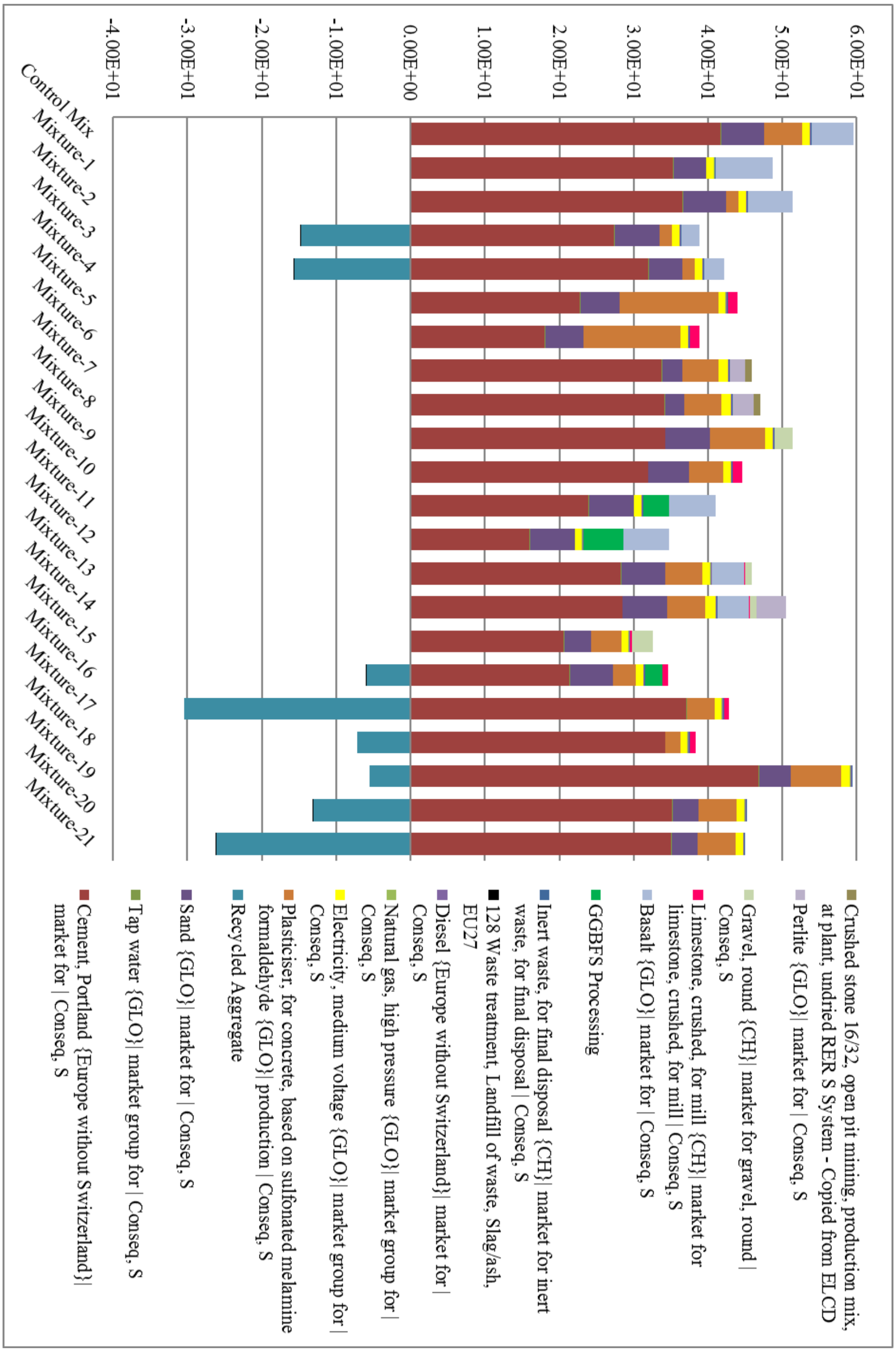


Figure 5.29. Characterization results of 1 m^3 concrete mixtures for HTP [1,4-DB eq]

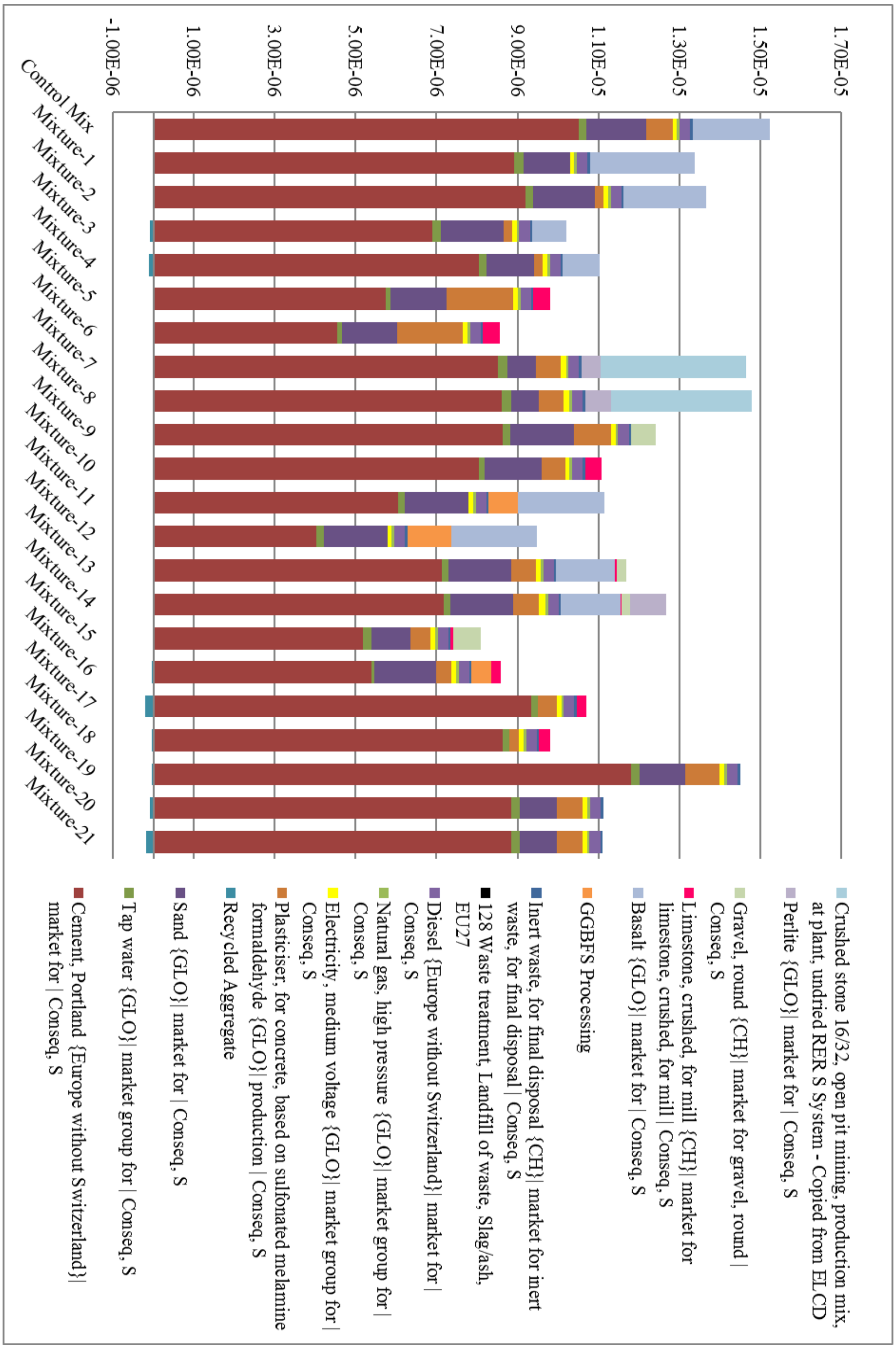


Figure 5.30. Characterization results of 1 m^3 concrete mixtures for ODP [kg CFC-11 eq]

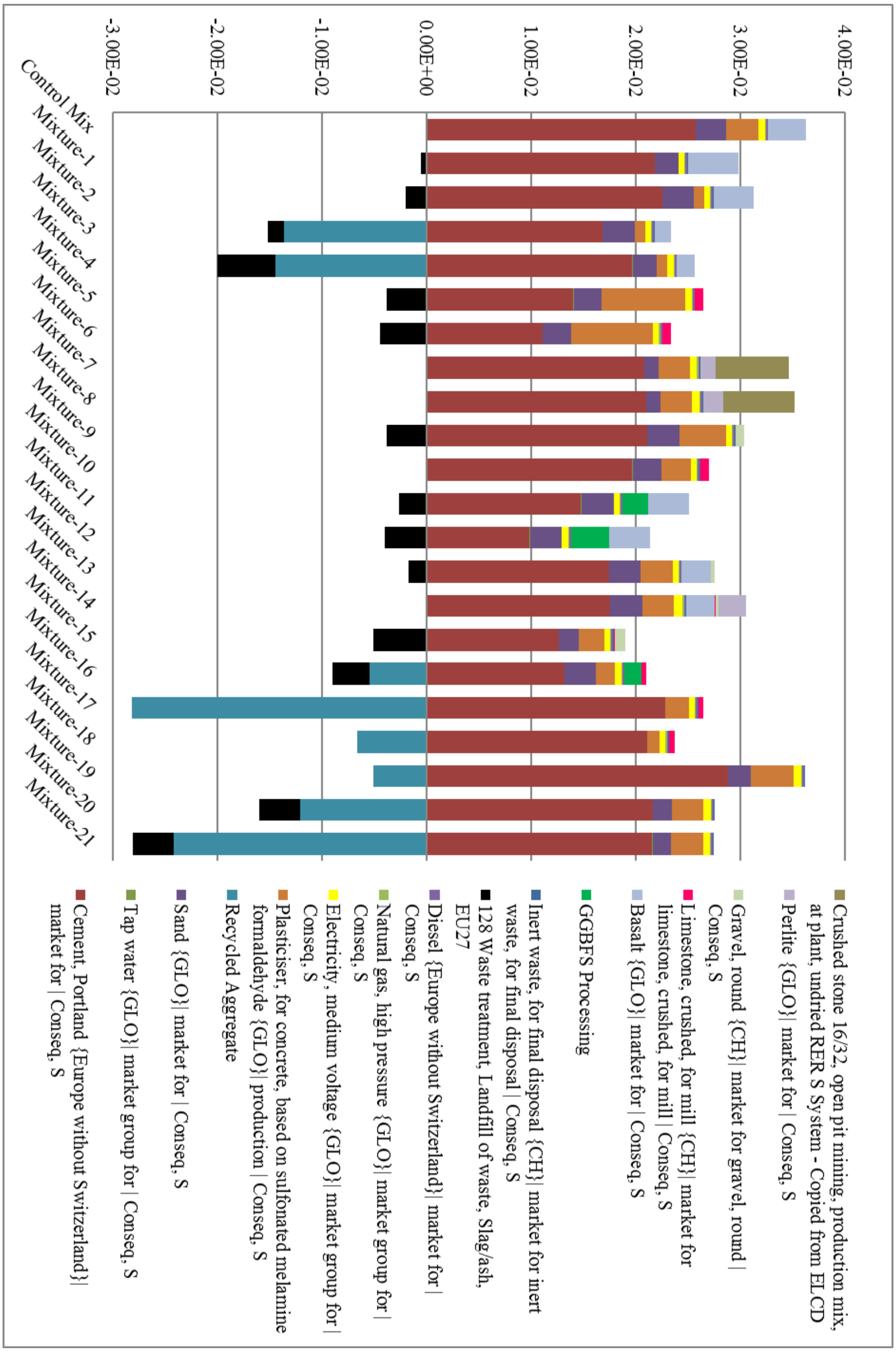


Figure 5.31. Characterization results of 1 m^3 concrete mixtures for POCP [kg C_2H_4 eq]

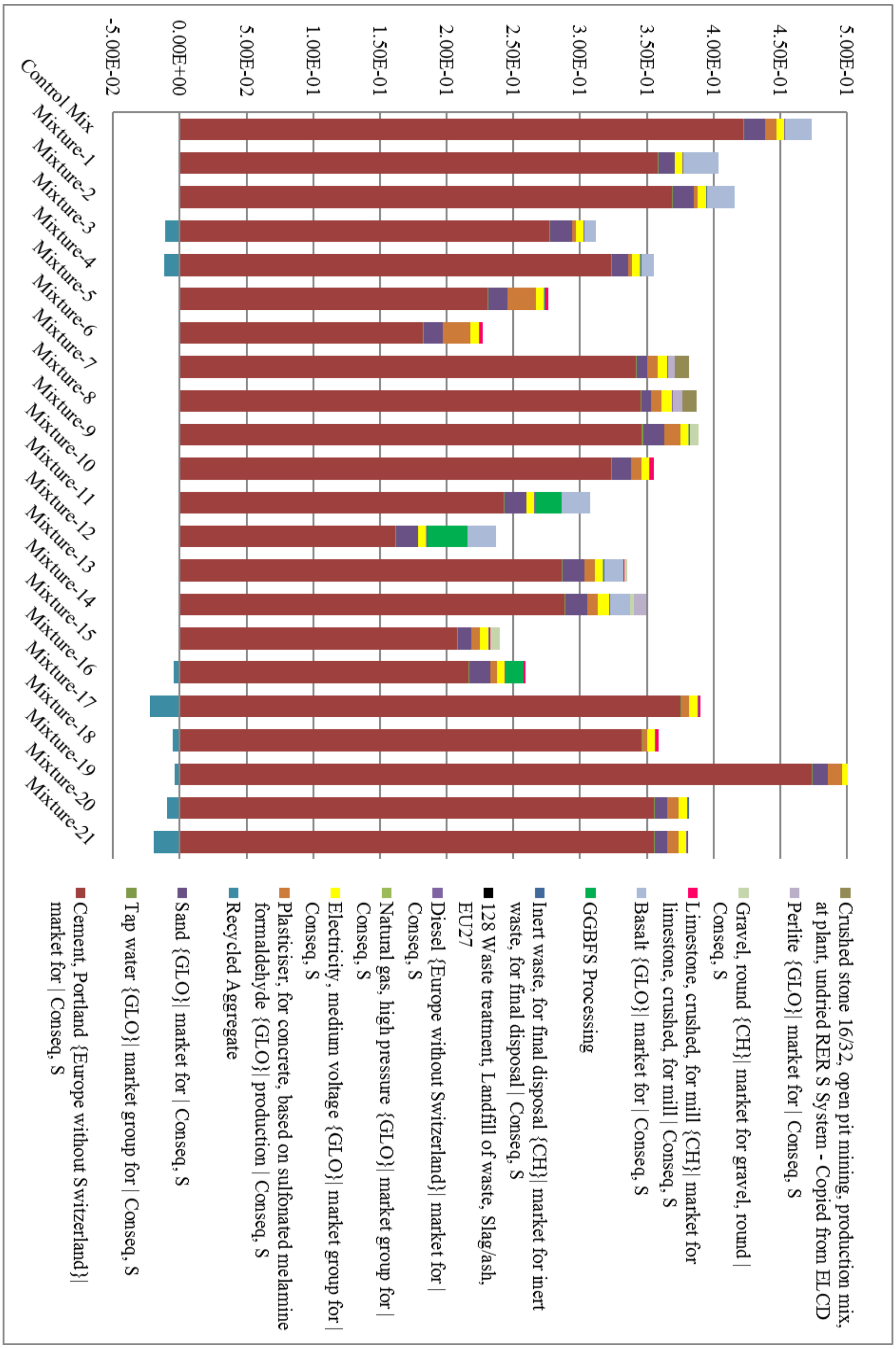


Figure 5.32. Characterization results of 1 m^3 concrete mixtures for TETP [1,4-DB eq]

From the comparison graphics given in between Figure 5.23 and Figure 5.32 and normalization results given in APPENDIX B, it can be clearly concluded that Portland cement is the main contributor to each mid-point impact category for all control concrete mix and concrete mixtures. The highest percentage contribution of the Portland cement is seen in the GWP impact category (> 90%). As pointed out in Section 2, cement production is responsible for 6% - 10% of global GHG emission and about 800 kg of CO_2 is emitted to produce one-ton cement. Therefore, these results are reasonable, and compatible with the literature studies. Schepper et al. [54] revealed in the LCA study conducted for 1 kg cement production by using CML baseline method that clinker production is the main reason for these high amount of CO_2 emission. They attributed this to the fact that decarbonisation processes and fuel combustion emit high amount of CO_2 during the clinker production. Remaining mid-point impact categories are also dominated by Portland cement. As stated by Schepper et al. [54], high amount of fossil fuel utilization and emissions due to quarrying and burning of raw materials in the clinker production are the main contributors to all mid-point impact categories. Furthermore, besides the clinker production, operating of cement plant causes the impacts on HTP, TETP, FAETP and EP due to electricity consumption and utilization of several substances such as lubricating oil, diesel and heavy metals [54].

Recycled aggregate has significant advantages since it has negative values at all mid-point impact categories, except FAETP. Recycled aggregate production, which was introduced into the SimaPro manually, has avoided environmental burdens and products such as wood chips, steel, land-derived material and landfilling of inert wastes. As can be seen in Figure 5.23, Figure 5.25, Figure 5.28, Figure 5.29, Figure 5.31, the significant environmental advantages are gained at the AP, ADP (fossil fuels), GWP, HTP and POCP. The LCA study performed by Estanqueiro [115] clearly states that avoidance of the landfill requirements while producing recycled aggregate enable to reduce the impact on human toxicity. According to the characterization and normalization results of the recycled aggregate production obtained from SimaPro, the significant negative values observed at the ADP (fossil fuels), GWP, AP and POCP mid-points are mainly due to avoided inert material landfill and avoided steel production since these processes require high amount of energy and fossil fuels utilization. The impact contribution of the recycled aggregate production is relatively high for the FAETP and TETP impact categories. This situation is explained in the LCA study, which is conducted by Rosado et al. [69] to assess the environmental impacts of recycled aggregate production made from CDW, as the transportation requirement for the recycled aggregates from suppliers to the consumer is the main reason behind these impacts.

Environmental impacts of natural aggregates such as sand, gravel, basalt, crushed stone and crushed limestone are limited although they have second and/or third rank after Portland cement as impact contributor. According to the characterization results, basalt, sand and crushed stone have the highest impact share in contrast with gravel and crushed limestone depending on the used amount. As can be seen from the characterization results natural aggregate production affects mainly on ADP, ODP, HTP, POCP, AP and EP mid-points impact categories. In the production of natural aggregate CO, NO_x, SO_x, CH_4, CO_2, N_2O, NMVOC and particulates are emitted into the atmosphere [8]. Therefore, impacts on these above mentioned categories seem reasonable. Kim et al. [116], clearly stated that natural aggregate production has an impact on AP due to the SO_2, H_2SO_4 and NO_3 emissions arising from logging and blasting phases. In addition, NH_3, NH_4, PO_4 and NO_x emissions from extraction and crushing processes have an impact on EP. In the same study [116], utilization of natural resources, coal and lubricating oil in the natural aggregate production were cited as the reason for the impacts on ADP. Respiratory organics such as $PM_{2.5}$, NO_x, NH_3 and SO_2 are emitted during blasting processes in the production of natural aggregate [69]. Therefore, impacts on HTP might be related with these pollutants.

According to the characterization results presented in between Figure 5.23 and Figure 5.32, avoided landfill requirement for cementitious materials has negative value for the ADP, GWP, AP, EP, HTP, POCP whereas the impact is zero for the TETP, FAETP and ODP mid-point impact categories. In the LCA study apply system expansion model, Knoeri et al [10] stated that avoided disposal requirement for the fillers such as fly ash reduce the impacts on carcinogens significantly. Therefore, this situation could explain the reduction in POCP and HTP mid-point impact category. Highest percentage impact reduction is observed in the POCP mid-point impact category as can be seen from the characterization results. This gain seems reasonable since waste degradation in landfill cause to CH_4, CO and VOC emissions that contribute high amount of C_2H_4 equivalent [117]. As explained in the recycled aggregate case, the avoided landfill requirement reduces the energy consumption and GHG released from landfill, hence the impacts on GWP and ADP could reduce.

Environmental impacts of admixtures such as plasticisers and superplasticisers are rarely considered in many LCA studies of concrete production and their environmental impacts are generally excluded from the scope since the amount of admixtures utilized in the concrete is very low (i.e. < 1% by binder mass) [53]. However, it was revealed that plasticisers have considerable impact contributions even though not as much as Portland cement. As can be seen from the above mentioned comparison graphs, highest impacts arising from admixture utilization is observed in the Mixture-5 and Mixture-6 as they include the highest admixture amount (4% by binder mass). According to the characterization results of these concrete mixtures, the percentage contribution of plasticiser reaches up to 39.20% for ADP and 10.87% for GWP. However, these amounts are 9.17% and 1.04%, respectively for the Mixture-18 having least admixture amount. Therefore, the amount used is important indicator to assess the environmental impacts of admixtures. In the LCA study conducted by Ozcelik et al. [118], it was concluded that admixtures can significantly increase the fuel consumption even used in small amount and the percentage contribution of the admixtures on ADP (fossil fuel) was found in between 8.7% and 15.3%, for different designated concrete mixtures. As presented in Figure 5.27 and Figure 5.29, impacts on FAETP and HTP are also considerable. According to the cradle-to-gate LCA study performed by EFCA [74], hazardous waste, non-hazardous waste and radioactive waste are the output flows for the production phase. Therefore, these generated wastes might be the reason behind the impacts on HTP and FAETP.

Correspond to the several LCA studies, the impacts of electricity, natural gas and diesel used for the operations of ready mixed concrete plant are very limited since used amounts are less than the energy consumption utilized in the production of materials used in concrete manufacturing such as Portland cement, aggregate and admixtures [53] [54]. To a very small extend, water utilized in concrete production and solid waste from ready mixed concrete plant have also contribution on impact categories. Even if the contribution of concrete batching plant operations, water utilization and solid waste are very limited according to the other materials, considering these components in the scope of LCA is very important to understand the whole environmental and ecological burdens of concrete production, especially while applying these concrete mixtures on case study building LCA.

Schepper et al. [54] conducted a cradle-to-cradle LCA study to quantify environmental impacts of two different completely recyclable concrete mixtures including fly ash and limestone filler. In addition, as stated in the article, impact assessment was accomplished via CML-1A baseline methodology and SimaPro was used as LCA software. The characterization results belonging to the study are presented in Figure 5.33. Considering the outputs of the LCA study conducted for different concrete mixtures comprising supplementary cementitious materials, it was pointed out that the results of this research are compatible with the literature. As can be seen from the figure, the highest impacts resulting from the 1 m^3 concrete manufacturing are observed in the MAETP mid-point impact category. In addition, Portland cement is the main impact contributor for each impact category especially for GWP, ADP, EP, AP, HTP and TETP. As in this research, the impacts based on admixture and aggregate utilization, and operation of ready mixed concrete plant are very remarkable even to a smaller extent.

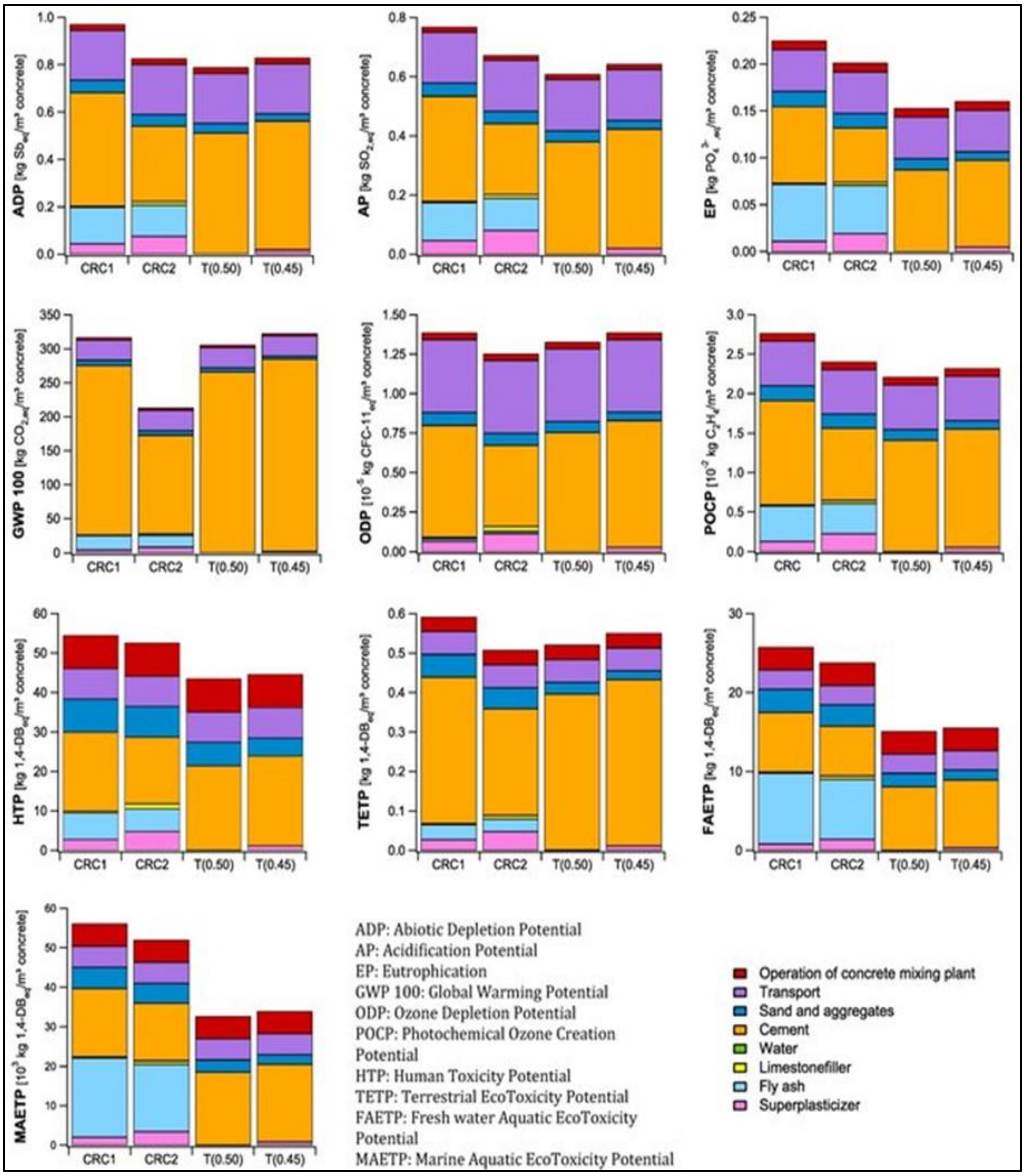


Figure 5.33. Characterization results of 1 m³ concrete mixtures for the study conducted by Schepper et al. [54]

Total normalization results of each concrete mixture are presented together in Figure 5.34 in terms of each mid-point impact category and given in a tabular form in APPENDIX D. According to the normalization results for concrete mixtures, highest impact on ADP (fossil fuels), GWP and TETP are originated from Mixture-19. The reason for these highest impacts is the Portland cement since the highest amount (410 kg) is used in Mixture-19. In addition, Mixture-19 does not include supplementary cementitious materials and amount used recycled aggregate is limited hence, avoided environmental burdens are not enough to reduce the impacts. On the contrary, the least impact on GWP is observed for Mixture-12 in which the utilized Portland cement amount (140 kg) is the lowest due to the use of cementitious materials. Among green concrete mixtures, Mixture-8 has the highest impact on ODP, POCP and AP because perlite is used in the mixture. As discussed above, natural materials cause impacts on these mid-point impact categories since processes such as extraction and blasting are required in the production. The highest amount of supplementary cementitious material is used in the Mixture-15, therefore, lowest impact on ODP, FAETP, AP and EP is observed for Mixture-15. Moreover, coarse aggregate replacement ratio with the recycled aggregate is 100% for the Mixture-17, thus, Mixture-17 contributes lowest impact on ADP, ADP (fossil fuel), HTP and POCP.

In comparison with the control concrete mix, it was concluded that approximately 58.45% impact reduction on GWP category might be achieved by producing Mixture-12. In addition, according to the control concrete mix, 45.32%, 48.17%, 53.57% and 50.42% less impact can be gained through using Mixture-15 for ODP, FAETP, AP and EP mid-point impact categories, respectively. Finally, environmental impacts could be reduced by 108%, 58%, 77% and 105% for the ADP, ADP (fossil fuel), HTP and POCP impact categories, respectively by using Mixture-17 instead of control concrete mix.

In considering total normalization results for concrete mixtures, it is concluded that control concrete mix contributes highest impacts. Moreover, Mixture-19 has the highest impact among green concrete mixtures whereas Mixture-17 has the least. Therefore, recycled aggregate has considerable environmental credits for concrete manufacturing. Apart from this, utilization of supplementary cementitious materials has significant environmental advantages since the amount used Portland cement is reduced and disposal of industrial by-products are avoided in this way

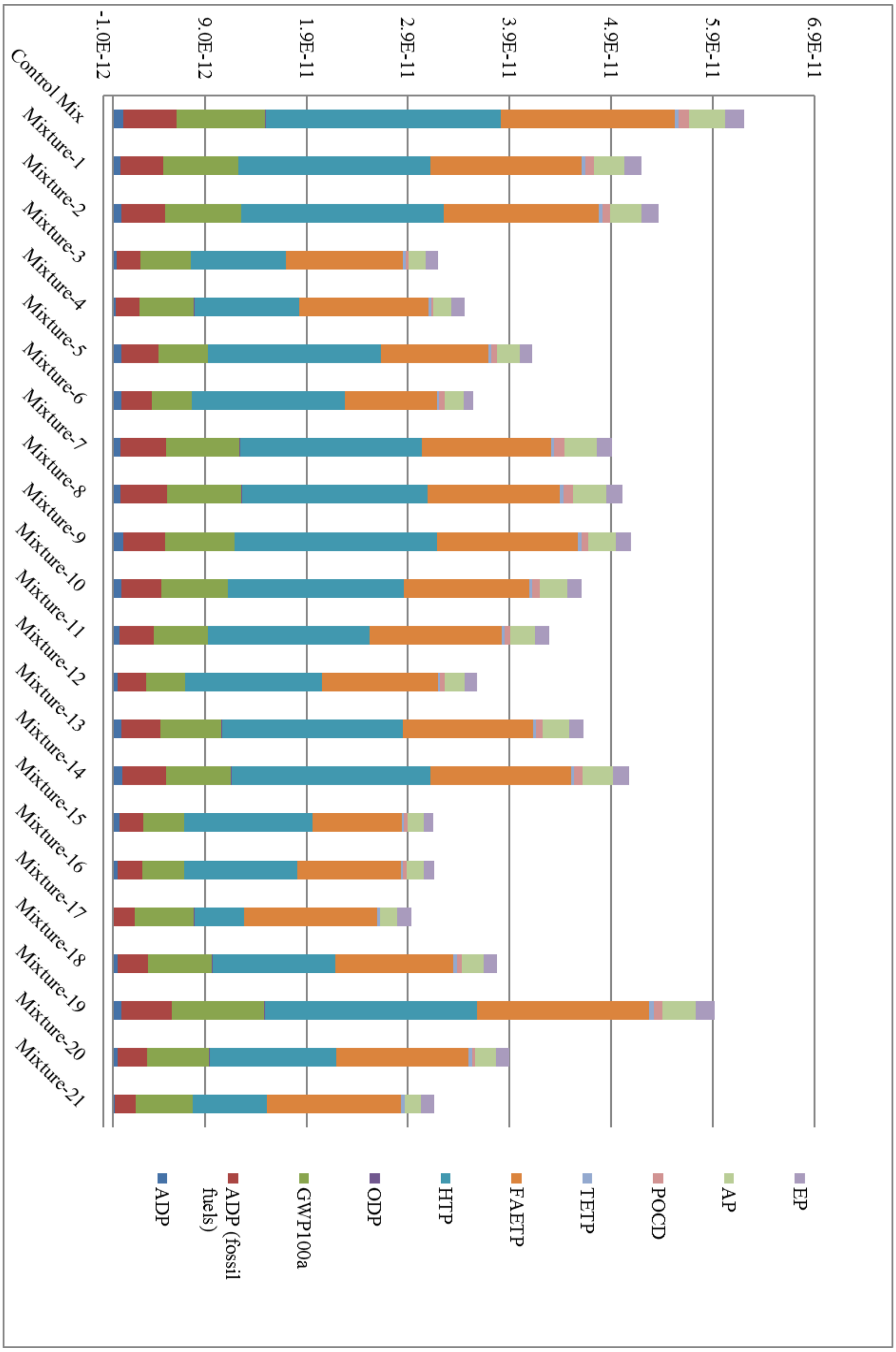


Figure 5.34. Total of normalization results for control mix and concrete mixtures

5.2.2. Comparison of Building Scenarios Including Different Concrete Mixtures

LCA results of the actual case study building, which is Prokon-Ekon Headquarter Building, are compared with different building scenarios that include control concrete mix and concrete mixtures designated in the scope of this study. The comparison is performed according to the characterization results per each impact category as can be seen in between Figure 5.35 and Figure 5.44. Total of characterization and normalization results belonging to actual case study building including control concrete mix and green concrete mixtures are presented in the tabular form in APPENDIX E and APPENDIX F, respectively.

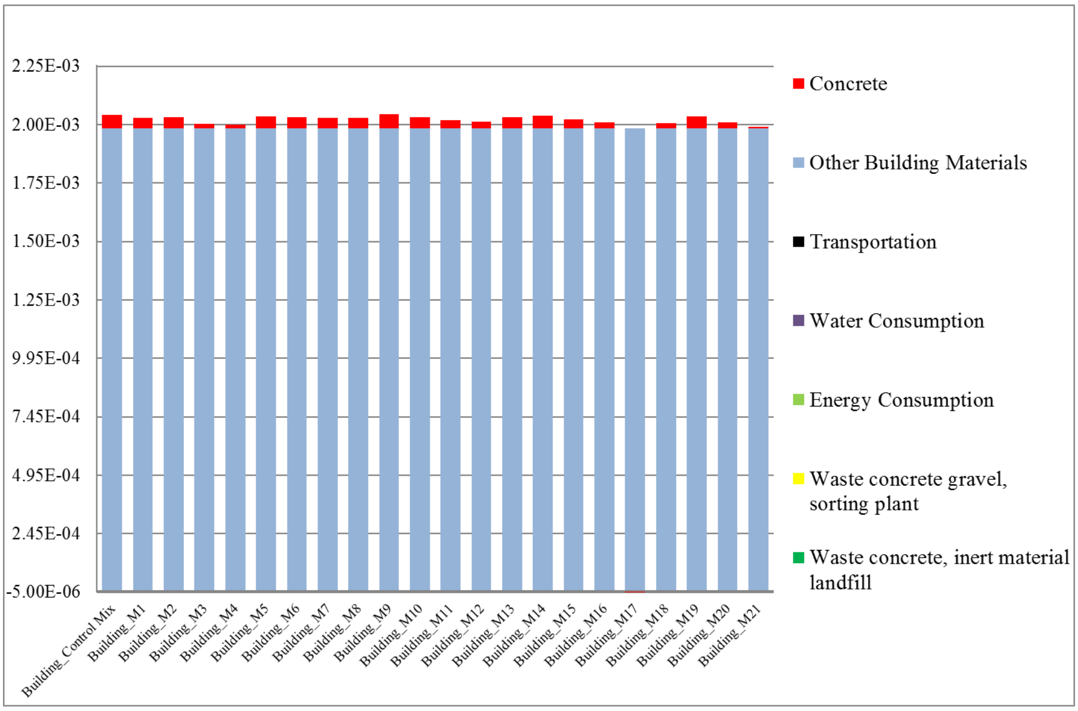


Figure 5.35. Characterization results of different building scenario for ADP [kg Sb eq]

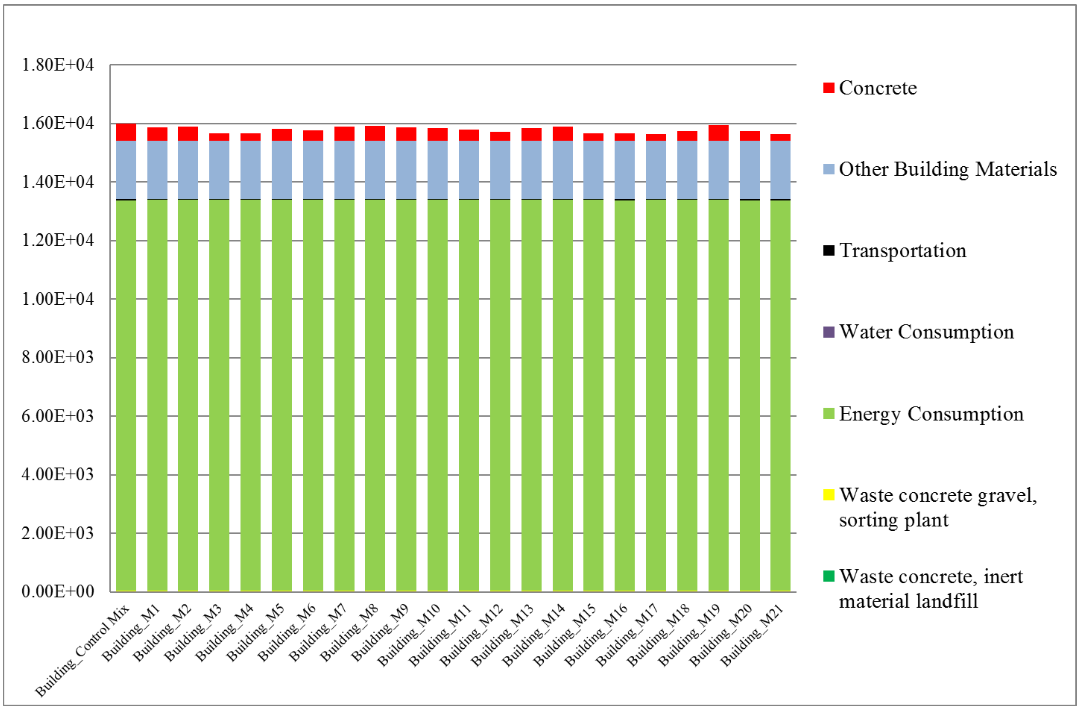


Figure 5.36. Characterization results of different building scenario for ADP (fossil fuel) [MJ]

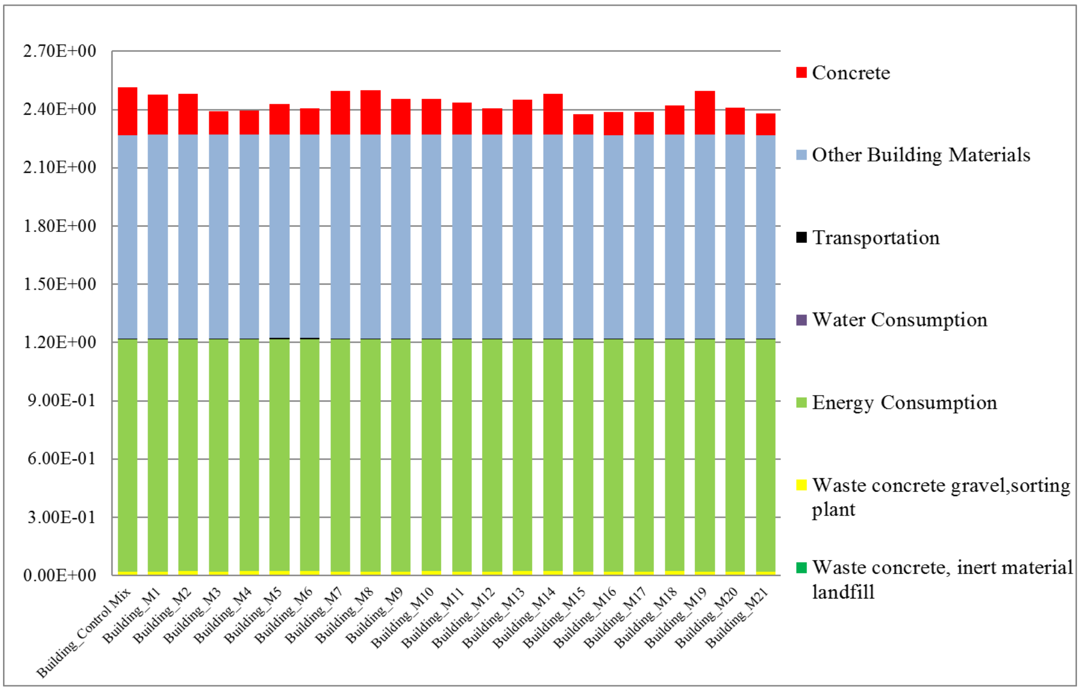


Figure 5.37. Characterization results of different building scenario for AP [kg SO2 eq]

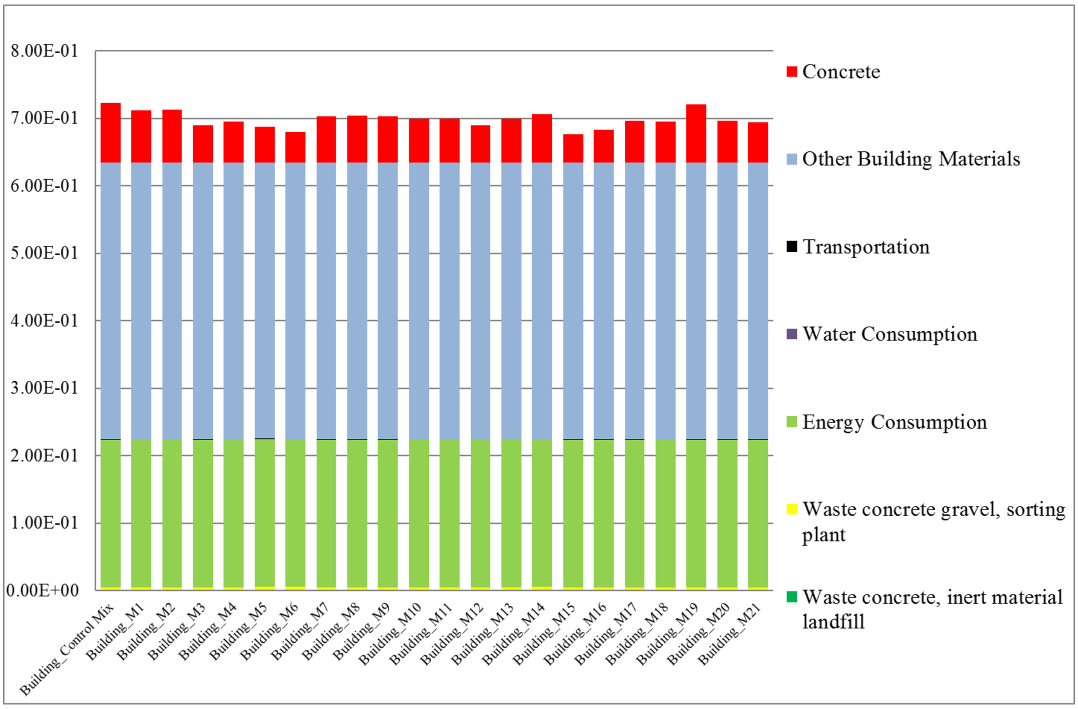


Figure 5.38. Characterization results of different building scenario for EP [kg PO4 eq]

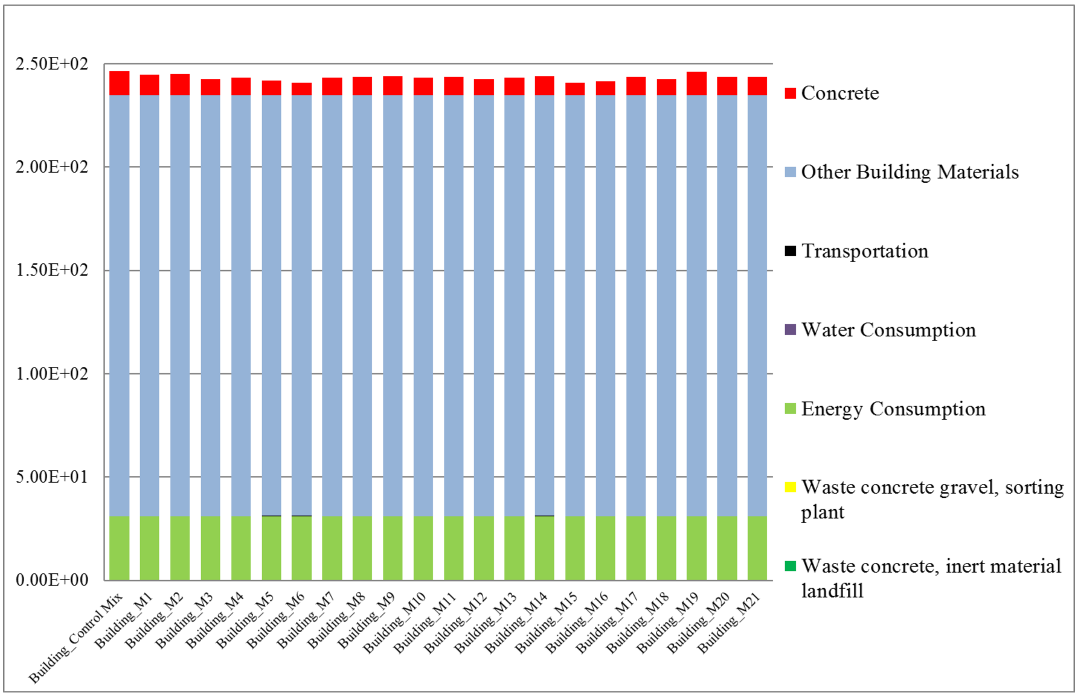


Figure 5.39. Characterization results of different building scenario for FAETP [1,4-DB eq]

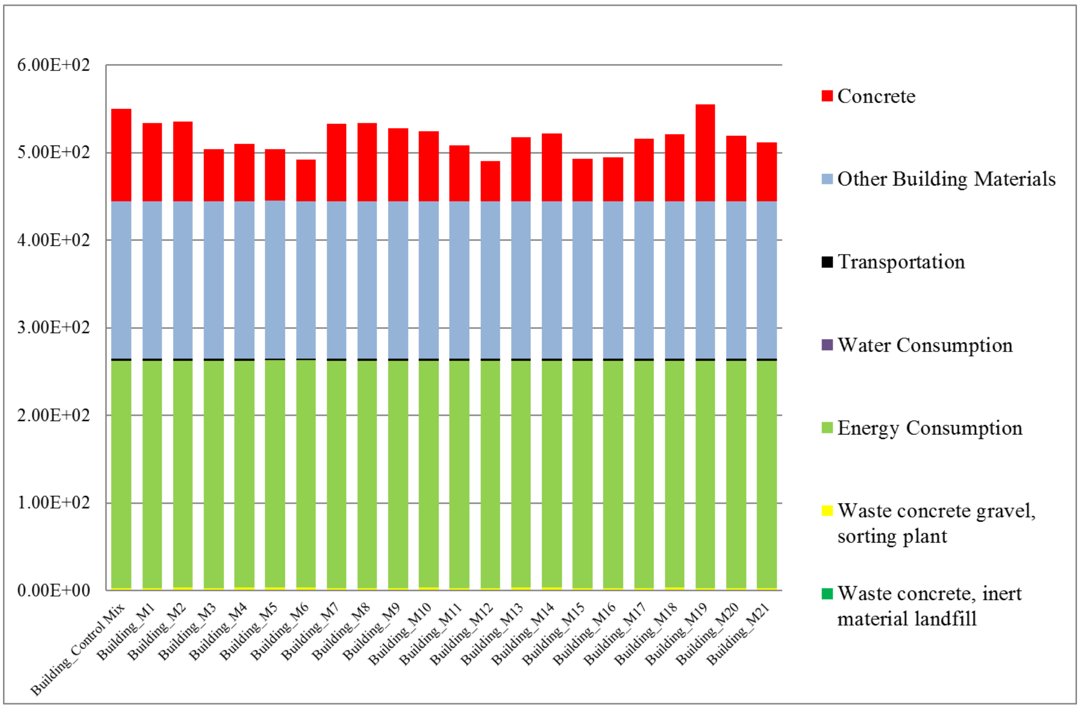


Figure 5.40. Characterization results of different building scenario for GWP [kg CO_2 eq]

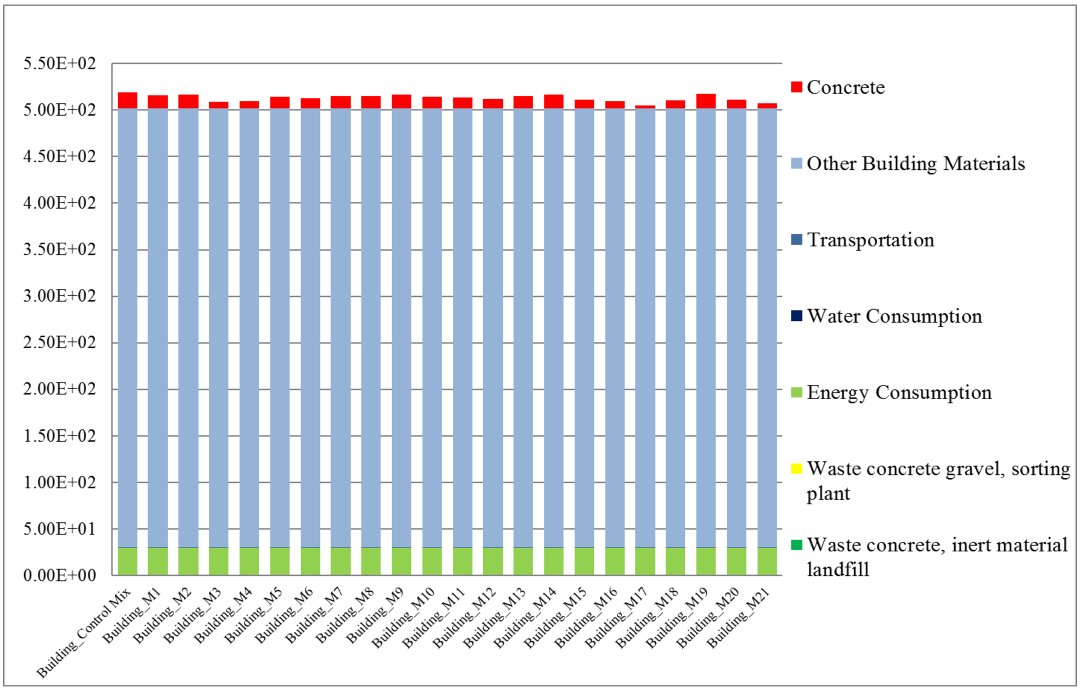


Figure 5.41. Characterization results of different building scenario for HTP [1,4-DB eq]

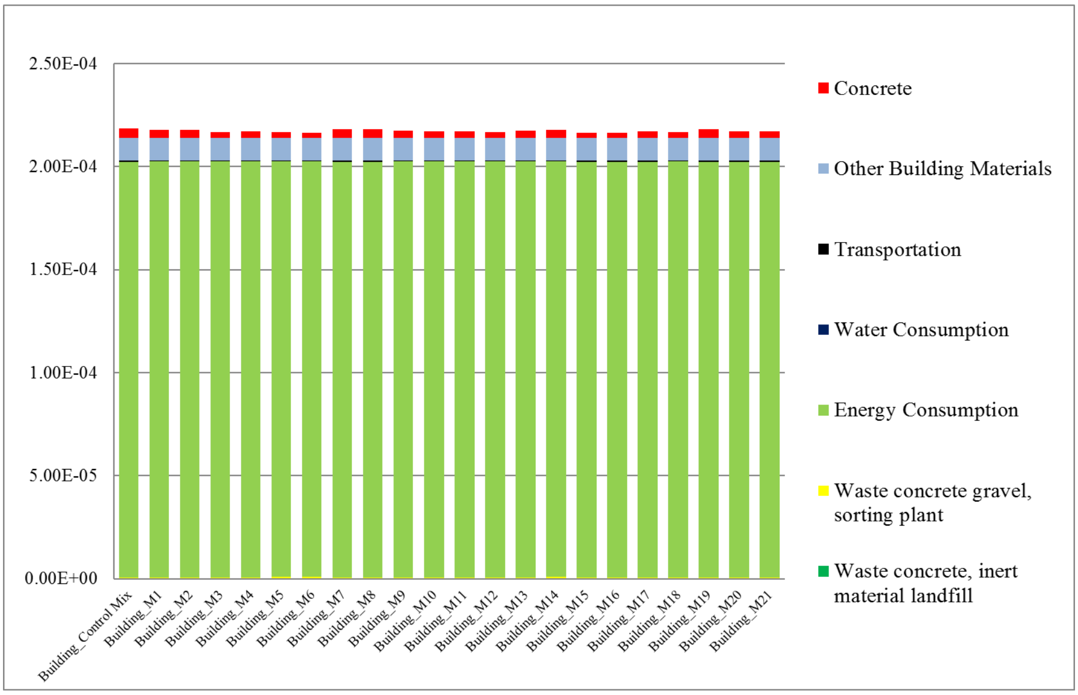


Figure 5.42. Characterization results of different building scenario for ODP [kg CFC-11 eq]

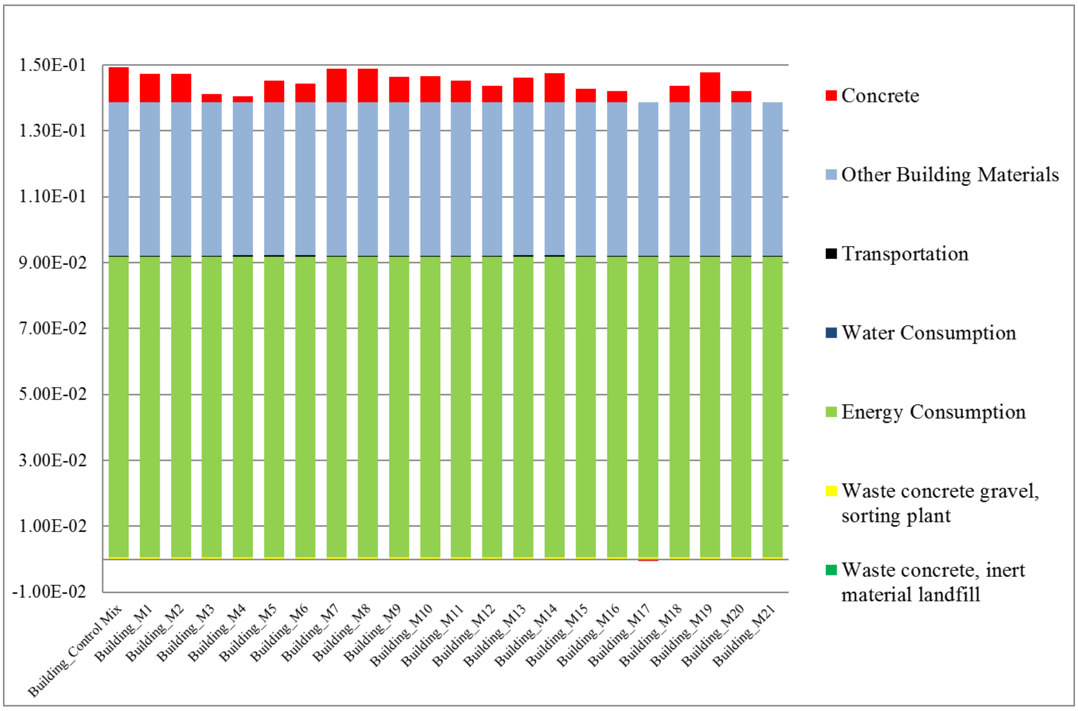


Figure 5.43. Characterization results of different building scenario for POCP [kg C_2H_4 eq]

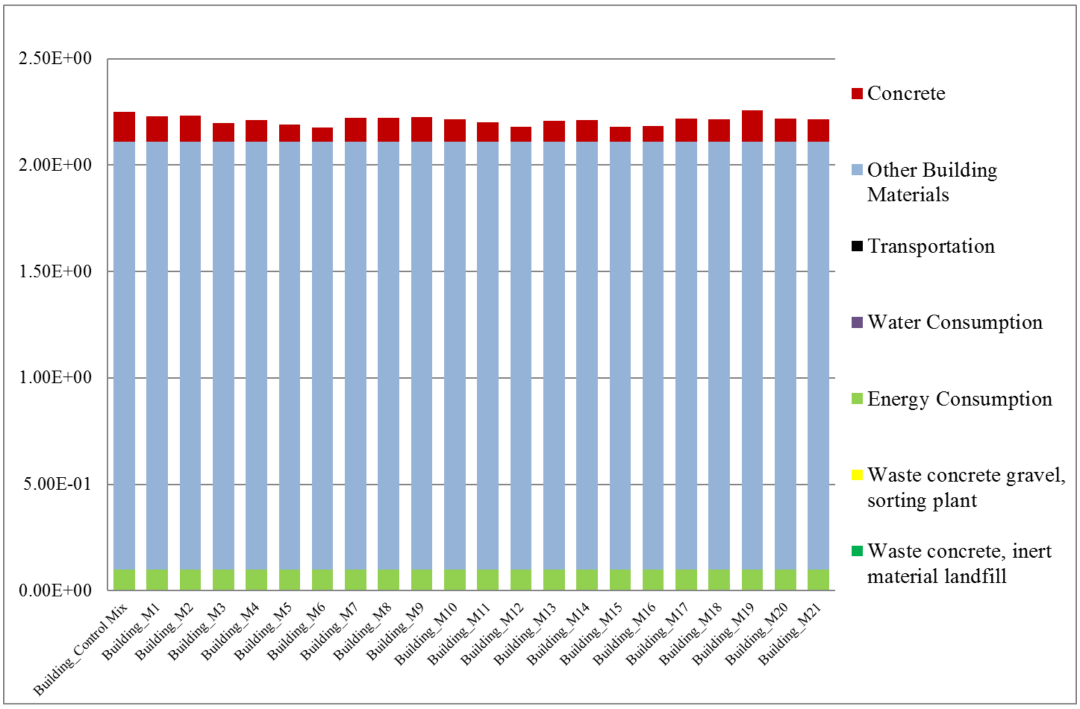


Figure 5.44. Characterization results of different building scenario for TETP [1,4-DB eq]

From aforecited comparison graphs, it is clearly seen that there are significant impact changes in the ADP, ADP (fossil fuel), AP, EP, GWP, HTP and POCP mid-point impact categories regarding LCA results for different building scenarios. Except building scenario with Mixture-19 (Building_M19), overall impacts of case study building includes control mix are reduced by using green concrete mixtures (see APPENDIX E and APPENDIX F). Total of GWP and TETP results are higher for Building_M19 than Building_Control Mix since utilized Portland cement is very high in the Mixture-19 as discussed in Section 5.2.1. Highest percentage impact contribution arising from concrete production is observed in GWP (15,48%) impact category for Building_Control Mix. Therefore, environmental gain for this category is important. As stated in the discussion part for the concrete mixtures (Sec 5.1.1), Mixture-12 has the lowest impact on GWP impact category among other concrete mixtures. As it can be seen from the characterization and normalization results, utilization of Mixture-12 reduces the impacts on GWP by 8.13% in total. Since Mixture-17 has the lowest impact on ADP, ADP (fossil fuel), HTP and POCP mid-point impact categories, most impact benefits are achieved from these impact categories by using Mixture-17. The overall impacts on ADP, ADP (fossil fuel), HTP and POCP are decreased by 3.05%, 2.00%, 2.36% and 4.68% in comparison with Bulding_Control Mix. Finally, highest environmental benefit is achieved at the AP and EP impact categories by using Mixture-15 as expected and the reduction rates are 4.38% and 4.84%, respectively. By considering the actual building is certified green building and it is predominantly steel construction, the impact reductions at these levels are very considerable and indicate the importance of concrete utilization in building sector.

Disposal of the concrete after demolition has very minor impact on each category since the amount is small in comparison with the other building components. In addition, results for the concrete waste landfilling are zero because infrastructure was excluded from the scope while analysing in the SimaPro.

Total normalization results of case study building with control concrete mix and different green concrete mixtures are presented together in Figure 5.45 in terms of each mid-point impact category and given in a tabular form in the APPENDIX F. According to the normalization results, Bulding_Control Mix has the highest impact among other building scenarios whereas, the least impact is observed for the Building_M15. This result is very interesting since the least impact was achieved for Mixture-17 in the cradle-to-gate study. However, in the application of concrete mixtures into the case study building life cycle model and considering use and disposal phases for concrete mixtures, this situation has changed. The reason for this is probably the disposal scenario. From the normalization results it was noticed that the impacts resulting from Mixture-17 production is lower than Mixture-15, however, total impacts including concrete disposal are higher for Mixture-17. In the disposal scenario mass of concretes were considered while calculating the amount of to be landfilled and recycled concrete and Mixture-17 (2298,085 kg) is slightly heavier than Mixture-15 (2268,80 kg). Therefore, this slight difference occurred in the building cases are considerable. In addition, it was concluded that disposal might be important in the whole-life cycle of concrete manufacturing even it has very few impacts.

It should be keep in mind that MAETP mid-point impact category was leaved out of the scope for both concrete production and building scenarios even if the results are provided in the appendices.

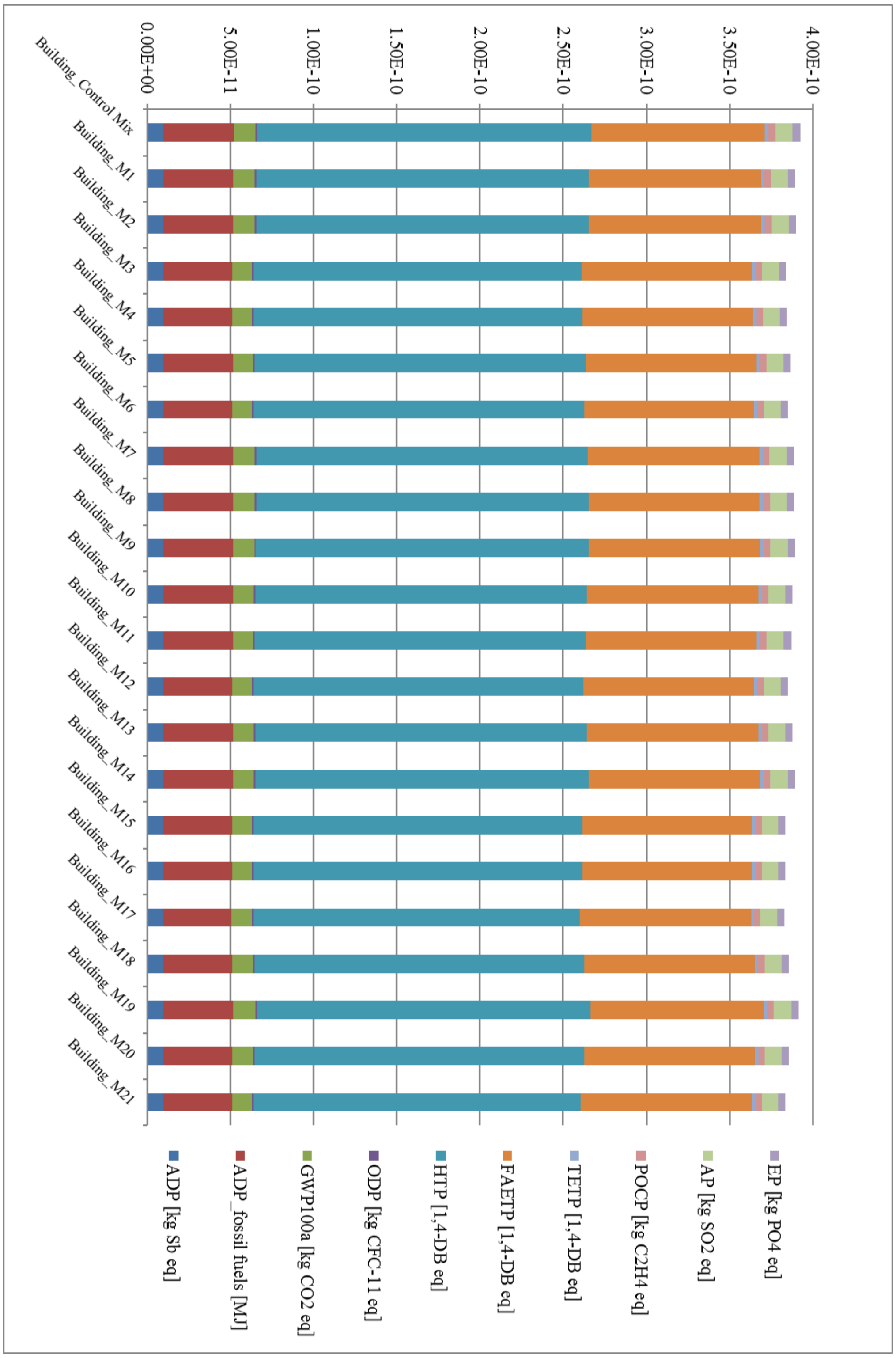


Figure 5.45. Total of normalization results for actual case study building and different building scenarios

In the current version of LEED, it is possible to gain extra points through LCA by achieving impact reduction in baseline building life cycle and optimizing environmental performance of building materials. In order to achieve this target, there are four options, namely, historic building use (5 points), renovation of abandoned or blighted building (5 points), building and material reuse (2–4 points) and whole-building LCA (3 points) [119]. Considering the scope of this dissertation, Option 4, whole building LCA, is discussed in the upcoming paragraph.

Option 4 states that minimum 10% reduction should be achieved compare to the baseline building when LCA applied for the different building scenarios. In addition, it is stipulated by LEED that this reduction should be achieved at least three impact categories among determined six impact categories including GWP, ODP, AP, EP, POCP and ADP (fossil fuel). However, it is also stated that GWP is the compulsory impact category that 10% reduction should be achieved. Apart from these provisions, considered impact category results in the scope of LCA should not exceed the impact results of baseline building more than 5% [119].

According to the LCA results belonging to the actual case study building and different building scenarios having same life span and same properties, highest environmental performance is achieved at GWP by replacing commercial concrete used in Prokon-Ekon Headquarter Building with the Mixture-12 and the reduction percentage is about 8.13% in total. On the other hand, Building_M19 has a 0.55% and 0.30% higher impact on GWP and TETP impact categories than actual case study building, respectively. Therefore, it can be clearly stated that gaining extra 3 points do not seem possible by replacing commercial concrete with designated green concrete mixtures although utilization of Mixture-19 does not prompt to increase the impacts by more than 5%.

5.2.3. Sensitivity Analysis

As detailed in Section 4.2.2, the Ecoinvent v3 offers two system models namely allocation (cut-off) system model and consequential system model. In the scope of the research, consequential system model was selected from the database since it uses different basic assumptions to assess the consequences of a change and it provides decision support. In order to understand how different system models selected from Ecoinvent v3 can effect the outputs of the LCA study, sensitivity analysis was conducted. Performing of sensitivity analysis is very essential since assumptions considered in the LCA studies can significantly affect the overall results. Therefore, sensitivity analysis enables to observe the change in results and to conclude the importance of assumptions [17]. In this context, sensitivity analysis was performed for the control concrete mix to evaluate the reliability of the results by changing consequential data with allocation data and keeping other variables constant. Then, this modified control concrete mix was applied to the case study building LCA model to observe the change of impacts on overall lifespan of the building. Comparison graph for the normalization results belonging to the building including control concrete mix (Building_Control Mix) and modified control concrete mix (Building_Modified Control Mix) are presented in Figure 5.46.

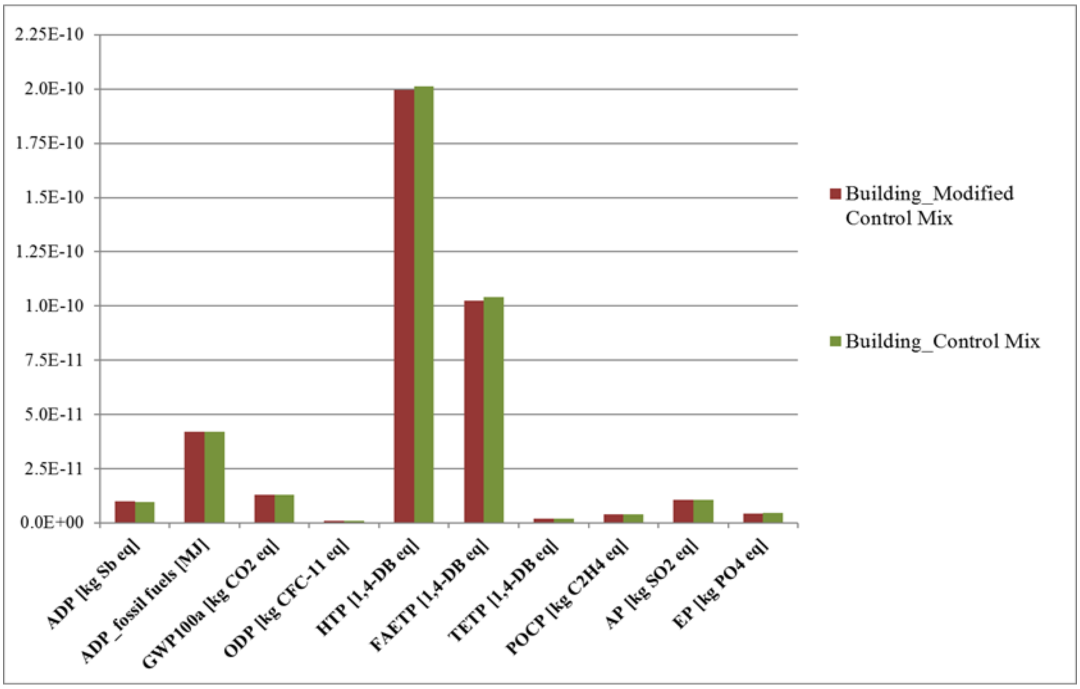


Figure 5.46. Total of normalization results for case study building with control mix and modified control mix

As can be pointed out from Figure 5.46, changing consequential data with allocation data does not considerably change the LCA results for case study building. According to the normalization results, impacts on ADP (fossiel_fuel), GWP, TETP and AP impact categories are equal to each other. However, impacts on ADP and ODP are slighlty higher for Building_Modified Control Mix with a ratio of 0.97% and 0.14%, respectively. On the contrary, imacts on HTP, FAETP, POCP and EP are slightly higher for Building_Control Mix by 0.90%, 1.58%, 0.19% and 3.27%, respectively. Therefore, it can be concluded as a result of the sensitivity anaylsis that selecting different system models does not affect the overall LCA results significantly.

CHAPTER 6

CONCLUSION

Construction industry is one of the main concerns in terms of environmental and sustainability since it has considerable impact share among other industries due to consumption of high amount raw materials and energy. Concrete is the most widely used construction material which emits huge amount GHGs, utilizes high amount raw materials and generates wastes. Therefore, assessment of environmental impacts resulting from concrete production with a holistic approach is becoming very important. For that purpose, different type of concrete mixtures including variable cementitious materials and recycled aggregate were examined and assessed through cradle to gate LCA. In addition, these concrete mixtures are integrated into the selected case study building that is Prokon-Ekon Headquarter Building located in Ankara. Each designated concrete mixtures were applied to the case study building LCA model and the results were compared with the baseline building results. In addition, disposal scenario for concrete is also performed to extend the study scope to cradle-to-grave. In the scope of LCA analyses, consequential (system expansion) model is applied and SimaPro 8.4.1.0 software is used.

According to the analysis results of the concrete mixtures, the following conclusions can be achieved;

- Portland cement is the main impact contributor to all mid-points, especially for GWP (>90%). In addition, amount of Portland cement is very important parameter while assessing the environmental credits of concrete production.
- As can be noticed in the normalization results, highest impacts resulting from production of 1 m^3 concrete mixtures are observed mostly at MAETP, FAETP and HTP mid-point impact categories.

- Avoided environmental burdens of industrial by-products disposal such as fly ash, silica fume, GGBFS and steel slag improves the environmental performance of the concrete manufacturing, as a consequence of system expansion model.
- Recycled aggregate used in the concrete production has significant environmental advantages especially for AP, ADP, GWP, HTP and POCP mid-point categories due to the avoided burdens resulting from landfilling of inert materials. Moreover, recycled aggregate is important since it help to reduce the raw material consumption such as natural aggregates.
- Natural aggregate usage contributes impacts mostly on ADP, ODP, HTP, POCP, AP and EP mid-point impact categories.
- Although amount of admixtures used in the concrete production is very low, environmental impacts of admixtures are considerable and should be assessed in the scope of LCA studies conducted for concrete production.
- Operation of ready-mix concrete mixture, water utilization and generated solid waste have no considerable impact on life-cycle of concrete production.

According to the LCA results belonging to the case study building includes control mix and other green concrete mixtures it is concluded that concrete has considerable impacts on whole-life span of the case study building even if used amount is very limited since it is steel construction. As a result of replacement of commercial concrete by designated concrete mixtures, it was noticed that overall impacts of might be reduced especially for the ADP, ADP (fossil fuel), AP, EP, GWP, HTP and POCP mid-point impact categories. In addition, importance of the disposal scenario was also revealed. Although total of normalization results for Mixture-17 has the least impacts in the cradle-to-gate study, Mixture-15 has the least impacts when it is applied into the case study building LCA model due to the disposal scenario.

To conclude, concrete production has significant environmental impacts on both environment and human health. Therefore, it is important to assess the impacts by applying scientific approaches like LCA not only for production but also use and disposal phases. In addition, considered mid-point impact categories should be wide range and should be handled as a whole.

CHAPTER 7

RECOMMENDATIONS

This study was conducted to assess the whole life cycle of concrete production and to determine the gained environmental performance when various supplementary cementitious materials are substituted by Portland cement. Therefore, primary objective of the study is impacts arising from materials used in the concrete production. Consequently, transportation of the materials from the supplier to the ready mix concrete plant is not considered in the scope of this dissertation. Impacts resulting from transportation of materials might change the results; therefore, it is recommended that transportation should be included to support this study. In addition, it is recommended that LCA approach should be applied for the concrete production and construction stage by decision makers, policy makers, designers, contractors, experts, academicians and students as LCA provides decision support. Moreover, it is recommended to LEED AP that LCA should be integrated into LEED because considerable environmental impact reduction can be achieved through applying LCA.

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APPENDICES

A. Characterization Results Regarding Midpoint Impact Categories for Control Mix and Concrete Mixtures

Table AA.1. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Control Mix*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.21E-04	3.88E-07	1.19E-05	3.98E-05	2.75E-05
ADP_fossil fuels [MJ]	1.39E+03	1.58E+00	1.97E+02	1.50E+02	1.91E+02
GWP100a [kg CO_2 eq]	3.28E+02	1.39E-01	1.39E+01	1.04E+01	7.59E+00
ODP [kg CFC-11 eq]	1.05E-05	1.72E-07	1.92E-06	1.49E-06	6.43E-07
HTP [1,4-DB eq]	4.17E+01	9.49E-02	5.65E+00	5.69E+00	5.16E+00
FAETP [1,4-DB eq]	3.05E+01	5.84E-02	4.32E+00	2.83E+00	1.49E+00

Table AA.1. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Control Mix-continued*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
MAETP [1,4-DB eq]	8.02E+04	1.64E+02	1.65E+04	9.42E+03	6.37E+03
TETP [1,4-DB eq]	4.23E-01	7.27E-04	1.95E-02	1.54E-02	8.30E-03
POCP [kg C_2H_4 eq]	2.57E-02	3.38E-05	3.61E-03	2.93E-03	3.11E-03
AP [kg SO_2 eq]	6.11E-01	5.69E-04	1.01E-01	6.09E-02	5.12E-02
EP [kg PO_4 eq]	2.36E-01	2.67E-04	3.31E-02	1.97E-02	7.86E-03

Table AA.1. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Control Mix-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	3.02E-04

Table AA.2. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-1*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**
ADP [kg Sb eq]	1.02E-04	5.47E-07	1.61E-05	3.03E-05	-1.36E-07
ADP_fossil fuels [MJ]	1.18E+03	2.24E+00	2.66E+02	1.14E+02	2.93E+01
GWP100a [kg CO_2 eq]	2.78E+02	1.96E-01	1.87E+01	7.95E+00	2.94E+00
ODP [kg CFC-11 eq]	8.91E-06	2.42E-07	2.60E-06	1.14E-06	1.13E-07
HTP [1,4-DB eq]	3.53E+01	1.34E-01	7.63E+00	4.34E+00	9.84E-01
FAETP [1,4-DB eq]	2.58E+01	8.25E-02	5.84E+00	2.16E+00	1.22E+00
MAETP [1,4-DB eq]	6.79E+04	2.32E+02	2.23E+04	7.19E+03	4.41E+03
TETP [1,4-DB eq]	3.58E-01	1.03E-03	2.63E-02	1.17E-02	6.02E-03
POCP [kg C_2H_4 eq]	2.18E-02	4.78E-05	4.88E-03	2.23E-03	5.75E-04
AP [kg SO_2 eq]	5.18E-01	8.04E-04	1.36E-01	4.65E-02	1.49E-02
EP [kg PO_4 eq]	2.00E-01	3.78E-04	4.47E-02	1.50E-02	7.87E-03

Table AA.2. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-1-continued*

Mid-point Impact Category	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	3.50E-08	3.73E-07	-8.14E-07	2.21E-07
ADP_fossil fuels [MJ]	1.22E+01	2.29E+01	-2.12E+01	5.05E+00
GWP100a [kg CO_2 eq]	9.07E-02	2.98E-01	-1.88E+00	1.87E-01
ODP [kg CFC-11 eq]	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	7.14E-02	1.22E-01	-6.40E-03	6.99E-02
FAETP [1,4-DB eq]	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	1.07E-04	1.67E-04	-5.88E-04	4.77E-05
AP [kg SO_2 eq]	2.07E-03	3.07E-03	-7.16E-03	1.08E-03
EP [kg PO_4 eq]	5.98E-05	4.68E-04	-7.73E-04	3.02E-04

Table AA.3. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-2*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.05E-04	4.36E-07	1.27E-05	4.06E-05	8.84E-06
ADP_fossil fuels [MJ]	1.22E+03	1.78E+00	2.10E+02	1.53E+02	6.16E+01
GWP100a [kg CO_2 eq]	2.87E+02	1.56E-01	1.48E+01	1.06E+01	2.44E+00
ODP [kg CFC-11 eq]	9.20E-06	1.93E-07	2.05E-06	1.53E-06	2.07E-07
HTP [1,4-DB eq]	3.65E+01	1.07E-01	6.02E+00	5.81E+00	1.66E+00
FAETP [1,4-DB eq]	2.66E+01	6.57E-02	4.61E+00	2.89E+00	4.80E-01
MAETP [1,4-DB eq]	7.01E+04	1.84E+02	1.76E+04	9.62E+03	2.05E+03
TETP [1,4-DB eq]	3.69E-01	8.18E-04	2.08E-02	1.57E-02	2.67E-03
POCP [kg C_2H_4 eq]	2.25E-02	3.80E-05	3.85E-03	2.99E-03	1.00E-03
AP [kg SO_2 eq]	5.35E-01	6.40E-04	1.07E-01	6.22E-02	1.65E-02
EP [kg PO_4 eq]	2.06E-01	3.01E-04	3.53E-02	2.01E-02	2.53E-03

Table AA.3. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-2-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.58E-08	3.73E-07	-2.78E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-7.26E+01	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-6.44E+00	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-2.19E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-2.01E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-2.45E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-2.64E-03	3.02E-04

Table AA.4. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-3*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	7.91E-05	4.56E-07	5.19E-06	4.16E-05	8.84E-06	-7.12E-05
ADP_fossil fuels [MJ]	9.14E+02	1.86E+00	8.60E+01	1.57E+02	6.16E+01	-3.25E+02
GWP100a [kg CO_2 eq]	2.15E+02	1.64E-01	6.05E+00	1.09E+01	2.44E+00	-2.77E+01
ODP [kg CFC-11 eq]	6.90E-06	2.02E-07	8.38E-07	1.56E-06	2.07E-07	-1.00E-07
HTP [1,4-DB eq]	2.74E+01	1.12E-01	2.46E+00	5.95E+00	1.66E+00	-1.47E+01
FAETP [1,4-DB eq]	2.00E+01	6.88E-02	1.89E+00	2.96E+00	4.80E-01	5.81E-01
MAETP [1,4-DB eq]	5.26E+04	1.93E+02	7.20E+03	9.85E+03	2.05E+03	-3.39E+03
TETP [1,4-DB eq]	2.77E-01	8.57E-04	8.51E-03	1.61E-02	2.67E-03	-1.09E-02
POCP [kg C_2H_4 eq]	1.68E-02	3.98E-05	1.57E-03	3.06E-03	1.00E-03	-1.37E-02
AP [kg SO_2 eq]	4.01E-01	6.70E-04	4.39E-02	6.37E-02	1.65E-02	-1.07E-01
EP [kg PO_4 eq]	1.55E-01	3.15E-04	1.44E-02	2.06E-02	2.53E-03	-8.08E-03

Table AA.4. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-3-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-2.10E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-5.48E+01	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-4.86E+00	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-1.65E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-1.52E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-1.85E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-2.00E-03	3.02E-04

Table AA.5. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-4*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	9.22E-05	4.13E-07	5.73E-06	3.16E-05	8.84E-06	-7.55E-05
ADP_fossil fuels [MJ]	1.07E+03	1.69E+00	9.49E+01	1.19E+02	6.16E+01	-3.45E+02
GWP100a [kg CO_2 eq]	2.51E+02	1.48E-01	6.68E+00	8.27E+00	2.44E+00	-2.94E+01
ODP [kg CFC-11 eq]	8.05E-06	1.83E-07	9.25E-07	1.19E-06	2.07E-07	-1.06E-07
HTP [1,4-DB eq]	3.19E+01	1.01E-01	2.72E+00	4.51E+00	1.66E+00	-1.56E+01
FAETP [1,4-DB eq]	2.33E+01	6.22E-02	2.08E+00	2.25E+00	4.79E-01	6.16E-01
MAETP [1,4-DB eq]	6.13E+04	1.75E+02	7.94E+03	7.48E+03	2.05E+03	-3.60E+03
TETP [1,4-DB eq]	3.23E-01	7.75E-04	9.39E-03	1.22E-02	2.67E-03	-1.15E-02
POCP [kg C_2H_4 eq]	1.97E-02	3.60E-05	1.74E-03	2.32E-03	9.99E-04	-1.45E-02
AP [kg SO_2 eq]	4.68E-01	6.06E-04	4.85E-02	1.65E-02	1.65E-02	-1.07E-01
EP [kg PO_4 eq]	1.81E-01	2.85E-04	1.59E-02	2.53E-03	2.53E-03	-8.08E-03

Table AA.5. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-4-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-7.56E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.98E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.76E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-5.96E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-5.48E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-6.67E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-7.21E-03	3.02E-04

Table AA.6. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-5*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	6.59E-05	2.57E-07	6.32E-06	3.67E-05	7.09E-05
ADP_fossil fuels [MJ]	7.61E+02	1.05E+00	3.83E+01	1.38E+02	4.93E+02
GWP100a [kg CO_2 eq]	1.79E+02	9.20E-02	2.75E+00	9.62E+00	1.95E+01
ODP [kg CFC-11 eq]	5.75E-06	1.14E-07	4.15E-07	1.38E-06	1.65E-06
HTP [1,4-DB eq]	2.28E+01	6.29E-02	1.29E+00	5.25E+00	1.33E+01
FAETP [1,4-DB eq]	1.66E+01	3.87E-02	5.21E-01	2.61E+00	3.84E+00
MAETP [1,4-DB eq]	4.38E+04	1.09E+02	2.52E+03	8.69E+03	1.64E+04
TETP [1,4-DB eq]	2.31E-01	4.82E-04	2.46E-03	1.42E-02	2.13E-02
POCP [kg C_2H_4 eq]	1.40E-02	2.24E-05	8.35E-04	2.70E-03	7.99E-03
AP [kg SO_2 eq]	3.34E-01	3.77E-04	4.26E-02	5.62E-02	1.32E-01
EP [kg PO_4 eq]	1.29E-01	1.77E-04	1.16E-02	1.82E-02	2.02E-02

Table AA.6. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-5-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-5.25E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.37E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.22E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-4.13E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-3.79E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-4.62E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-4.99E-03	3.02E-04

Table AA.7. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-6*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	5.21E-05	2.80E-07	6.23E-06	3.61E-05	6.98E-05
ADP_fossil fuels [MJ]	6.02E+02	1.14E+00	3.78E+01	1.36E+02	4.85E+02
GWP100a [kg CO_2 eq]	1.42E+02	1.00E-01	2.72E+00	9.47E+00	1.92E+01
ODP [kg CFC-11 eq]	4.54E-06	1.24E-07	4.09E-07	1.36E-06	1.63E-06
HTP [1,4-DB eq]	1.80E+01	6.85E-02	1.28E+00	5.17E+00	1.31E+01
FAETP [1,4-DB eq]	1.32E+01	4.22E-02	5.13E-01	2.57E+00	3.78E+00
MAETP [1,4-DB eq]	3.46E+04	1.18E+02	2.49E+03	8.56E+03	1.61E+04
TETP [1,4-DB eq]	1.82E-01	5.25E-04	2.43E-03	1.40E-02	2.10E-02
POCP [kg C_2H_4 eq]	1.11E-02	2.44E-05	8.23E-04	2.66E-03	7.87E-03
AP [kg SO_2 eq]	2.64E-01	4.11E-04	4.20E-02	5.54E-02	1.30E-01
EP [kg PO_4 eq]	1.02E-01	1.93E-04	1.16E-02	1.82E-02	2.02E-02

Table AA.7. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-6-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-6.20E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.62E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.43E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-4.87E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-4.48E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-5.45E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-5.89E-03	3.02E-04

Table AA.8. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System - Copied from ELCD**	**Perlite {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	9.75E-05	5.41E-07	4.72E-07	5.09E-06	1.86E-05
ADP_fossil fuels [MJ]	1.13E+03	2.21E+00	1.93E+02	5.06E+01	7.02E+01
GWP100a [kg CO_2 eq]	2.66E+02	1.94E-01	1.79E+01	3.77E+00	4.88E+00
ODP [kg CFC-11 eq]	8.51E-06	2.40E-07	3.60E-06	4.80E-07	7.00E-07
HTP [1,4-DB eq]	3.37E+01	1.32E-01	9.05E-01	2.11E+00	2.66E+00
FAETP [1,4-DB eq]	2.46E+01	8.16E-02	2.94E-02	1.01E+00	1.33E+00
MAETP [1,4-DB eq]	6.48E+04	2.29E+02	5.66E+03	3.58E+03	4.41E+03
TETP [1,4-DB eq]	3.42E-01	1.02E-03	1.07E-02	5.11E-03	7.21E-03
POCP [kg C_2H_4 eq]	2.08E-02	4.73E-05	7.04E-03	1.44E-03	1.37E-03
AP [kg SO_2 eq]	4.94E-01	7.95E-04	1.34E-01	4.19E-02	2.85E-02
EP [kg PO_4 eq]	1.91E-01	3.73E-04	9.39E-03	9.59E-03	9.23E-03

Table AA.8. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	2.62E-05	-1.36E-07	3.50E-08	3.73E-07	-3.13E-08	2.21E-07
ADP_fossil fuels [MJ]	1.82E+02	2.93E+01	1.22E+01	2.29E+01	6.74E+00	5.05E+00
GWP100a [kg CO_2 eq]	7.21E+00	2.94E+00	9.07E-02	2.98E-01	6.75E-01	1.87E-01
ODP [kg CFC-11 eq]	6.11E-07	1.13E-07	6.03E-08	2.64E-07	2.59E-08	5.78E-08
HTP [1,4-DB eq]	4.90E+00	9.84E-01	7.14E-02	1.22E-01	2.26E-01	6.99E-02
FAETP [1,4-DB eq]	1.42E+00	1.22E+00	2.46E-02	5.76E-02	2.81E-01	2.83E-02
MAETP [1,4-DB eq]	6.05E+03	4.41E+03	8.88E+01	4.45E+02	1.01E+03	9.18E+01
TETP [1,4-DB eq]	7.89E-03	6.02E-03	7.19E-05	5.20E-04	1.38E-03	2.00E-04

Table AA.8. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	2.95E-03	5.75E-04	1.07E-04	1.67E-04	1.32E-04	4.77E-05
AP [kg SO_2 eq]	4.87E-02	1.49E-02	2.07E-03	3.07E-03	3.42E-03	1.08E-03
EP [kg PO_4 eq]	7.47E-03	7.87E-03	5.98E-05	4.68E-04	1.81E-03	3.02E-04

Table AA.9. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System - Copied from ELCD**	**Perlite {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	9.85E-05	5.55E-07	4.59E-07	6.81E-06	1.81E-05
ADP_fossil fuels [MJ]	1.14E+03	2.27E+00	1.87E+02	6.77E+01	6.81E+01
GWP100a [kg CO_2 eq]	2.68E+02	1.99E-01	1.74E+01	5.04E+00	4.74E+00
ODP [kg CFC-11 eq]	8.60E-06	2.46E-07	3.49E-06	6.42E-07	6.79E-07
HTP [1,4-DB eq]	3.41E+01	1.36E-01	8.79E-01	2.82E+00	2.58E+00
FAETP [1,4-DB eq]	2.49E+01	8.36E-02	2.85E-02	1.35E+00	1.29E+00
MAETP [1,4-DB eq]	6.55E+04	2.35E+02	5.49E+03	4.79E+03	4.28E+03
TETP [1,4-DB eq]	3.45E-01	1.04E-03	1.04E-02	6.84E-03	7.00E-03
POCP [kg C_2H_4 eq]	2.10E-02	4.85E-05	6.83E-03	1.93E-03	1.33E-03
AP [kg SO_2 eq]	4.99E-01	8.15E-04	1.30E-01	5.60E-02	2.77E-02
EP [kg PO_4 eq]	1.93E-01	3.83E-04	9.12E-03	1.28E-02	8.95E-03

Table AA.9. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	2.62E-05	-1.36E-07	3.50E-08	3.73E-07	-1.36E-07	2.21E-07
ADP_fossil fuels [MJ]	1.82E+02	2.93E+01	1.22E+01	2.29E+01	2.93E+01	5.05E+00
GWP100a [kg CO_2 eq]	7.21E+00	2.94E+00	9.07E-02	2.98E-01	2.94E+00	1.87E-01
ODP [kg CFC-11 eq]	6.11E-07	1.13E-07	6.03E-08	2.64E-07	1.13E-07	5.78E-08
HTP [1,4-DB eq]	4.90E+00	9.84E-01	7.14E-02	1.22E-01	9.84E-01	6.99E-02
FAETP [1,4-DB eq]	1.42E+00	1.22E+00	2.46E-02	5.76E-02	1.22E+00	2.83E-02
MAETP [1,4-DB eq]	6.05E+03	4.41E+03	8.88E+01	4.45E+02	4.41E+03	9.18E+01
TETP [1,4-DB eq]	7.89E-03	6.02E-03	7.19E-05	5.20E-04	6.02E-03	2.00E-04

Table AA.9. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	2.95E-03	5.75E-04	1.07E-04	1.67E-04	5.75E-04	4.77E-05
AP [kg SO_2 eq]	4.87E-02	1.49E-02	2.07E-03	3.07E-03	1.49E-02	1.08E-03
EP [kg PO_4 eq]	7.47E-03	7.87E-03	5.98E-05	4.68E-04	7.87E-03	3.02E-04

Table AA.10. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-9*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	9.88E-05	4.36E-07	2.84E-05	4.17E-05	3.93E-05
ADP_fossil fuels [MJ]	1.14E+03	1.78E+00	5.46E+01	1.57E+02	2.74E+02
GWP100a [kg CO_2 eq]	2.69E+02	1.56E-01	3.62E+00	1.09E+01	1.09E+01
ODP [kg CFC-11 eq]	8.63E-06	1.93E-07	6.00E-07	1.57E-06	9.22E-07
HTP [1,4-DB eq]	3.42E+01	1.07E-01	2.51E+00	5.97E+00	7.39E+00
FAETP [1,4-DB eq]	2.50E+01	6.57E-02	1.15E+00	2.97E+00	2.14E+00
MAETP [1,4-DB eq]	6.57E+04	1.84E+02	3.19E+03	9.89E+03	9.12E+03
TETP [1,4-DB eq]	3.46E-01	8.18E-04	6.74E-03	1.62E-02	1.19E-02
POCP [kg C_2H_4 eq]	2.11E-02	3.80E-05	8.28E-04	3.07E-03	4.45E-03
AP [kg SO_2 eq]	5.01E-01	6.40E-04	1.70E-02	6.39E-02	7.34E-02
EP [kg PO_4 eq]	1.94E-01	3.01E-04	6.95E-03	2.07E-02	1.13E-02

Table AA.10. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-9-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-5.25E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.37E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.22E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-4.13E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-3.79E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-4.62E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-4.99E-03	3.02E-04

Table AA.11. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-10*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**
ADP [kg Sb eq]	9.22E-05	2.87E-07	5.77E-06	3.79E-05	3.69E-07
ADP_fossil fuels [MJ]	1.07E+03	1.17E+00	3.50E+01	1.43E+02	2.24E+00
GWP100a [kg CO_2 eq]	2.51E+02	1.03E-01	2.51E+00	9.93E+00	1.61E-01
ODP [kg CFC-11 eq]	8.05E-06	1.27E-07	3.79E-07	1.42E-06	2.42E-08
HTP [1,4-DB eq]	3.19E+01	7.02E-02	1.18E+00	5.42E+00	7.55E-02
FAETP [1,4-DB eq]	2.33E+01	4.32E-02	4.75E-01	2.70E+00	3.04E-02
MAETP [1,4-DB eq]	6.13E+04	1.21E+02	2.30E+03	8.98E+03	1.47E+02
TETP [1,4-DB eq]	3.23E-01	5.38E-04	2.25E-03	1.47E-02	1.44E-04
POCP [kg C_2H_4 eq]	1.97E-02	2.50E-05	7.62E-04	2.79E-03	4.87E-05
AP [kg SO_2 eq]	4.68E-01	4.21E-04	3.88E-02	5.80E-02	2.49E-03
EP [kg PO_4 eq]	1.81E-01	1.98E-04	1.05E-02	1.88E-02	6.75E-04

Table AA.11. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-10-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	2.49E-05	-1.36E-07	3.50E-08	3.73E-07	2.21E-07
ADP_fossil fuels [MJ]	1.72E+02	2.93E+01	1.22E+01	2.29E+01	5.05E+00
GWP100a [kg CO_2 eq]	6.83E+00	2.94E+00	9.07E-02	2.98E-01	1.87E-01
ODP [kg CFC-11 eq]	5.80E-07	1.13E-07	6.03E-08	2.64E-07	5.78E-08
HTP [1,4-DB eq]	4.64E+00	9.84E-01	7.14E-02	1.22E-01	6.99E-02
FAETP [1,4-DB eq]	1.34E+00	1.22E+00	2.46E-02	5.76E-02	2.83E-02
MAETP [1,4-DB eq]	5.73E+03	4.41E+03	8.88E+01	4.45E+02	9.18E+01
TETP [1,4-DB eq]	7.47E-03	6.02E-03	7.19E-05	5.20E-04	2.00E-04
POCP [kg C_2H_4 eq]	2.80E-03	5.75E-04	1.07E-04	1.67E-04	4.77E-05
AP [kg SO_2 eq]	4.61E-02	1.49E-02	2.07E-03	3.07E-03	1.08E-03
EP [kg PO_4 eq]	7.08E-03	7.87E-03	5.98E-05	4.68E-04	3.02E-04

Table AA.12. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-11*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**GGBFS Processing**
ADP [kg Sb eq]	6.92E-05	4.01E-07	1.31E-05	4.20E-05	-1.38E-07
ADP_fossil fuels [MJ]	8.00E+02	1.64E+00	2.17E+02	1.58E+02	1.56E+02
GWP100a [kg CO_2 eq]	1.88E+02	1.44E-01	1.53E+01	1.10E+01	9.98E+00
ODP [kg CFC-11 eq]	6.04E-06	1.78E-07	2.12E-06	1.58E-06	7.28E-07
HTP [1,4-DB eq]	2.39E+01	9.82E-02	6.22E+00	6.00E+00	3.53E+00
FAETP [1,4-DB eq]	1.75E+01	6.05E-02	4.76E+00	2.99E+00	4.07E+00
MAETP [1,4-DB eq]	4.60E+04	1.70E+02	1.82E+04	9.94E+03	1.48E+04
TETP [1,4-DB eq]	2.42E-01	7.53E-04	2.15E-02	1.63E-02	1.99E-02
POCP [kg C_2H_4 eq]	1.47E-02	3.50E-05	3.97E-03	3.09E-03	2.38E-03
AP [kg SO_2 eq]	3.51E-01	5.89E-04	1.11E-01	6.43E-02	5.81E-02
EP [kg PO_4 eq]	1.35E-01	2.77E-04	3.65E-02	2.08E-02	2.58E-02

Table AA.12. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-11-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-3.68E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-9.59E+01	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-8.51E+00	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-2.89E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-2.65E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-3.23E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-3.49E-03	3.02E-04

Table AA.13. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-12*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**GGBFS Processing**
ADP [kg Sb eq]	4.61E-05	4.01E-07	1.31E-05	-2.07E-07	4.19E-05
ADP_fossil fuels [MJ]	5.33E+02	1.64E+00	2.16E+02	2.34E+02	1.58E+02
GWP100a [kg CO_2 eq]	1.26E+02	1.44E-01	1.52E+01	1.50E+01	1.10E+01
ODP [kg CFC-11 eq]	4.03E-06	1.78E-07	2.11E-06	1.09E-06	1.57E-06
HTP [1,4-DB eq]	1.60E+01	9.82E-02	6.20E+00	5.29E+00	5.99E+00
FAETP [1,4-DB eq]	1.17E+01	6.05E-02	4.75E+00	6.10E+00	2.98E+00
MAETP [1,4-DB eq]	3.07E+04	1.70E+02	1.81E+04	2.22E+04	9.92E+03
TETP [1,4-DB eq]	1.62E-01	7.53E-04	2.14E-02	2.99E-02	1.62E-02
POCP [kg C_2H_4 eq]	9.83E-03	3.50E-05	3.96E-03	3.57E-03	3.08E-03
AP [kg SO_2 eq]	2.34E-01	5.89E-04	1.11E-01	8.71E-02	6.41E-02
EP [kg PO_4 eq]	9.03E-02	2.77E-04	3.64E-02	3.88E-02	2.07E-02

Table AA.13. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-12-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-5.52E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.44E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.28E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-4.33E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-3.98E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-4.85E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-5.24E-03	3.02E-04

Table AA.14. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	8.17E-05	3.62E-07	5.95E-07	9.04E-06	1.05E-05	4.14E-05
ADP_fossil fuels [MJ]	9.44E+02	1.48E+00	3.60E+00	1.50E+02	2.01E+01	1.56E+02
GWP100a [kg CO_2 eq]	2.23E+02	1.30E-01	2.59E-01	1.05E+01	1.33E+00	1.08E+01
ODP [kg CFC-11 eq]	7.13E-06	1.60E-07	3.90E-08	1.46E-06	2.21E-07	1.55E-06
HTP [1,4-DB eq]	2.83E+01	8.86E-02	1.22E-01	4.29E+00	9.24E-01	5.92E+00
FAETP [1,4-DB eq]	2.06E+01	5.45E-02	4.90E-02	3.28E+00	4.22E-01	2.95E+00
MAETP [1,4-DB eq]	5.43E+04	1.53E+02	2.37E+02	1.25E+04	1.17E+03	9.80E+03
TETP [1,4-DB eq]	2.86E-01	6.79E-04	2.32E-04	1.48E-02	2.48E-03	1.60E-02

Table AA.14. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13-continued*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
POCP [kg C_2H_4 eq]	1.74E-02	3.16E-05	7.85E-05	2.74E-03	3.05E-04	3.05E-03
AP [kg SO_2 eq]	4.14E-01	5.32E-04	4.00E-03	7.65E-02	6.27E-03	6.34E-02
EP [kg PO_4 eq]	1.60E-01	2.50E-04	1.09E-03	2.52E-02	2.56E-03	2.05E-02

Table AA.14. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	2.67E-05	-1.36E-07	3.50E-08	3.73E-07	-2.37E-06	2.21E-07
ADP_fossil fuels [MJ]	1.86E+02	2.93E+01	1.22E+01	2.29E+01	-6.18E+01	5.05E+00
GWP100a [kg CO_2 eq]	7.37E+00	2.94E+00	9.07E-02	2.98E-01	-5.48E+00	1.87E-01
ODP [kg CFC-11 eq]	6.24E-07	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	5.01E+00	9.84E-01	7.14E-02	1.22E-01	-1.86E-02	6.99E-02
FAETP [1,4-DB eq]	1.45E+00	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	6.19E+03	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	8.06E-03	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04

Table AA.14. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	3.02E-03	5.75E-04	1.07E-04	1.67E-04	-1.71E-03	4.77E-05
AP [kg SO_2 eq]	4.98E-02	1.49E-02	2.07E-03	3.07E-03	-2.08E-02	1.08E-03
EP [kg PO_4 eq]	7.64E-03	7.87E-03	5.98E-05	4.68E-04	-2.25E-03	3.02E-04

Table AA.15. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Perlite {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	8.23E-05	3.64E-07	3.76E-07	9.37E-06	1.05E-05	9.10E-06
ADP_fossil fuels [MJ]	9.51E+02	1.49E+00	2.68E+00	9.31E+01	2.02E+01	1.51E+02
GWP100a [kg CO_2 eq]	2.24E+02	1.31E-01	1.94E-01	6.94E+00	1.34E+00	1.06E+01
ODP [kg CFC-11 eq]	7.18E-06	1.61E-07	2.82E-08	8.84E-07	2.22E-07	1.47E-06
HTP [1,4-DB eq]	2.85E+01	8.92E-02	8.30E-02	3.88E+00	9.31E-01	4.32E+00
FAETP [1,4-DB eq]	2.08E+01	5.49E-02	3.68E-02	1.85E+00	4.25E-01	3.31E+00
MAETP [1,4-DB eq]	5.47E+04	1.54E+02	1.73E+02	6.60E+03	1.18E+03	1.26E+04
TETP [1,4-DB eq]	2.88E-01	6.84E-04	1.60E-04	9.41E-03	2.50E-03	1.49E-02

Table AA.15. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Perlite {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**
POCP [kg C_2H_4 eq]	1.75E-02	3.18E-05	5.35E-05	2.66E-03	3.07E-04	2.76E-03
AP [kg SO_2 eq]	4.17E-01	5.35E-04	2.66E-03	7.71E-02	6.31E-03	7.70E-02
EP [kg PO_4 eq]	1.61E-01	2.51E-04	7.32E-04	1.77E-02	2.58E-03	2.53E-02

Table AA.15. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland }| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	4.17E-05	2.69E-05	-1.36E-07	3.50E-08	3.73E-07	-5.77E-08	2.21E-07
ADP_fossil fuel [MJ]	1.57E+02	1.87E+02	2.93E+01	1.22E+01	2.29E+01	1.24E+01	5.05E+00
GWP100a [kg CO_2 eq]	1.09E+01	7.43E+00	2.94E+00	9.07E-02	2.98E-01	1.24E+00	1.87E-01
ODP [kg CFC-11 eq]	1.56E-06	6.29E-07	1.13E-07	6.03E-08	2.64E-07	4.77E-08	5.78E-08
HTP [1,4-DB eq]	5.96E+00	5.05E+00	9.84E-01	7.14E-02	1.22E-01	4.16E-01	6.99E-02

Table AA.15. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland }| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
FAETP [1,4-DB eq]	2.97E+00	1.46E+00	1.22E+00	2.46E-02	5.76E-02	5.17E-01	2.83E-02
MAETP [1,4-DB eq]	9.87E+03	6.23E+03	4.41E+03	8.88E+01	4.45E+02	1.86E+03	9.18E+01
TETP [1,4-DB eq]	1.61E-02	8.12E-03	6.02E-03	7.19E-05	5.20E-04	2.55E-03	2.00E-04
POCP [kg C_2H_4 eq]	3.07E-03	3.04E-03	5.75E-04	1.07E-04	1.67E-04	2.44E-04	4.77E-05
AP [kg SO_2 eq]	6.38E-02	5.02E-02	1.49E-02	2.07E-03	3.07E-03	6.30E-03	1.08E-03
EP [kg PO_4 eq]	2.06E-02	7.69E-03	7.87E-03	5.98E-05	4.68E-04	3.33E-03	3.02E-04

Table AA.16. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-15*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	5.93E-05	4.54E-07	1.18E-06	3.20E-05	2.59E-05	2.12E-05
ADP_fossil fuels [MJ]	6.85E+02	1.85E+00	7.13E+00	6.15E+01	9.76E+01	1.48E+02
GWP100a [kg CO_2 eq]	1.62E+02	1.63E-01	5.12E-01	4.07E+00	6.79E+00	5.86E+00
ODP [kg CFC-11 eq]	5.18E-06	2.01E-07	7.72E-08	6.76E-07	9.74E-07	4.96E-07
HTP [1,4-DB eq]	2.05E+01	1.11E-01	2.41E-01	2.83E+00	3.71E+00	3.98E+00
FAETP [1,4-DB eq]	1.50E+01	6.84E-02	9.69E-02	1.29E+00	1.85E+00	1.15E+00
MAETP [1,4-DB eq]	3.94E+04	1.92E+02	4.69E+02	3.59E+03	6.14E+03	4.91E+03
TETP [1,4-DB eq]	2.08E-01	8.52E-04	4.58E-04	7.59E-03	1.00E-02	6.40E-03
POCP [kg C_2H_4 eq]	1.26E-02	3.96E-05	1.55E-04	9.32E-04	1.91E-03	2.40E-03
AP [kg SO_2 eq]	3.01E-01	6.67E-04	7.92E-03	1.92E-02	3.97E-02	3.95E-02
EP [kg PO_4 eq]	1.16E-01	3.13E-04	2.15E-03	7.83E-03	1.28E-02	6.07E-03

Table AA.16. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-15-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-7.09E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.85E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.64E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-5.57E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-5.12E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-6.23E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-6.74E-03	3.02E-04

Table AA.17. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-16*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**GGBFS Processing**	**Sand {GLO}| market for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	6.18E-05	1.63E-07	-9.25E-08	4.04E-05	3.42E-06	-2.83E-05
ADP_fossil fuels [MJ]	7.14E+02	6.67E-01	1.04E+02	1.52E+02	2.07E+01	-1.29E+02
GWP100a [kg CO_2 eq]	1.68E+02	5.85E-02	6.68E+00	1.06E+01	1.49E+00	-1.10E+01
ODP [kg CFC-11 eq]	5.39E-06	7.23E-08	4.88E-07	1.52E-06	2.25E-07	-3.97E-08
HTP [1,4-DB eq]	2.14E+01	4.00E-02	2.36E+00	5.77E+00	7.00E-01	-5.84E+00
FAETP [1,4-DB eq]	1.56E+01	2.46E-02	2.72E+00	2.87E+00	2.82E-01	2.31E-01
MAETP [1,4-DB eq]	4.11E+04	6.92E+01	9.89E+03	9.56E+03	1.37E+03	-1.35E+03
TETP [1,4-DB eq]	2.16E-01	3.07E-04	1.34E-02	1.56E-02	1.33E-03	-4.31E-03
POCP [kg C_2H_4 eq]	1.32E-02	1.43E-05	1.60E-03	2.97E-03	4.52E-04	-5.43E-03
AP [kg SO_2 eq]	3.13E-01	2.40E-04	3.89E-02	6.18E-02	2.30E-02	-4.26E-02
EP [kg PO_4 eq]	1.21E-01	1.13E-04	1.73E-02	2.00E-02	6.26E-03	-3.21E-03

Table AA.17. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-16-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.66E-05	-1.36E-07	3.50E-08	3.73E-07	-4.93E-06	2.21E-07
ADP_fossil fuels [MJ]	1.16E+02	2.93E+01	1.22E+01	2.29E+01	-1.28E+02	5.05E+00
GWP100a [kg CO_2 eq]	4.58E+00	2.94E+00	9.07E-02	2.98E-01	-1.14E+01	1.87E-01
ODP [kg CFC-11 eq]	3.89E-07	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	3.11E+00	9.84E-01	7.14E-02	1.22E-01	-3.87E-02	6.99E-02
FAETP [1,4-DB eq]	9.00E-01	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	3.84E+03	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	5.01E-03	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04

Table AA.17. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-16-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	1.88E-03	5.75E-04	1.07E-04	1.67E-04	-3.56E-03	4.77E-05
AP [kg SO_2 eq]	3.09E-02	1.49E-02	2.07E-03	3.07E-03	-4.33E-02	1.08E-03
EP [kg PO_4 eq]	4.75E-03	7.87E-03	5.98E-05	4.68E-04	-4.68E-03	3.02E-04

Table AA.18. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-17*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.07E-04	3.72E-07	3.60E-06	-1.47E-04	1.99E-05
ADP_fossil fuels [MJ]	1.24E+03	1.52E+00	2.18E+01	-6.71E+02	1.38E+02
GWP100a [kg CO_2 eq]	2.92E+02	1.33E-01	1.57E+00	-5.73E+01	5.48E+00
ODP [kg CFC-11 eq]	9.34E-06	1.64E-07	2.36E-07	-2.07E-07	4.64E-07
HTP [1,4-DB eq]	3.70E+01	9.09E-02	7.37E-01	-3.04E+01	3.72E+00
FAETP [1,4-DB eq]	2.71E+01	5.60E-02	2.97E-01	1.20E+00	1.08E+00
MAETP [1,4-DB eq]	7.12E+04	1.57E+02	1.44E+03	-7.00E+03	4.59E+03
TETP [1,4-DB eq]	3.75E-01	6.97E-04	1.40E-03	-2.24E-02	5.99E-03
POCP [kg C_2H_4 eq]	2.28E-02	3.24E-05	4.76E-04	-2.82E-02	2.24E-03
AP [kg SO_2 eq]	5.43E-01	5.46E-04	2.43E-02	-2.21E-01	3.70E-02
EP [kg PO_4 eq]	2.10E-01	2.56E-04	6.59E-03	-1.67E-02	5.67E-03

Table AA.18. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-17_continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	3.02E-04

Table AA.19. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-18*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	9.88E-05	3.78E-07	4.04E-06	-3.48E-05	1.05E-05
ADP_fossil fuels [MJ]	1.14E+03	1.55E+00	2.44E+01	-1.59E+02	7.32E+01
GWP100a [kg CO_2 eq]	2.69E+02	1.36E-01	1.76E+00	-1.35E+01	2.90E+00
ODP [kg CFC-11 eq]	8.63E-06	1.67E-07	2.65E-07	-4.89E-08	2.47E-07
HTP [1,4-DB eq]	3.42E+01	9.26E-02	8.25E-01	-7.19E+00	1.97E+00
FAETP [1,4-DB eq]	2.50E+01	5.70E-02	3.32E-01	2.84E-01	5.70E-01
MAETP [1,4-DB eq]	6.57E+04	1.60E+02	1.61E+03	-1.66E+03	2.43E+03
TETP [1,4-DB eq]	3.46E-01	7.10E-04	1.57E-03	-5.31E-03	3.17E-03
POCP [kg C_2H_4 eq]	2.11E-02	3.30E-05	5.33E-04	-6.68E-03	1.19E-03
AP [kg SO_2 eq]	5.01E-01	5.56E-04	2.72E-02	-5.24E-02	1.96E-02
EP [kg PO_4 eq]	1.94E-01	2.61E-04	7.37E-03	-3.95E-03	3.00E-03

Table AA.19. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-18-continued*

<table>
<tr><th>Mid-point Impact Category</th><th>Electricity, medium voltage {GLO}| market group for | Conseq, S</th><th>Natural gas, high pressure {GLO}| market group for | Conseq, S</th><th>Diesel {Europe without Switzerland}| market for | Conseq, S</th><th>Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S</th></tr>
<tr><td>ADP [kg Sb eq]</td><td>-1.36E-07</td><td>3.50E-08</td><td>3.73E-07</td><td>2.21E-07</td></tr>
<tr><td>ADP_fossil fuels [MJ]</td><td>2.93E+01</td><td>1.22E+01</td><td>2.29E+01</td><td>5.05E+00</td></tr>
<tr><td>GWP100a [kg CO_2 eq]</td><td>2.94E+00</td><td>9.07E-02</td><td>2.98E-01</td><td>1.87E-01</td></tr>
<tr><td>ODP [kg CFC-11 eq]</td><td>1.13E-07</td><td>6.03E-08</td><td>2.64E-07</td><td>5.78E-08</td></tr>
<tr><td>HTP [1,4-DB eq]</td><td>9.84E-01</td><td>7.14E-02</td><td>1.22E-01</td><td>6.99E-02</td></tr>
<tr><td>FAETP [1,4-DB eq]</td><td>1.22E+00</td><td>2.46E-02</td><td>5.76E-02</td><td>2.83E-02</td></tr>
<tr><td>MAETP [1,4-DB eq]</td><td>4.41E+03</td><td>8.88E+01</td><td>4.45E+02</td><td>9.18E+01</td></tr>
<tr><td>TETP [1,4-DB eq]</td><td>6.02E-03</td><td>7.19E-05</td><td>5.20E-04</td><td>2.00E-04</td></tr>
<tr><td>POCP [kg C_2H_4 eq]</td><td>5.75E-04</td><td>1.07E-04</td><td>1.67E-04</td><td>4.77E-05</td></tr>
<tr><td>AP [kg SO_2 eq]</td><td>1.49E-02</td><td>2.07E-03</td><td>3.07E-03</td><td>1.08E-03</td></tr>
<tr><td>EP [kg PO_4 eq]</td><td>7.87E-03</td><td>5.98E-05</td><td>4.68E-04</td><td>3.02E-04</td></tr>
</table>

Table AA.20. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-19*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.35E-04	5.16E-07	2.95E-05	-2.67E-05	3.62E-05
ADP_fossil fuels [MJ]	1.56E+03	2.11E+00	1.11E+02	-1.22E+02	2.52E+02
GWP100a [kg CO_2 eq]	3.68E+02	1.85E-01	7.72E+00	-1.04E+01	1.00E+01
ODP [kg CFC-11 eq]	1.18E-05	2.28E-07	1.11E-06	-3.75E-08	8.49E-07
HTP [1,4-DB eq]	4.67E+01	1.26E-01	4.21E+00	-5.52E+00	6.80E+00
FAETP [1,4-DB eq]	3.41E+01	7.78E-02	2.10E+00	2.18E-01	1.97E+00
MAETP [1,4-DB eq]	8.98E+04	2.18E+02	6.98E+03	-1.27E+03	8.39E+03
TETP [1,4-DB eq]	4.73E-01	9.69E-04	1.14E-02	-4.07E-03	1.09E-02
POCP [kg C_2H_4 eq]	2.88E-02	4.51E-05	2.17E-03	-5.13E-03	4.10E-03
AP [kg SO_2 eq]	6.85E-01	7.58E-04	4.51E-02	-4.02E-02	6.76E-02
EP [kg PO_4 eq]	2.64E-01	3.56E-04	1.46E-02	-3.03E-03	1.04E-02

Table AA.20. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-19-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for granite crushing)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-2.78E-08	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	5.99E+00	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	6.00E-01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	2.30E-08	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	2.01E-01	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	2.50E-01	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	9.00E+02	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	1.23E-03	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	1.18E-04	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	3.04E-03	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	1.61E-03	3.02E-04

Table AA.21. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-20*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.01E-04	5.16E-07	2.41E-05	-6.31E-05	2.73E-05
ADP_fossil fuels [MJ]	1.17E+03	2.11E+00	9.09E+01	-2.88E+02	1.90E+02
GWP100a [kg CO_2 eq]	2.76E+02	1.85E-01	6.32E+00	-2.46E+01	7.51E+00
ODP [kg CFC-11 eq]	8.84E-06	2.28E-07	9.07E-07	-8.86E-08	6.36E-07
HTP [1,4-DB eq]	3.51E+01	1.26E-01	3.45E+00	-1.30E+01	5.11E+00
FAETP [1,4-DB eq]	2.56E+01	7.78E-02	1.72E+00	5.15E-01	1.48E+00
MAETP [1,4-DB eq]	6.73E+04	2.18E+02	5.72E+03	-3.01E+03	6.31E+03
TETP [1,4-DB eq]	3.55E-01	9.69E-04	9.34E-03	-9.63E-03	8.22E-03
POCP [kg C_2H_4 eq]	2.16E-02	4.51E-05	1.78E-03	-1.21E-02	3.07E-03
AP [kg SO_2 eq]	5.14E-01	7.58E-04	3.70E-02	-9.50E-02	5.07E-02
EP [kg PO_4 eq]	1.98E-01	3.56E-04	1.20E-02	-7.16E-03	7.78E-03

Table AA.21. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-20-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for granite crushing)**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-1.64E-08	-5.39E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	3.54E+00	-1.40E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	3.54E-01	-1.25E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	1.36E-08	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	1.19E-01	-4.23E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	1.47E-01	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	5.32E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	7.27E-04	0.00E+00	2.00E-04

Table AA.21. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-20-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for granite crushing)**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	6.94E-05	-3.89E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	1.80E-03	-4.73E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	9.50E-04	-5.11E-03	3.02E-04

Table AA.22. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-21*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	1.01E-04	5.16E-07	2.41E-05	-1.26E-04	2.73E-05
ADP_fossil fuels [MJ]	1.17E+03	2.11E+00	9.09E+01	-5.75E+02	1.89E+02
GWP100a [kg CO_2 eq]	2.76E+02	1.85E-01	6.32E+00	-4.91E+01	7.51E+00
ODP [kg CFC-11 eq]	8.84E-06	2.28E-07	9.07E-07	-1.77E-07	6.36E-07
HTP [1,4-DB eq]	3.51E+01	1.26E-01	3.45E+00	-2.61E+01	5.10E+00
FAETP [1,4-DB eq]	2.56E+01	7.78E-02	1.72E+00	1.03E+00	1.48E+00
MAETP [1,4-DB eq]	6.73E+04	2.18E+02	5.72E+03	-6.00E+03	6.30E+03
TETP [1,4-DB eq]	3.55E-01	9.69E-04	9.34E-03	-1.92E-02	8.21E-03
POCP [kg C_2H_4 eq]	2.16E-02	4.51E-05	1.78E-03	-2.42E-02	3.07E-03
AP [kg SO_2 eq]	5.14E-01	7.58E-04	3.70E-02	-1.90E-01	5.07E-02
EP [kg PO_4 eq]	1.98E-01	3.56E-04	1.20E-02	-1.43E-02	7.78E-03

Table AA.22. *Characterization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-21-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-1.36E-07	3.50E-08	3.73E-07	-5.39E-06	2.21E-07
ADP_fossil fuels [MJ]	2.93E+01	1.22E+01	2.29E+01	-1.40E+02	5.05E+00
GWP100a [kg CO_2 eq]	2.94E+00	9.07E-02	2.98E-01	-1.25E+01	1.87E-01
ODP [kg CFC-11 eq]	1.13E-07	6.03E-08	2.64E-07	0.00E+00	5.78E-08
HTP [1,4-DB eq]	9.84E-01	7.14E-02	1.22E-01	-4.23E-02	6.99E-02
FAETP [1,4-DB eq]	1.22E+00	2.46E-02	5.76E-02	0.00E+00	2.83E-02
MAETP [1,4-DB eq]	4.41E+03	8.88E+01	4.45E+02	0.00E+00	9.18E+01
TETP [1,4-DB eq]	6.02E-03	7.19E-05	5.20E-04	0.00E+00	2.00E-04
POCP [kg C_2H_4 eq]	5.75E-04	1.07E-04	1.67E-04	-3.89E-03	4.77E-05
AP [kg SO_2 eq]	1.49E-02	2.07E-03	3.07E-03	-4.73E-02	1.08E-03
EP [kg PO_4 eq]	7.87E-03	5.98E-05	4.68E-04	-5.11E-03	3.02E-04

B. Normalization Results Regarding Midpoint Impact Categories for Control Mix and Concrete Mixtures

Table AB.1. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Control Mix*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	5.76E-13	1.85E-15	5.69E-14	1.9E-13	1.32E-13
ADP_fossil fuels [MJ]	3.66E-12	4.16E-15	5.18E-13	3.94E-13	5.04E-13
GWP100a [kg CO_2 eq]	7.85E-12	3.32E-15	3.32E-13	2.49E-13	1.81E-13
ODP [kg CFC-11 eq]	4.64E-14	7.56E-16	8.48E-15	6.59E-15	2.84E-15
HTP [1,4-DB eq]	1.62E-11	3.68E-14	2.19E-12	2.21E-12	2.0E-12
FAETP [1,4-DB eq]	1.29E-11	2.47E-14	1.83E-12	1.2E-12	6.31E-13
MAETP [1,4-DB eq]	4.14E-10	8.46E-13	8.51E-11	4.86E-11	3.29E-11
TETP [1,4-DB eq]	3.87E-13	6.66E-16	1.78E-14	1.41E-14	7.59E-15
POCP [kg C_2H_4 eq]	6.99E-13	9.2E-16	9.82E-14	7.97E-14	8.45E-14
AP [kg SO_2 eq]	2.56E-12	2.38E-15	4.22E-13	2.55E-13	2.15E-13
EP [kg PO_4 eq]	1.49E-12	1.69E-15	2.09E-13	1.25E-13	4.97E-14

Table AB.1. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Control Mix-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	1.91E-15

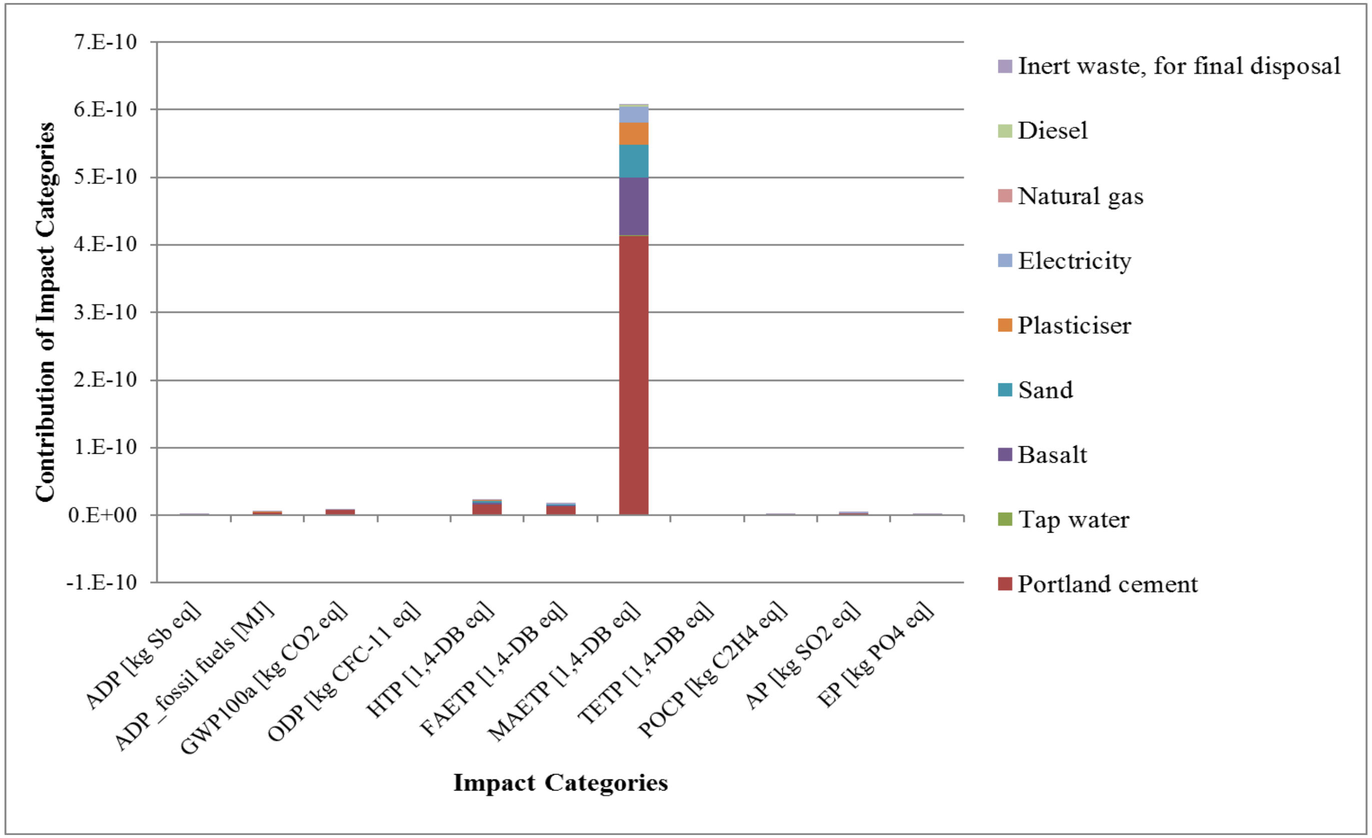

Figure AB.1. Normalized impact assessment results for Control Mix

Table AB.2. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-1*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**
ADP [kg Sb eq]	4.88E-13	2.62E-15	7.68E-14	1.45E-13	-6.51E-16
ADP_fossil fuels [MJ]	3.1E-12	5.88E-15	7.0E-13	3.01E-13	7.7E-14
GWP100a [kg CO_2 eq]	6.65E-12	4.69E-15	4.48E-13	1.9E-13	7.01E-14
ODP [kg CFC-11 eq]	3.93E-14	1.07E-15	1.14E-14	5.03E-15	4.97E-16
HTP [1,4-DB eq]	1.37E-11	5.2E-14	2.96E-12	1.68E-12	3.82E-13
FAETP [1,4-DB eq]	1.09E-11	3.49E-14	2.47E-12	9.13E-13	5.17E-13
MAETP [1,4-DB eq]	3.5E-10	1.2E-12	1.15E-10	3.71E-11	2.27E-11
TETP [1,4-DB eq]	3.27E-13	9.4E-16	2.41E-14	1.07E-14	5.51E-15
POCP [kg C_2H_4 eq]	5.92E-13	1.3E-15	1.33E-13	6.08E-14	1.57E-14
AP [kg SO_2 eq]	2.17E-12	3.37E-15	5.7E-13	1.95E-13	6.23E-14
EP [kg PO_4 eq]	1.26E-12	2.39E-15	2.83E-13	9.5E-14	4.98E-14

Table AB.2. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-1-continued*

Mid-point Impact Category	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.67E-16	1.79E-15	-3.89E-15	1.06E-15
ADP_fossil fuels [MJ]	3.2E-14	6.02E-14	-5.58E-14	1.33E-14
GWP100a [kg CO_2 eq]	2.17E-15	7.12E-15	-4.5E-14	4.48E-15
ODP [kg CFC-11 eq]	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	2.77E-14	4.72E-14	-2.48E-15	2.71E-14
FAETP [1,4-DB eq]	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	2.92E-15	4.54E-15	-1.6E-14	1.3E-15
AP [kg SO_2 eq]	8.66E-15	1.29E-14	-3.0E-14	4.53E-15
EP [kg PO_4 eq]	3.78E-16	2.96E-15	-4.89E-15	1.91E-15

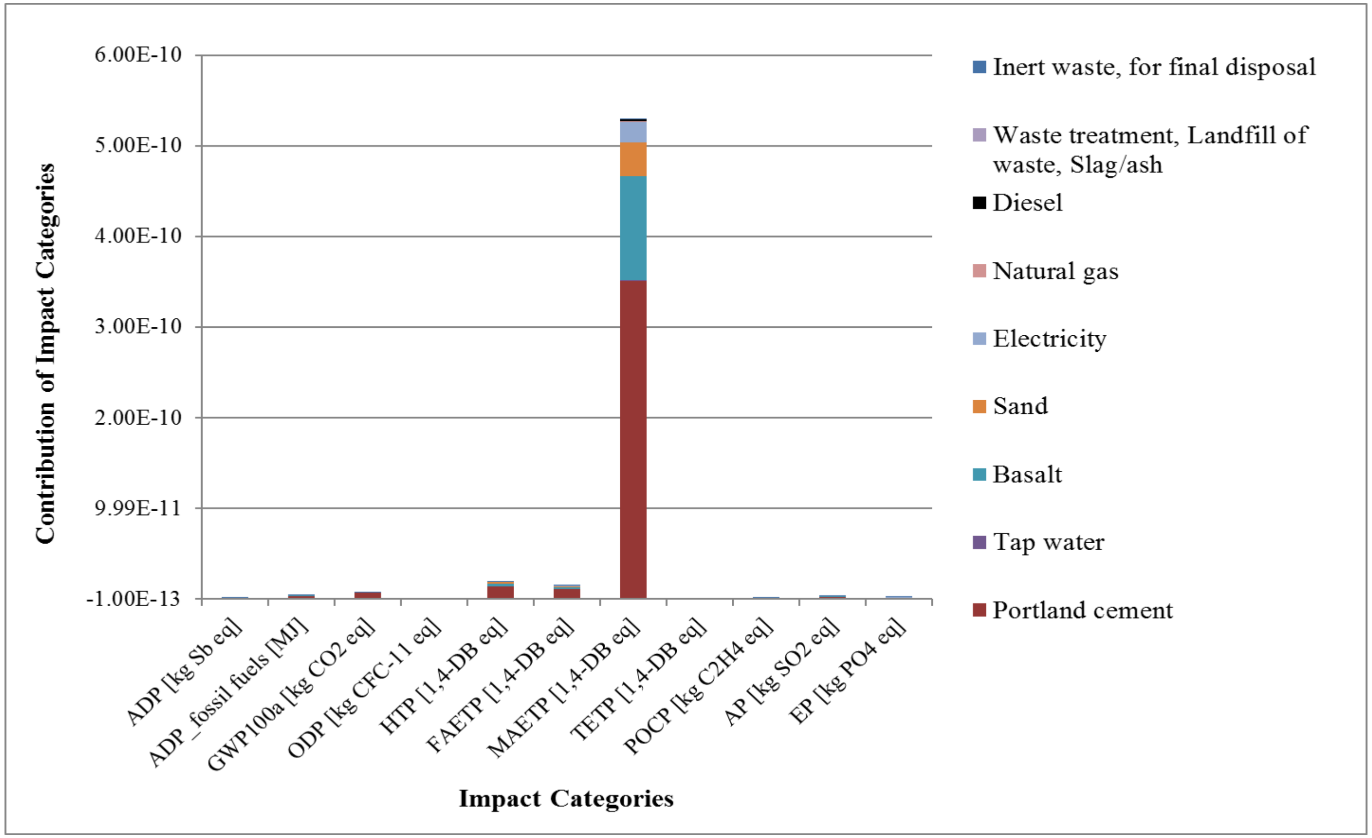

Figure AB.2. Normalized impact assessment results for Mixture-1

Table AB.3. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-2*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	5.04E-13	2.08E-15	6.06E-14	1.94E-13	4.23E-14
ADP_fossil fuels [MJ]	3.2E-12	4.68E-15	5.52E-13	4.02E-13	1.62E-13
GWP100a [kg CO_2 eq]	6.86E-12	3.73E-15	3.53E-13	2.54E-13	5.83E-14
ODP [kg CFC-11 eq]	4.06E-14	8.5E-16	9.03E-15	6.73E-15	9.12E-16
HTP [1,4-DB eq]	1.42E-11	4.14E-14	2.34E-12	2.25E-12	6.43E-13
FAETP [1,4-DB eq]	1.13E-11	2.78E-14	1.95E-12	1.22E-12	2.03E-13
MAETP [1,4-DB eq]	3.62E-10	9.52E-13	9.07E-11	4.97E-11	1.06E-11
TETP [1,4-DB eq]	3.38E-13	7.48E-16	1.9E-14	1.44E-14	2.44E-15
POCP [kg C_2H_4 eq]	6.11E-13	1.03E-15	1.05E-13	8.14E-14	2.72E-14
AP [kg SO_2 eq]	2.24E-12	2.68E-15	4.5E-13	2.61E-13	6.9E-14
EP [kg PO_4 eq]	1.3E-12	1.9E-15	2.23E-13	1.27E-13	1.6E-14

Table AB.3. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-2-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-1.33E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-1.91E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-1.54E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-8.49E-15	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-5.47E-14	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-1.03E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-1.67E-14	1.91E-15

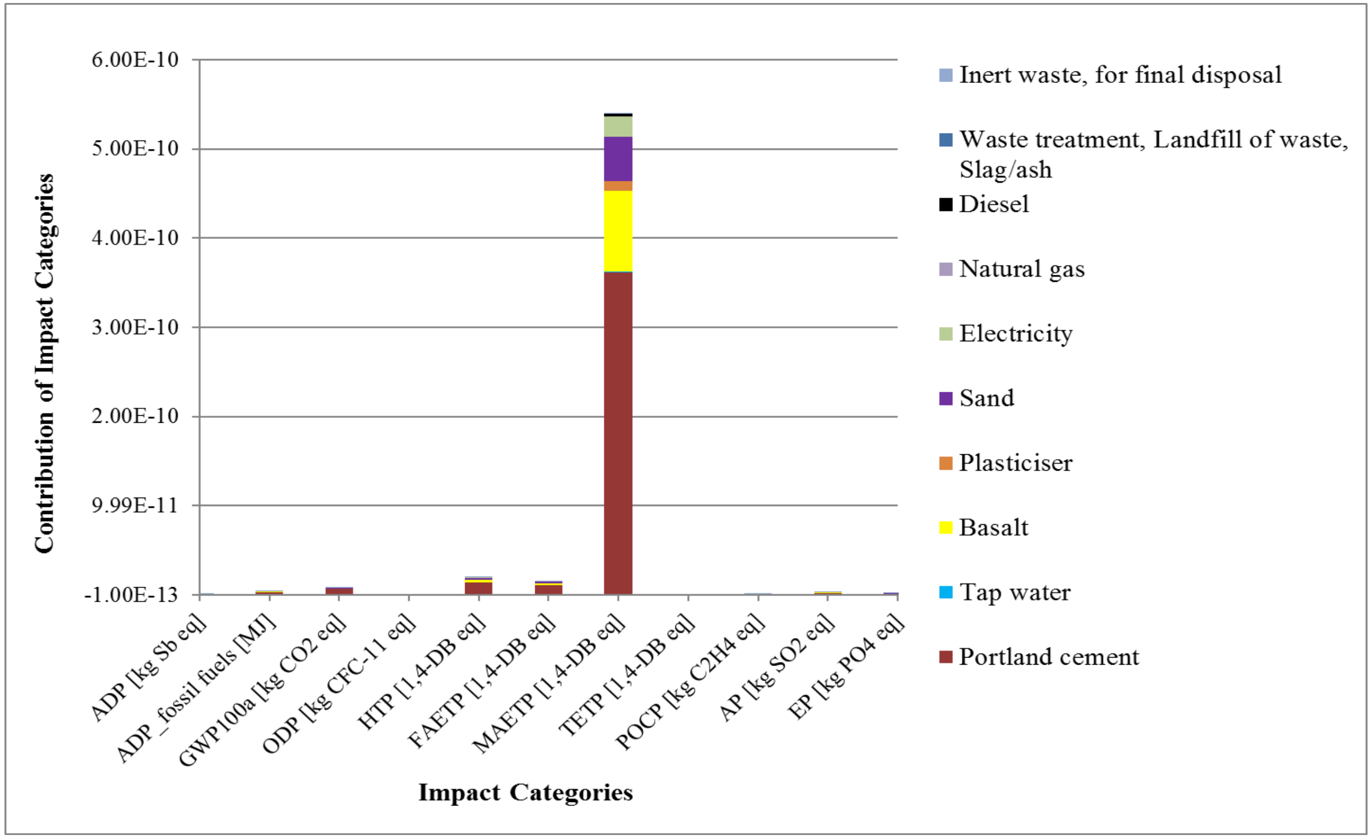

Figure AB.3. Normalized impact assessment results for Mixture-2

Table AB.4. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-3*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	3.78E-13	2.18E-15	2.48E-14	1.99E-13	4.23E-14	-3.4E-13
ADP_fossil fuels [MJ]	2.4E-12	4.9E-15	2.26E-13	4.12E-13	1.62E-13	-8.54E-13
GWP100a [kg CO_2 eq]	5.15E-12	3.91E-15	1.45E-13	2.61E-13	5.83E-14	-6.63E-13
ODP [kg CFC-11 eq]	3.04E-14	8.91E-16	3.7E-15	6.89E-15	9.12E-16	-4.41E-16
HTP [1,4-DB eq]	1.06E-11	4.33E-14	9.56E-13	2.31E-12	6.43E-13	-5.71E-12
FAETP [1,4-DB eq]	8.45E-12	2.91E-14	7.98E-13	1.25E-12	2.03E-13	2.46E-13
MAETP [1,4-DB eq]	2.71E-10	9.97E-13	3.71E-11	5.08E-11	1.06E-11	-1.75E-11
TETP [1,4-DB eq]	2.54E-13	7.84E-16	7.78E-15	1.47E-14	2.44E-15	-9.94E-15
POCP [kg C_2H_4 eq]	4.58E-13	1.08E-15	4.28E-14	8.33E-14	2.72E-14	-3.72E-13
AP [kg SO_2 eq]	1.68E-12	2.81E-15	1.84E-13	2.67E-13	6.9E-14	-4.49E-13
EP [kg PO_4 eq]	9.78E-13	1.99E-15	9.13E-14	1.3E-13	1.6E-14	-5.11E-14

Table AB.4. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-3-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-1.0E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-1.44E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-1.16E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-6.4E-15	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-4.13E-14	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-7.74E-14	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-1.26E-14	1.91E-15

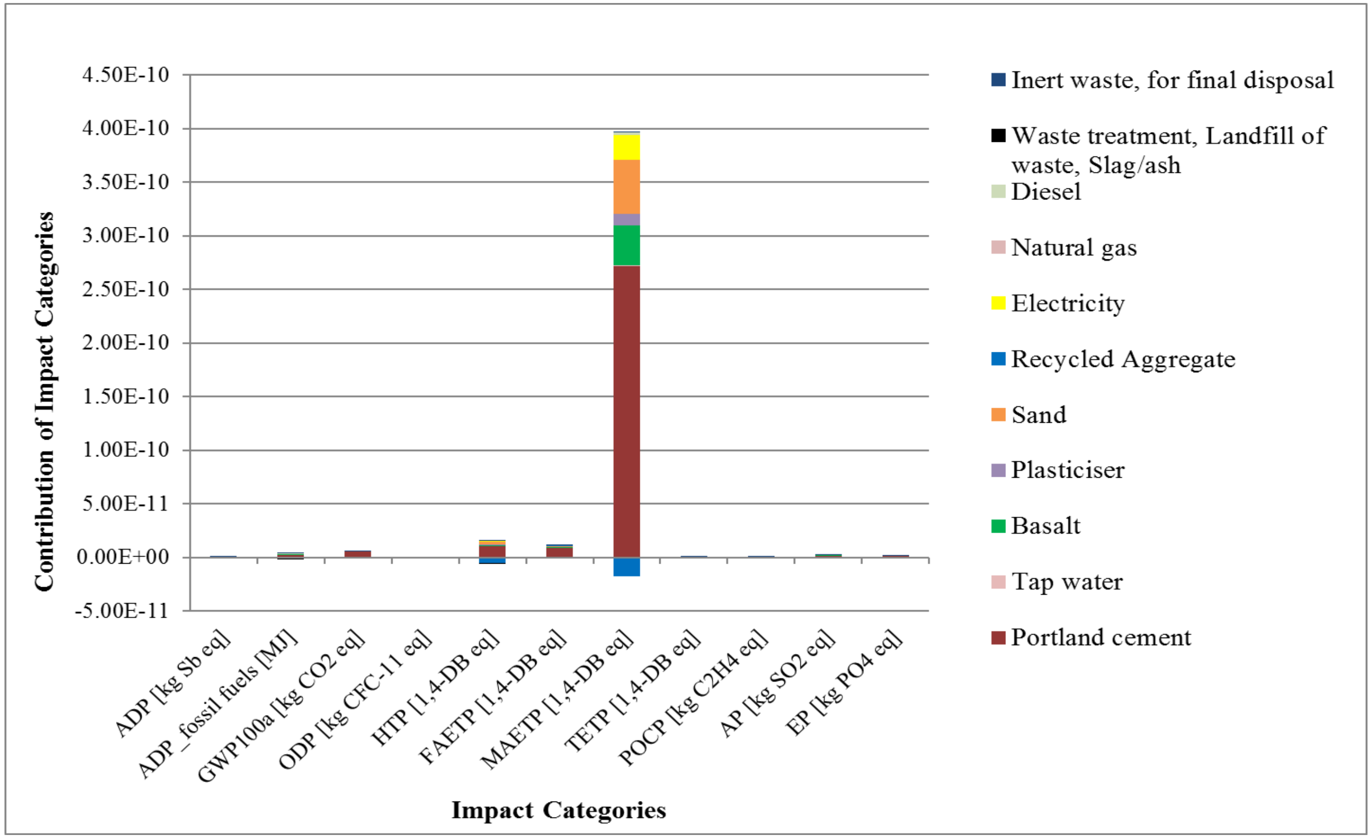

Figure AB.4. Normalized impact assessment results for Mixture-3

Table AB.5. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-4*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	4.41E-13	1.97E-15	2.74E-14	1.51E-13	4.23E-14	-3.61E-13
ADP_fossil fuels [MJ]	2.8E-12	4.43E-15	2.49E-13	3.13E-13	1.62E-13	-9.06E-13
GWP100a [kg CO_2 eq]	6.01E-12	3.53E-15	1.6E-13	1.98E-13	5.83E-14	-7.03E-13
ODP [kg CFC-11 eq]	3.55E-14	8.06E-16	4.08E-15	5.23E-15	9.12E-16	-4.68E-16
HTP [1,4-DB eq]	1.24E-11	3.92E-14	1.05E-12	1.75E-12	6.43E-13	-6.06E-12
FAETP [1,4-DB eq]	9.86E-12	2.63E-14	8.8E-13	9.5E-13	2.03E-13	2.61E-13
MAETP [1,4-DB eq]	3.16E-10	9.02E-13	4.1E-11	3.86E-11	1.06E-11	-1.86E-11
TETP [1,4-DB eq]	2.96E-13	7.09E-16	8.59E-15	1.12E-14	2.44E-15	-1.05E-14
POCP [kg C_2H_4 eq]	5.35E-13	9.8E-16	4.73E-14	6.32E-14	2.72E-14	-3.94E-13
AP [kg SO_2 eq]	1.96E-12	2.54E-15	2.03E-13	2.03E-13	6.9E-14	-4.77E-13
EP [kg PO_4 eq]	1.14E-12	1.8E-15	1.01E-13	9.88E-14	1.6E-14	-5.41E-14

Table AB.5. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-4-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-3.63E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-5.2E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-4.2E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-2.31E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.49E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-2.8E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-4.56E-14	1.91E-15

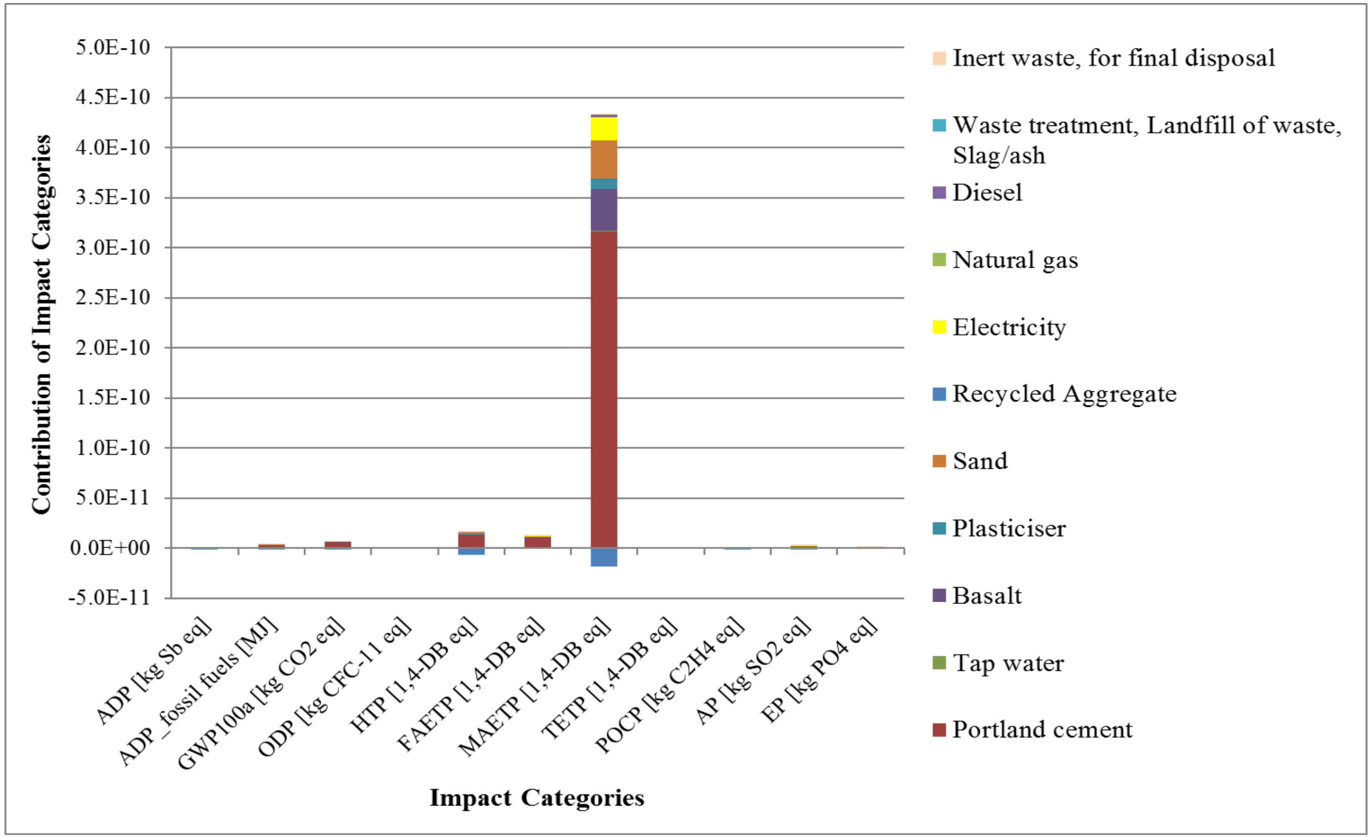

Figure AB.5. Normalized impact assessment results for Mixture-4

Table AB.6. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-5*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	3.15E-13	1.23E-15	3.02E-14	1.75E-13	3.38E-13
ADP_fossil fuels [MJ]	2.0E-12	2.76E-15	1.01E-13	3.64E-13	1.3E-12
GWP100a [kg CO_2 eq]	4.29E-12	2.2E-15	6.58E-14	2.3E-13	4.67E-13
ODP [kg CFC-11 eq]	2.54E-14	5.01E-16	1.83E-15	6.08E-15	7.3E-15
HTP [1,4-DB eq]	8.85E-12	2.44E-14	5.02E-13	2.04E-12	5.15E-12
FAETP [1,4-DB eq]	7.04E-12	1.64E-14	2.2E-13	1.11E-12	1.62E-12
MAETP [1,4-DB eq]	2.26E-10	5.61E-13	1.3E-11	4.49E-11	8.45E-11
TETP [1,4-DB eq]	2.11E-13	4.41E-16	2.26E-15	1.3E-14	1.95E-14
POCP [kg C_2H_4 eq]	3.82E-13	6.1E-16	2.27E-14	7.35E-14	2.17E-13
AP [kg SO_2 eq]	1.4E-12	1.58E-15	1.78E-13	2.36E-13	5.52E-13
EP [kg PO_4 eq]	8.15E-13	1.12E-15	7.3E-14	1.15E-13	1.28E-13

Table AB.6. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-5-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-2.51E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-3.6E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-2.91E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.6E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.03E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-1.93E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-3.15E-14	1.91E-15

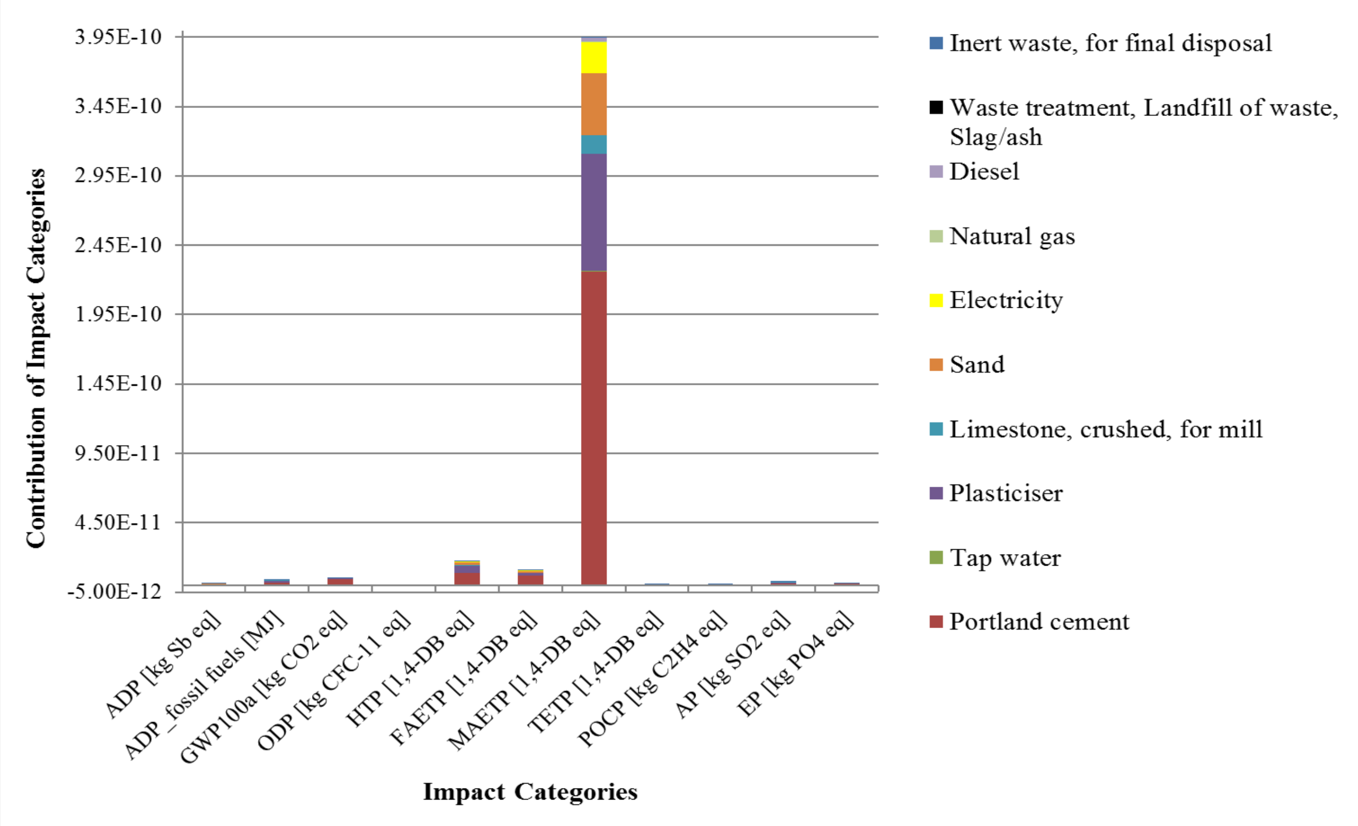

Figure AB.6. Normalized impact assessment results for Mixture-5

Table AB.7. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-6*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	2.49E-13	1.34E-15	2.98E-14	1.73E-13	3.33E-13
ADP_fossil fuels [MJ]	1.58E-12	3.0E-15	9.93E-14	3.58E-13	1.28E-12
GWP100a [kg CO_2 eq]	3.39E-12	2.4E-15	6.49E-14	2.26E-13	4.6E-13
ODP [kg CFC-11 eq]	2.0E-14	5.46E-16	1.8E-15	5.99E-15	7.19E-15
HTP [1,4-DB eq]	6.99E-12	2.66E-14	4.95E-13	2.01E-12	5.07E-12
FAETP [1,4-DB eq]	5.56E-12	1.78E-14	2.17E-13	1.09E-12	1.6E-12
MAETP [1,4-DB eq]	1.79E-10	6.11E-13	1.28E-11	4.42E-11	8.32E-11
TETP [1,4-DB eq]	1.67E-13	4.81E-16	2.22E-15	1.28E-14	1.92E-14
POCP [kg C_2H_4 eq]	3.02E-13	6.64E-16	2.24E-14	7.24E-14	2.14E-13
AP [kg SO_2 eq]	1.11E-12	1.72E-15	1.76E-13	2.32E-13	5.44E-13
EP [kg PO_4 eq]	6.44E-13	1.22E-15	7.2E-14	1.13E-13	1.26E-13

Table AB.7. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-6-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-2.96E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-4.25E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-3.43E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.89E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.22E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-2.28E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-3.72E-14	1.91E-15

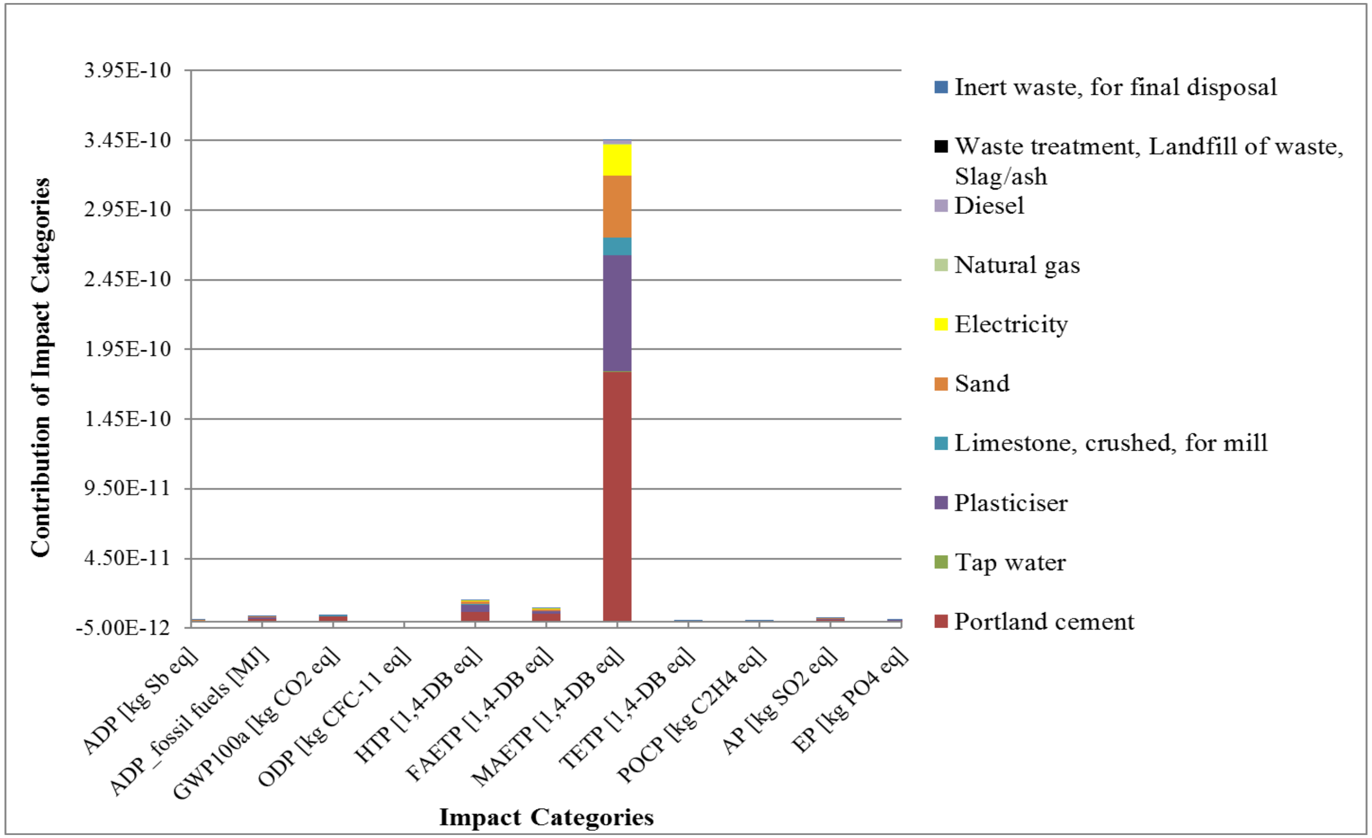

Figure AB.7. Normalized impact assessment results for Mixture-6

Table AB.8. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System - Copied from ELCD**	**Perlite {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	4.66E-13	2.59E-15	2.26E-15	2.43E-14	8.9E-14
ADP_fossil fuels [MJ]	2.96E-12	5.81E-15	5.06E-13	1.33E-13	1.85E-13
GWP100a [kg CO_2 eq]	6.35E-12	4.63E-15	4.28E-13	9.01E-14	1.17E-13
ODP [kg CFC-11 eq]	3.75E-14	1.06E-15	1.59E-14	2.12E-15	3.09E-15
HTP [1,4-DB eq]	1.31E-11	5.14E-14	3.51E-13	8.19E-13	1.03E-12
FAETP [1,4-DB eq]	1.04E-11	3.45E-14	1.24E-14	4.26E-13	5.61E-13
MAETP [1,4-DB eq]	3.34E-10	1.18E-12	2.92E-11	1.85E-11	2.28E-11
TETP [1,4-DB eq]	3.13E-13	9.3E-16	9.76E-15	4.68E-15	6.6E-15
POCP [kg C_2H_4 eq]	5.65E-13	1.29E-15	1.91E-13	3.93E-14	3.73E-14
AP [kg SO_2 eq]	2.07E-12	3.33E-15	5.62E-13	1.75E-13	1.2E-13
EP [kg PO_4 eq]	1.21E-12	2.36E-15	5.94E-14	6.06E-14	5.83E-14

Table AB.8. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.25E-13	-6.51E-16	1.67E-16	1.79E-15	-1.5E-16	1.06E-15
ADP_fossil fuels [MJ]	4.79E-13	7.7E-14	3.2E-14	6.02E-14	1.77E-14	1.33E-14
GWP100a [kg CO_2 eq]	1.73E-13	7.01E-14	2.17E-15	7.12E-15	1.61E-14	4.48E-15
ODP [kg CFC-11 eq]	2.7E-15	4.97E-16	2.66E-16	1.16E-15	1.14E-16	2.55E-16
HTP [1,4-DB eq]	1.9E-12	3.82E-13	2.77E-14	4.72E-14	8.78E-14	2.71E-14
FAETP [1,4-DB eq]	6.0E-13	5.17E-13	1.04E-14	2.43E-14	1.19E-13	1.2E-14
MAETP [1,4-DB eq]	3.13E-11	2.27E-11	4.58E-13	2.29E-12	5.23E-12	4.74E-13
TETP [1,4-DB eq]	7.23E-15	5.51E-15	6.58E-17	4.76E-16	1.27E-15	1.83E-16

Table AB.8. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-7-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	8.04E-14	1.57E-14	2.92E-15	4.54E-15	3.6E-15	1.3E-15
AP [kg SO_2 eq]	2.04E-13	6.23E-14	8.66E-15	1.29E-14	1.43E-14	4.53E-15
EP [kg PO_4 eq]	4.73E-14	4.98E-14	3.78E-16	2.96E-15	1.14E-14	1.91E-15

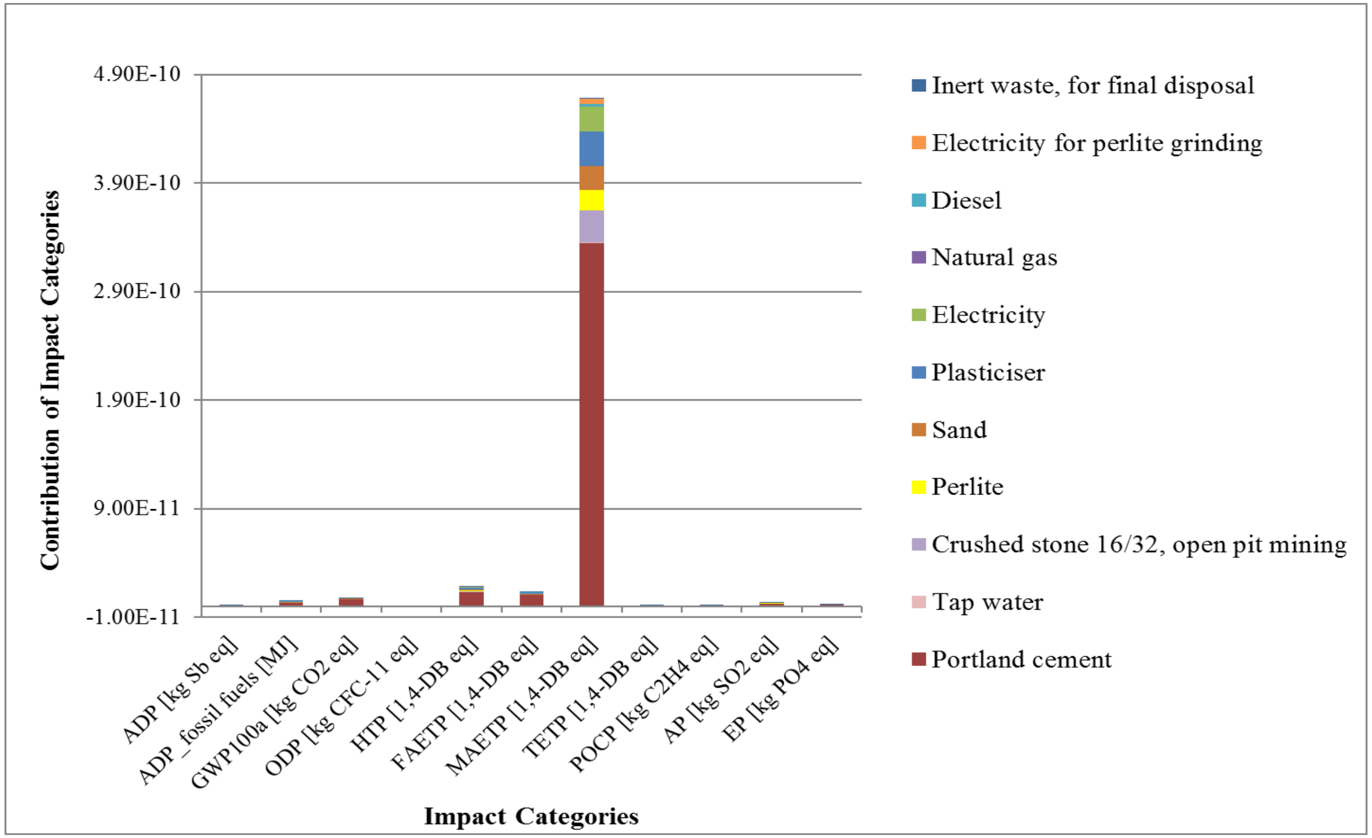

Figure AB.8. Normalized impact assessment results for Mixture-7

Table AB.9. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Crushed stone 16/32, open pit mining, production mix, at plant, undried RER S System - Copied from ELCD**	**Perlite {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	4.71E-13	2.65E-15	2.19E-15	3.25E-14	8.64E-14
ADP_fossil fuels [MJ]	2.99E-12	5.96E-15	4.92E-13	1.78E-13	1.79E-13
GWP100a [kg CO_2 eq]	6.41E-12	4.75E-15	4.16E-13	1.2E-13	1.13E-13
ODP [kg CFC-11 eq]	3.79E-14	1.08E-15	1.54E-14	2.83E-15	2.99E-15
HTP [1,4-DB eq]	1.32E-11	5.27E-14	3.41E-13	1.1E-12	1.0E-12
FAETP [1,4-DB eq]	1.05E-11	3.54E-14	1.21E-14	5.7E-13	5.44E-13
MAETP [1,4-DB eq]	3.38E-10	1.21E-12	2.83E-11	2.47E-11	2.21E-11
TETP [1,4-DB eq]	3.16E-13	9.53E-16	9.48E-15	6.26E-15	6.4E-15
POCP [kg C_2H_4 eq]	5.71E-13	1.32E-15	1.86E-13	5.25E-14	3.62E-14
AP [kg SO_2 eq]	2.09E-12	3.41E-15	5.46E-13	2.35E-13	1.16E-13
EP [kg PO_4 eq]	1.22E-12	2.42E-15	5.77E-14	8.11E-14	5.66E-14

Table AB.9. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.27E-13	-6.51E-16	1.67E-16	1.79E-15	-2.0E-16	1.06E-15
ADP_fossil fuels [MJ]	4.84E-13	7.7E-14	3.2E-14	6.02E-14	2.36E-14	1.33E-14
GWP100a [kg CO_2 eq]	1.74E-13	7.01E-14	2.17E-15	7.12E-15	2.15E-14	4.48E-15
ODP [kg CFC-11 eq]	2.73E-15	4.97E-16	2.66E-16	1.16E-15	1.52E-16	2.55E-16
HTP [1,4-DB eq]	1.92E-12	3.82E-13	2.77E-14	4.72E-14	1.17E-13	2.71E-14
FAETP [1,4-DB eq]	6.06E-13	5.17E-13	1.04E-14	2.43E-14	1.58E-13	1.2E-14
MAETP [1,4-DB eq]	3.16E-11	2.27E-11	4.58E-13	2.29E-12	6.97E-12	4.74E-13
TETP [1,4-DB eq]	7.3E-15	5.51E-15	6.58E-17	4.76E-16	1.69E-15	1.83E-16

Table AB.9. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-8-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
POCP [kg C_2H_4 eq]	8.13E-14	1.57E-14	2.92E-15	4.54E-15	4.8E-15	1.3E-15
AP [kg SO_2 eq]	2.06E-13	6.23E-14	8.66E-15	1.29E-14	1.91E-14	4.53E-15
EP [kg PO_4 eq]	4.78E-14	4.98E-14	3.78E-16	2.96E-15	1.53E-14	1.91E-15

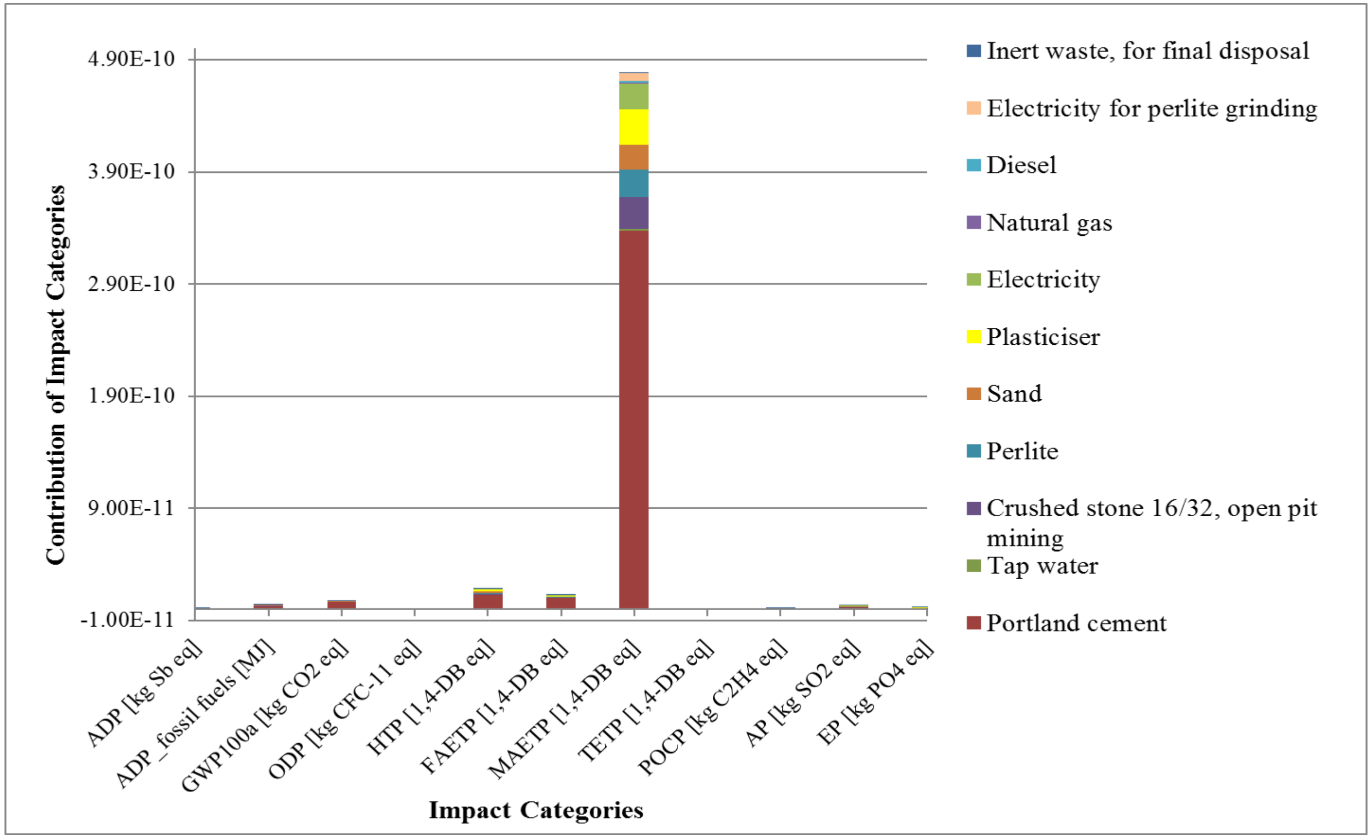

Figure AB.9. Normalized impact assessment results for Mixture-8

Table AB.10. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-9*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	4.72E-13	2.08E-15	1.36E-13	2.0E-13	1.88E-13
ADP_fossil fuels [MJ]	3.0E-12	4.68E-15	1.44E-13	4.14E-13	7.21E-13
GWP100a [kg CO_2 eq]	6.43E-12	3.73E-15	8.64E-14	2.62E-13	2.6E-13
ODP [kg CFC-11 eq]	3.8E-14	8.5E-16	2.65E-15	6.92E-15	4.06E-15
HTP [1,4-DB eq]	1.33E-11	4.14E-14	9.74E-13	2.32E-12	2.86E-12
FAETP [1,4-DB eq]	1.06E-11	2.78E-14	4.85E-13	1.26E-12	9.02E-13
MAETP [1,4-DB eq]	3.39E-10	9.52E-13	1.64E-11	5.1E-11	4.7E-11
TETP [1,4-DB eq]	3.17E-13	7.48E-16	6.17E-15	1.48E-14	1.09E-14
POCP [kg C_2H_4 eq]	5.73E-13	1.03E-15	2.25E-14	8.36E-14	1.21E-13
AP [kg SO_2 eq]	2.1E-12	2.68E-15	7.13E-14	2.68E-13	3.07E-13
EP [kg PO_4 eq]	1.22E-12	1.9E-15	4.39E-14	1.31E-13	7.11E-14

Table AB.10. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-9-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-2.51E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-3.6E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-2.91E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.6E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.03E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-1.93E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-3.15E-14	1.91E-15

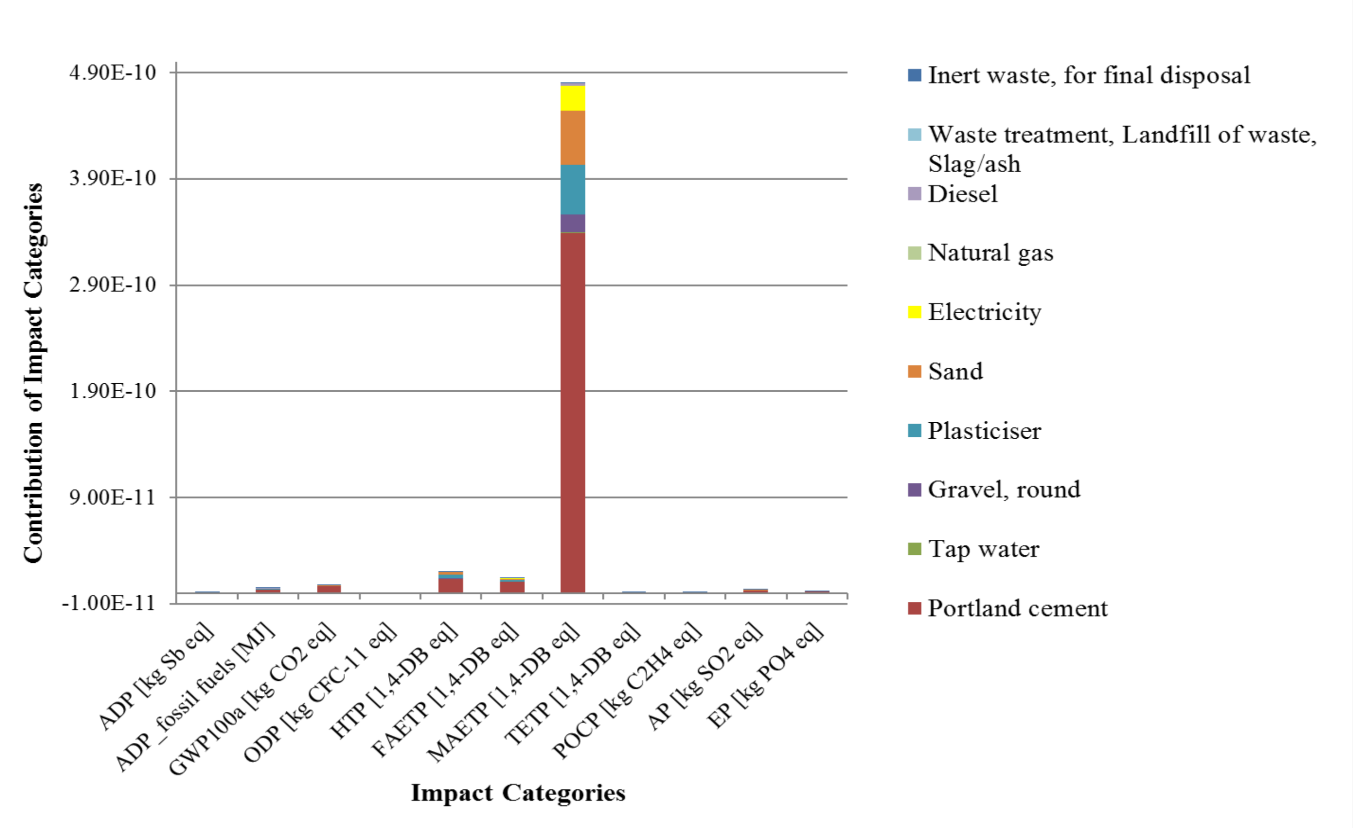

Figure AB.10. Normalized impact assessment results for Mixture-9

Table AB.11. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-10*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**
ADP [kg Sb eq]	4.41E-13	1.37E-15	2.76E-14	1.81E-13	1.76E-15
ADP_fossil fuels [MJ]	2.8E-12	3.08E-15	9.19E-14	3.75E-13	5.88E-15
GWP100a [kg CO_2 eq]	6.01E-12	2.45E-15	6.01E-14	2.37E-13	3.84E-15
ODP [kg CFC-11 eq]	3.55E-14	5.59E-16	1.67E-15	6.28E-15	1.07E-16
HTP [1,4-DB eq]	1.24E-11	2.72E-14	4.58E-13	2.1E-12	2.93E-14
FAETP [1,4-DB eq]	9.86E-12	1.83E-14	2.01E-13	1.14E-12	1.29E-14
MAETP [1,4-DB eq]	3.16E-10	6.26E-13	1.19E-11	4.63E-11	7.6E-13
TETP [1,4-DB eq]	2.96E-13	4.92E-16	2.06E-15	1.34E-14	1.32E-16
POCP [kg C_2H_4 eq]	5.35E-13	6.81E-16	2.07E-14	7.59E-14	1.33E-15
AP [kg SO_2 eq]	1.96E-12	1.76E-15	1.63E-13	2.43E-13	1.04E-14
EP [kg PO_4 eq]	1.14E-12	1.25E-15	6.66E-14	1.19E-13	4.26E-15

Table AB.11. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-10-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.18E-13	-6.51E-16	1.67E-16	1.79E-15	1.06E-15
ADP_fossil fuels [MJ]	4.53E-13	7.7E-14	3.2E-14	6.02E-14	1.33E-14
GWP100a [kg CO_2 eq]	1.63E-13	7.01E-14	2.17E-15	7.12E-15	4.48E-15
ODP [kg CFC-11 eq]	2.55E-15	4.97E-16	2.66E-16	1.16E-15	2.55E-16
HTP [1,4-DB eq]	1.8E-12	3.82E-13	2.77E-14	4.72E-14	2.71E-14
FAETP [1,4-DB eq]	5.68E-13	5.17E-13	1.04E-14	2.43E-14	1.2E-14
MAETP [1,4-DB eq]	2.96E-11	2.27E-11	4.58E-13	2.29E-12	4.74E-13
TETP [1,4-DB eq]	6.84E-15	5.51E-15	6.58E-17	4.76E-16	1.83E-16
POCP [kg C_2H_4 eq]	7.61E-14	1.57E-14	2.92E-15	4.54E-15	1.3E-15
AP [kg SO_2 eq]	1.93E-13	1.49E-02	2.07E-03	3.07E-03	1.08E-03
EP [kg PO_4 eq]	4.47E-14	7.87E-03	5.98E-05	4.68E-04	3.02E-04

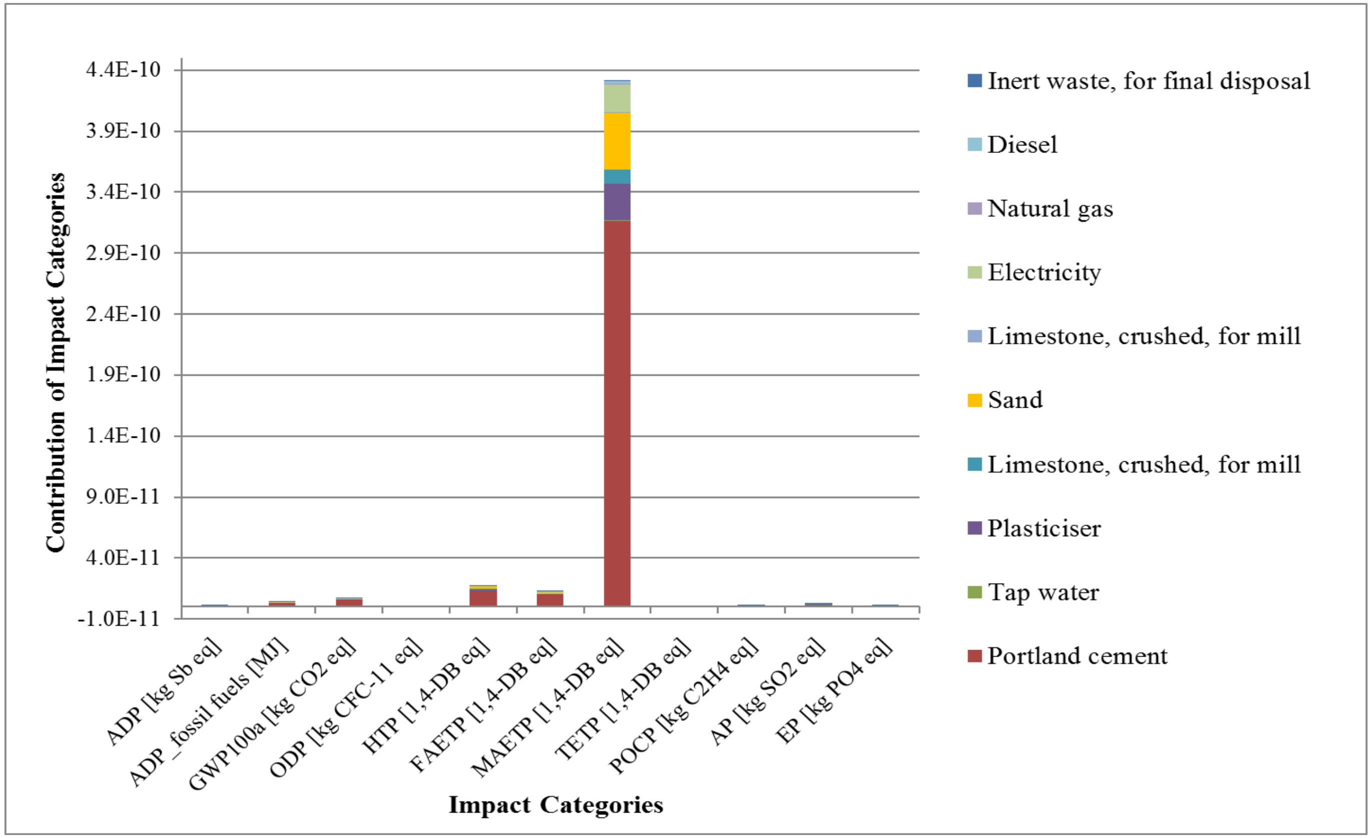

Figure AB.11. Normalized impact assessment results for Mixture-10

Table AB.12. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-11*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**GGBFS Processing**
ADP [kg Sb eq]	3.31E-13	1.92E-15	6.26E-14	2.01E-13	-6.6E-16
ADP_fossil fuels [MJ]	2.1E-12	4.31E-15	5.71E-13	4.16E-13	4.1E-13
GWP100a [kg CO_2 eq]	4.5E-12	3.44E-15	3.65E-13	2.63E-13	2.38E-13
ODP [kg CFC-11 eq]	2.66E-14	7.83E-16	9.33E-15	6.95E-15	3.21E-15
HTP [1,4-DB eq]	9.29E-12	3.81E-14	2.41E-12	2.33E-12	1.37E-12
FAETP [1,4-DB eq]	7.39E-12	2.56E-14	2.01E-12	1.26E-12	1.72E-12
MAETP [1,4-DB eq]	2.37E-10	8.76E-13	9.37E-11	5.13E-11	7.62E-11
TETP [1,4-DB eq]	2.22E-13	6.89E-16	1.96E-14	1.49E-14	1.83E-14
POCP [kg C_2H_4 eq]	4.01E-13	9.53E-16	1.08E-13	8.41E-14	6.48E-14
AP [kg SO_2 eq]	1.47E-12	2.47E-15	4.65E-13	2.69E-13	2.43E-13
EP [kg PO_4 eq]	8.56E-13	1.75E-15	2.3E-13	1.31E-13	1.63E-13

Table AB.12. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-11-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-1.76E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-2.52E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-2.03E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.12E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-7.22E-14	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-1.35E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-2.21E-14	1.91E-15

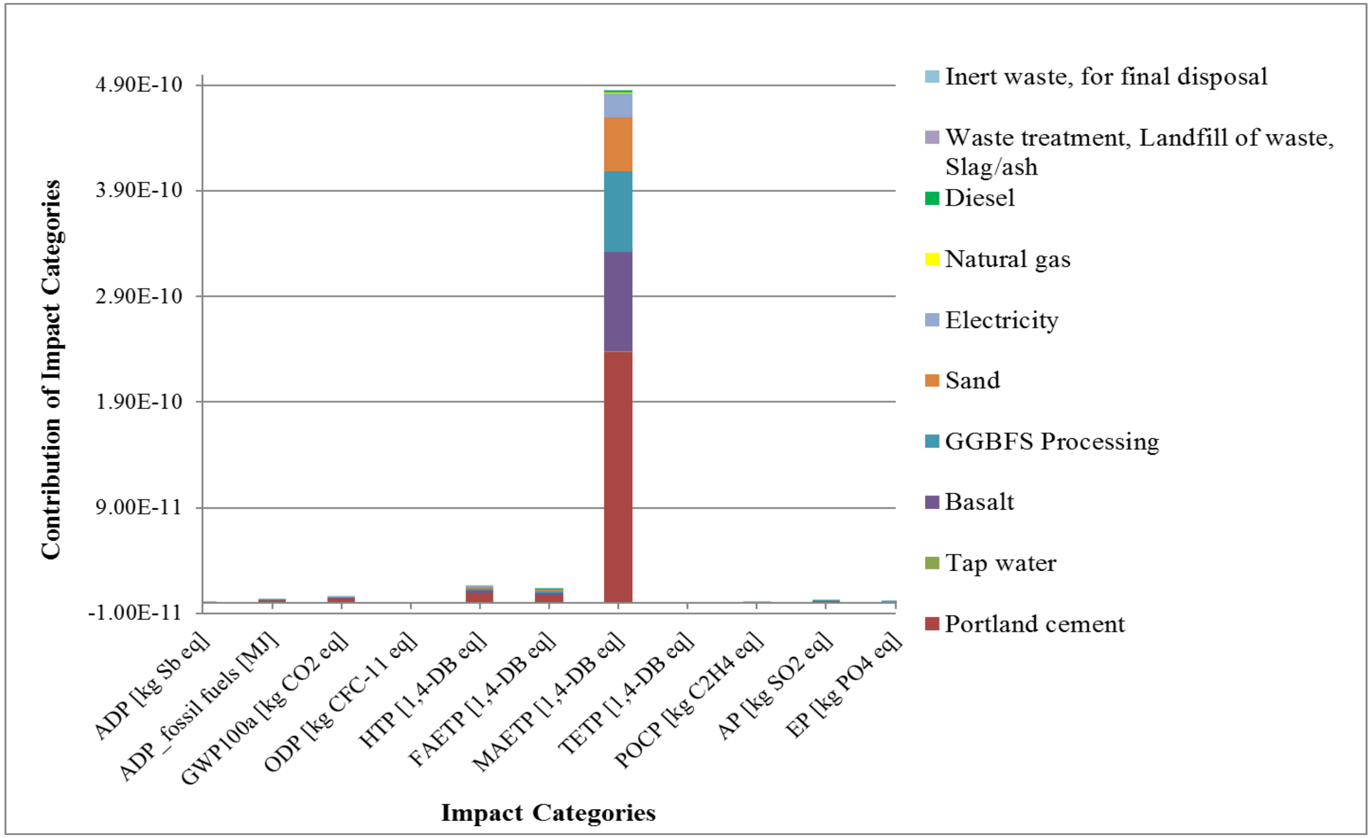

Figure AB.12. Normalized impact assessment results for Mixture-11

Table AB.13. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-12*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**GGBFS Processing**
ADP [kg Sb eq]	2.2E-13	1.92E-15	6.24E-14	2.0E-13	-9.9E-16
ADP_fossil fuels [MJ]	1.4E-12	4.31E-15	5.69E-13	4.15E-13	6.15E-13
GWP100a [kg CO_2 eq]	3.0E-12	3.44E-15	3.64E-13	2.62E-13	3.58E-13
ODP [kg CFC-11 eq]	1.78E-14	7.83E-16	9.31E-15	6.94E-15	4.82E-15
HTP [1,4-DB eq]	6.19E-12	3.81E-14	2.41E-12	2.32E-12	2.05E-12
FAETP [1,4-DB eq]	4.93E-12	2.56E-14	2.01E-12	1.26E-12	2.58E-12
MAETP [1,4-DB eq]	1.58E-10	8.76E-13	9.35E-11	5.12E-11	1.14E-10
TETP [1,4-DB eq]	1.48E-13	6.89E-16	1.96E-14	1.48E-14	2.74E-14
POCP [kg C_2H_4 eq]	2.67E-13	9.53E-16	1.08E-13	8.38E-14	9.72E-14
AP [kg SO_2 eq]	9.8E-13	2.47E-15	4.63E-13	2.69E-13	3.65E-13
EP [kg PO_4 eq]	5.71E-13	1.75E-15	2.3E-13	1.31E-13	2.45E-13

Table AB.13. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-12-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-2.64E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-3.78E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-3.05E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.68E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.08E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-2.03E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-3.31E-14	1.91E-15

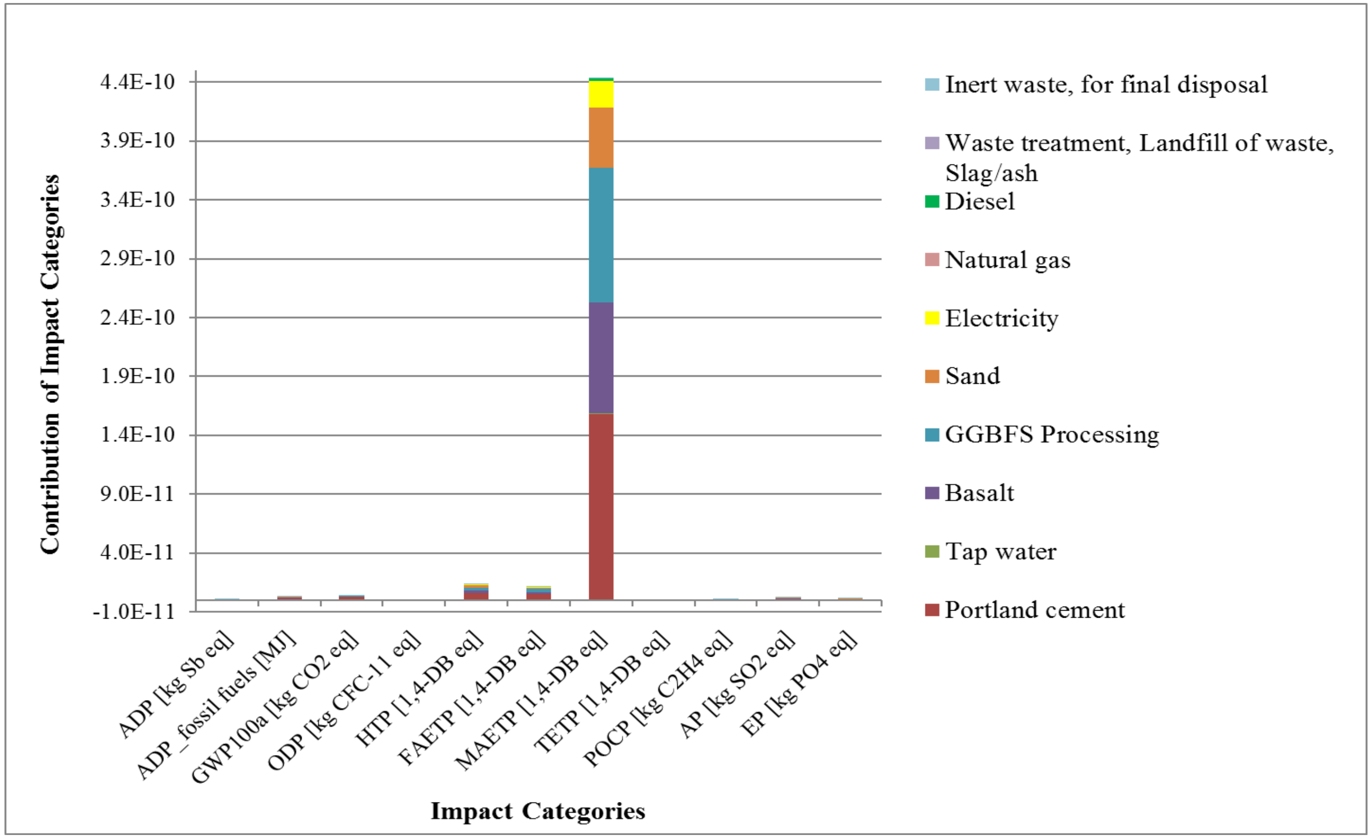

Figure AB.13. Normalized impact assessment results for Mixture-12

Table AB.14. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	3.91E-13	1.73E-15	2.84E-15	4.32E-14	5.0E-14	1.98E-13
ADP_fossil fuels [MJ]	2.48E-12	3.89E-15	9.48E-15	3.94E-13	5.29E-14	4.1E-13
GWP100a [kg CO_2 eq]	5.32E-12	3.1E-15	6.19E-15	2.52E-13	3.18E-14	2.59E-13
ODP [kg CFC-11 eq]	3.14E-14	7.06E-16	1.72E-16	6.44E-15	9.74E-16	6.86E-15
HTP [1,4-DB eq]	1.1E-11	3.44E-14	4.72E-14	1.66E-12	3.59E-13	2.3E-12
FAETP [1,4-DB eq]	8.73E-12	2.31E-14	2.07E-14	1.39E-12	1.78E-13	1.25E-12
MAETP [1,4-DB eq]	2.8E-10	7.9E-13	1.22E-12	6.47E-11	6.05E-12	5.06E-11
TETP [1,4-DB eq]	2.62E-13	6.22E-16	2.12E-16	1.36E-14	2.27E-15	1.47E-14
POCP [kg C_2H_4 eq]	4.73E-13	8.6E-16	2.14E-15	7.46E-14	8.29E-15	8.29E-14

Table AB.14. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13-continued*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**
AP [kg SO_2 eq]	1.74E-12	2.23E-15	1.68E-14	3.21E-13	2.63E-14	2.66E-13
EP [kg PO_4 eq]	1.01E-12	1.58E-15	6.87E-15	1.59E-13	1.62E-14	1.3E-13

Table AB.14. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-13-continued*

Mid-point Impact Category	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.28E-13	-6.51E-16	1.67E-16	1.79E-15	-1.13E-14	1.06E-15
ADP_fossil fuels [MJ]	4.89E-13	7.7E-14	3.2E-14	6.02E-14	-1.62E-13	1.33E-14
GWP100a [kg CO_2 eq]	1.76E-13	7.01E-14	2.17E-15	7.12E-15	-1.31E-13	4.48E-15
ODP [kg CFC-11 eq]	2.75E-15	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	1.94E-12	3.82E-13	2.77E-14	4.72E-14	-7.22E-15	2.71E-14
FAETP [1,4-DB eq]	6.12E-13	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	3.19E-11	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	7.37E-15	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	8.21E-14	1.57E-14	2.92E-15	4.54E-15	-4.65E-14	1.3E-15
AP [kg SO_2 eq]	2.08E-13	6.23E-14	8.66E-15	1.29E-14	-8.72E-14	4.53E-15
EP [kg PO_4 eq]	4.82E-14	4.98E-14	3.78E-16	2.96E-15	-1.42E-14	1.91E-15

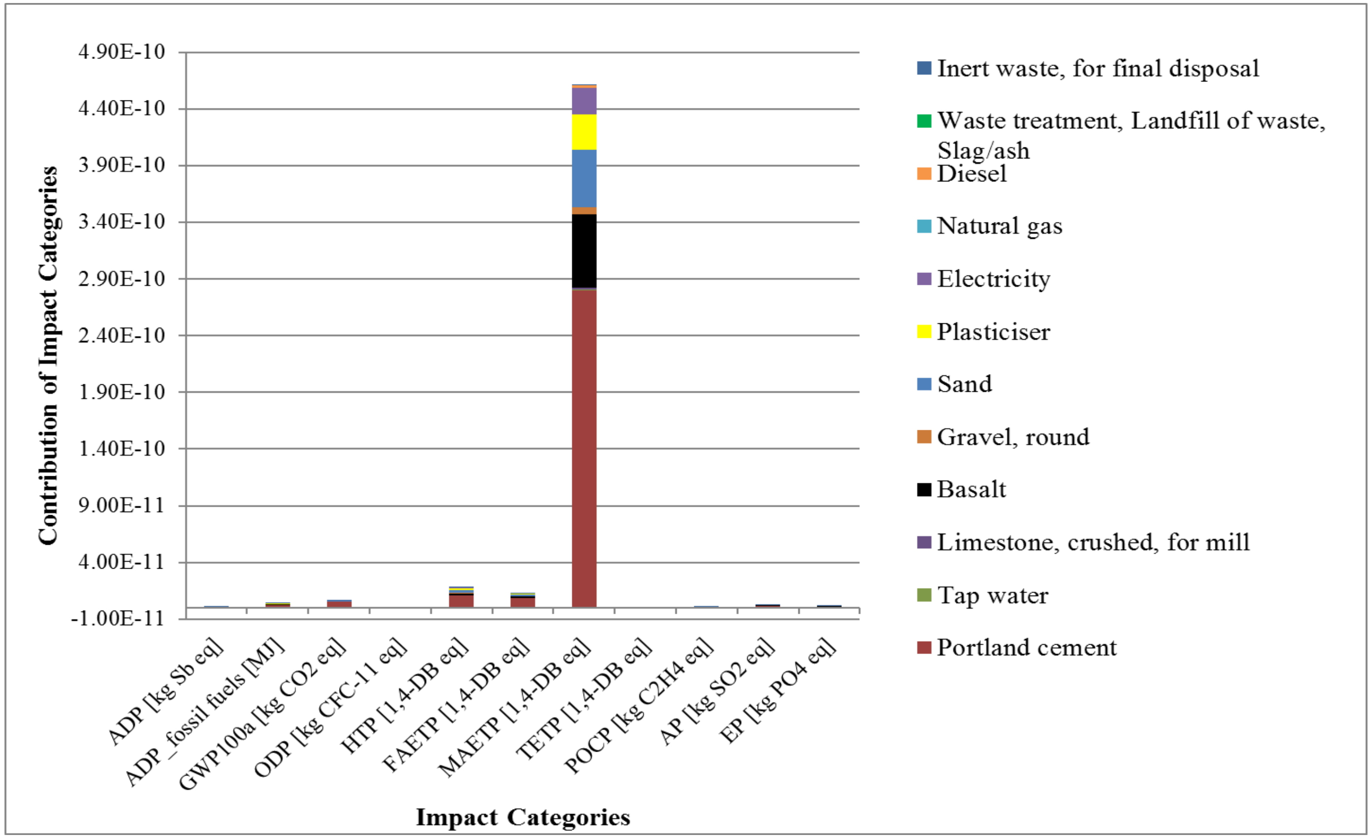

Figure AB.14. Normalized impact assessment results for Mixture-13

Table AB.15. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Perlite {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**
ADP [kg Sb eq]	3.93E-13	1.74E-15	1.8E-15	4.48E-14	5.03E-14	4.35E-14
ADP_fossil fuels [MJ]	2.5E-12	3.91E-15	7.05E-15	2.45E-13	5.32E-14	3.96E-13
GWP100a [kg CO_2 eq]	5.36E-12	3.12E-15	4.63E-15	1.66E-13	3.2E-14	2.54E-13
ODP [kg CFC-11 eq]	3.17E-14	7.11E-16	1.24E-16	3.9E-15	9.81E-16	6.48E-15
HTP [1,4-DB eq]	1.1E-11	3.46E-14	3.22E-14	1.51E-12	3.61E-13	1.68E-12
FAETP [1,4-DB eq]	8.79E-12	2.32E-14	1.56E-14	7.84E-13	1.8E-13	1.4E-12
MAETP [1,4-DB eq]	2.82E-10	7.96E-13	8.93E-13	3.4E-11	6.09E-12	6.51E-11
TETP [1,4-DB eq]	2.64E-13	6.26E-16	1.47E-16	8.61E-15	2.29E-15	1.36E-14

Table AB.15. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Perlite {GLO}| market for | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Basalt {GLO}| market for | Conseq, S**
POCP [kg C_2H_4 eq]	4.77E-13	8.65E-16	1.46E-15	7.23E-14	8.34E-15	7.51E-14
AP [kg SO_2 eq]	1.75E-12	2.24E-15	1.11E-14	3.23E-13	2.64E-14	3.23E-13
EP [kg PO_4 eq]	1.02E-12	1.59E-15	4.63E-15	1.12E-13	1.63E-14	1.6E-13

Table AB.15. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland }| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	1.99E-13	1.29E-13	-6.51E-16	1.67E-16	1.79E-15	-2.76E-16	1.06E-15
ADP_fossil fuel [MJ]	4.13E-13	4.92E-13	7.7E-14	3.2E-14	6.02E-14	3.26E-14	1.33E-14
GWP100a [kg CO_2 eq]	2.61E-13	1.77E-13	7.01E-14	2.17E-15	7.12E-15	2.97E-14	4.48E-15
ODP [kg CFC-11 eq]	6.9E-15	2.77E-15	4.97E-16	2.66E-16	1.16E-15	2.1E-16	2.55E-16
HTP [1,4-DB eq]	2.31E-12	1.96E-12	3.82E-13	2.77E-14	4.72E-14	1.62E-13	2.71E-14

Table AB.15. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-14-continued*

Mid-point Impact Category	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland }| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for perlite grinding)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
FAETP [1,4-DB eq]	1.25E-12	6.17E-13	5.17E-13	1.04E-14	2.43E-14	2.19E-13	1.2E-14
MAETP [1,4-DB eq]	5.09E-11	3.21E-11	2.27E-11	4.58E-13	2.29E-12	9.62E-12	4.74E-13
TETP [1,4-DB eq]	1.48E-14	7.42E-15	5.51E-15	6.58E-17	4.76E-16	2.33E-15	1.83E-16
POCP [kg C_2H_4 eq]	8.34E-14	8.26E-14	1.57E-14	2.92E-15	4.54E-15	6.63E-15	1.3E-15
AP [kg SO_2 eq]	2.67E-13	2.1E-13	6.23E-14	8.66E-15	1.29E-14	2.64E-14	4.53E-15
EP [kg PO_4 eq]	1.3E-13	4.86E-14	4.98E-14	3.78E-16	2.96E-15	2.11E-14	1.91E-15

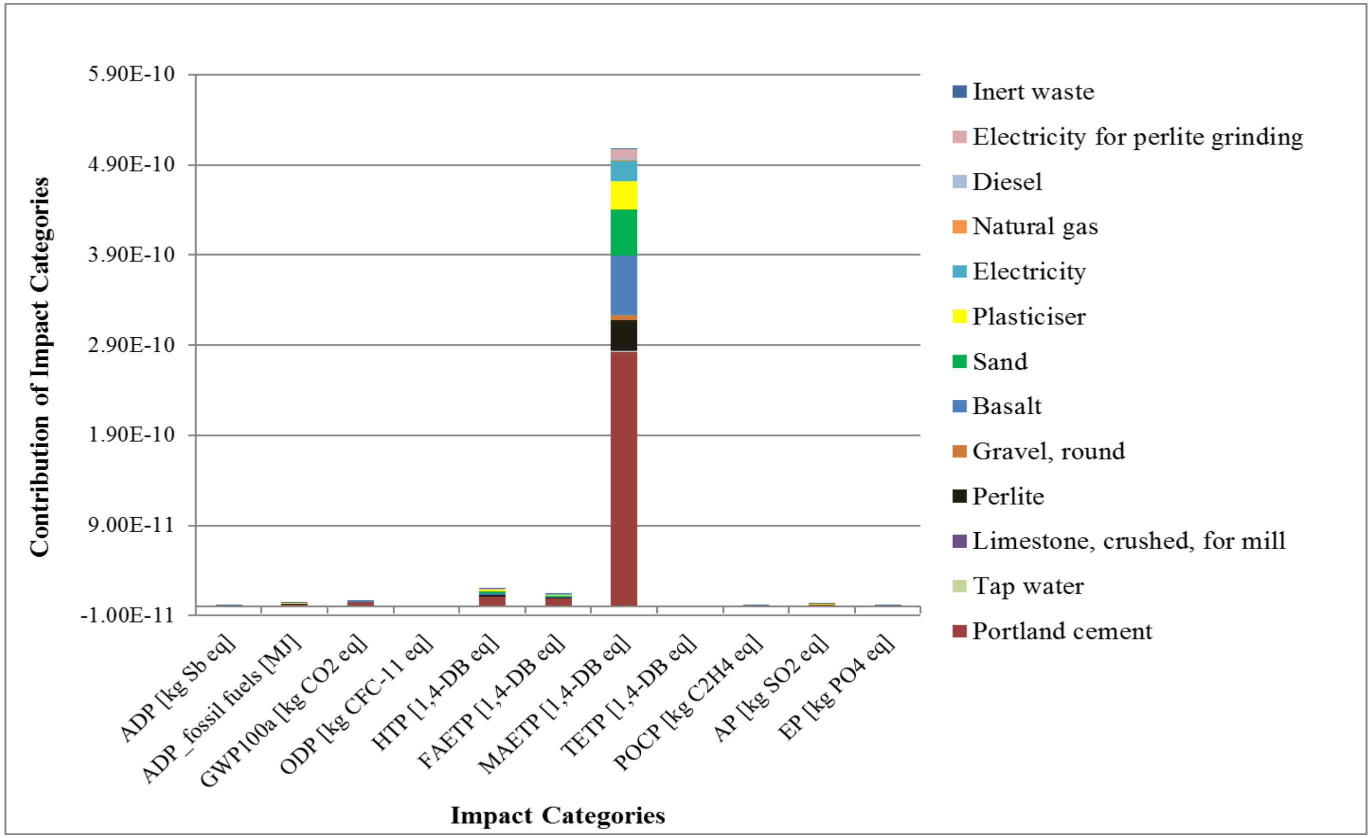

Figure AB.15. Normalized impact assessment results for Mixture-14

Table AB.16. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-15*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Gravel, round {CH}| market for gravel, round | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	2.83E-13	2.17E-15	5.62E-15	1.53E-13	1.24E-13	1.02E-13
ADP_fossil fuels [MJ]	1.8E-12	4.88E-15	1.87E-14	1.62E-13	2.57E-13	3.89E-13
GWP100a [kg CO_2 eq]	3.86E-12	3.89E-15	1.22E-14	9.73E-14	1.62E-13	1.4E-13
ODP [kg CFC-11 eq]	2.28E-14	8.86E-16	3.4E-16	2.98E-15	4.29E-15	2.19E-15
HTP [1,4-DB eq]	7.96E-12	4.31E-14	9.33E-14	1.1E-12	1.44E-12	1.54E-12
FAETP [1,4-DB eq]	6.34E-12	2.89E-14	4.1E-14	5.46E-13	7.8E-13	4.87E-13
MAETP [1,4-DB eq]	2.03E-10	9.92E-13	2.42E-12	1.85E-11	3.17E-11	2.54E-11
TETP [1,4-DB eq]	1.9E-13	7.8E-16	4.19E-16	6.95E-15	9.18E-15	5.86E-15
POCP [kg C_2H_4 eq]	3.44E-13	1.08E-15	4.22E-15	2.54E-14	5.19E-14	6.52E-14
AP [kg SO_2 eq]	1.26E-12	2.79E-15	3.32E-14	8.03E-14	1.66E-13	1.66E-13
EP [kg PO_4 eq]	7.34E-13	1.98E-15	1.36E-14	4.95E-14	8.11E-14	3.83E-14

Table AB.16. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-15-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-3.39E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-4.86E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-3.92E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0.0E+00	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-2.16E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0.0E+00	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0.0E+00	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0.0E+00	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.39E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-2.61E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-4.26E-14	1.91E-15

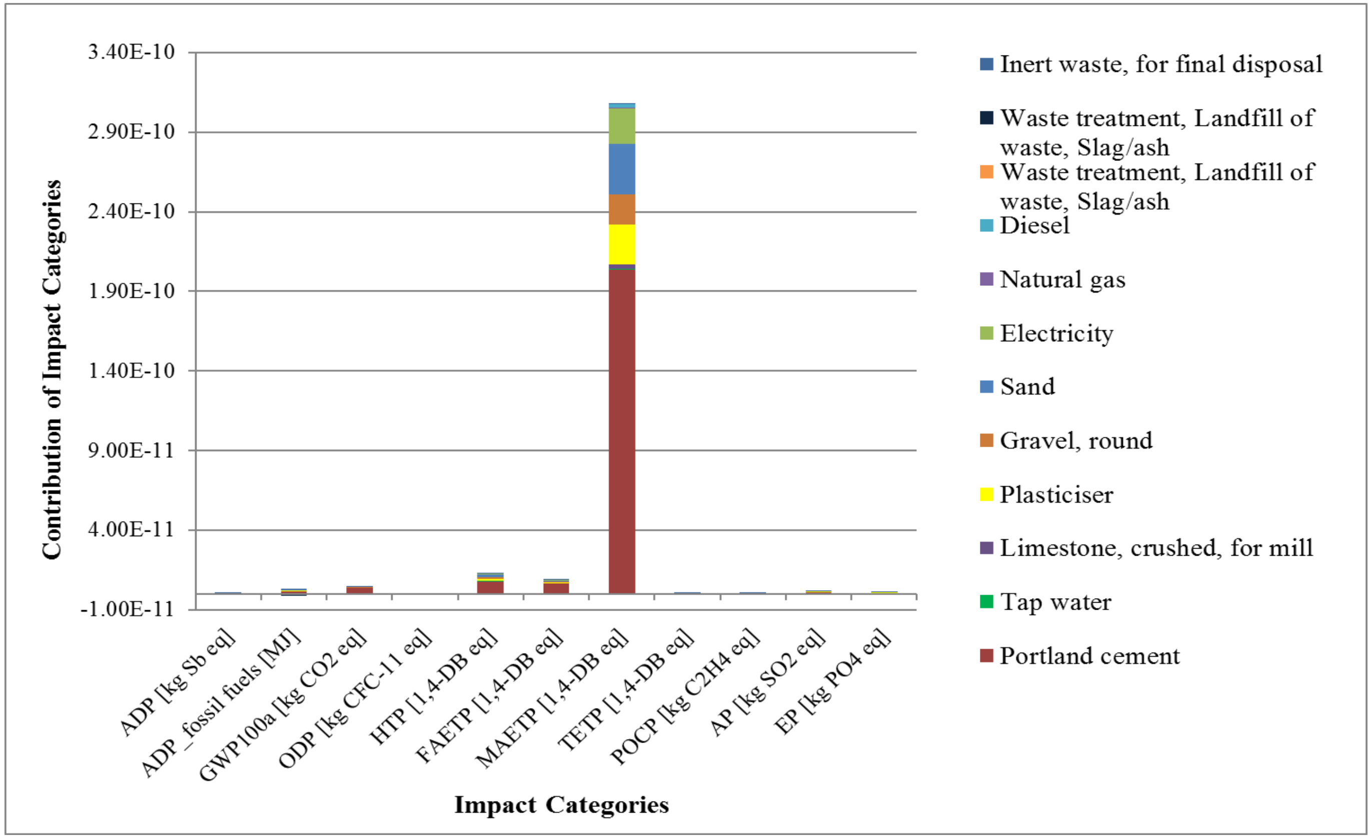

Figure AB.16. Normalized impact assessment results for Mixture-15

Table AB.17. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-16*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**GGBFS Processing**	**Sand {GLO}| market for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**
ADP [kg Sb eq]	2.95E-13	7.81E-16	-4.42E-16	1.93E-13	1.64E-14	-1.35E-13
ADP_fossil fuels [MJ]	1.88E-12	1.75E-15	2.75E-13	4.0E-13	5.45E-14	-3.39E-13
GWP100a [kg CO_2 eq]	4.02E-12	1.4E-15	1.6E-13	2.53E-13	3.56E-14	-2.63E-13
ODP [kg CFC-11 eq]	2.38E-14	3.19E-16	2.15E-15	6.69E-15	9.91E-16	-1.75E-16
HTP [1,4-DB eq]	8.29E-12	1.55E-14	9.17E-13	2.24E-12	2.72E-13	-2.27E-12
FAETP [1,4-DB eq]	6.6E-12	1.04E-14	1.15E-12	1.22E-12	1.19E-13	9.76E-14
MAETP [1,4-DB eq]	2.12E-10	3.57E-13	5.1E-11	4.93E-11	7.05E-12	-6.95E-12
TETP [1,4-DB eq]	1.98E-13	2.81E-16	1.22E-14	1.43E-14	1.22E-15	-3.95E-15
POCP [kg C_2H_4 eq]	3.58E-13	3.88E-16	4.34E-14	8.09E-14	1.23E-14	-1.48E-13
AP [kg SO_2 eq]	1.31E-12	1.01E-15	1.63E-13	2.59E-13	9.65E-14	-1.78E-13
EP [kg PO_4 eq]	7.64E-13	7.12E-16	1.09E-13	1.26E-13	3.95E-14	-2.03E-14

Table AB.17. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-16-continued*

Mid-point Impact Category	Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S	Electricity, medium voltage {GLO}| market group for | Conseq, S	Natural gas, high pressure {GLO}| market group for | Conseq, S	Diesel {Europe without Switzerland}| market for | Conseq, S	128 Waste treatment, Landfill of waste, Slag/ash, EU27	Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S
ADP [kg Sb eq]	7.93E-14	-6.51E-16	1.67E-16	1.79E-15	-2.35E-14	1.06E-15
ADP_fossil fuels [MJ]	3.04E-13	7.7E-14	3.2E-14	6.02E-14	-3.38E-13	1.33E-14
GWP100a [kg CO_2 eq]	1.09E-13	7.01E-14	2.17E-15	7.12E-15	-2.72E-13	4.48E-15
ODP [kg CFC-11 eq]	1.71E-15	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	1.21E-12	3.82E-13	2.77E-14	4.72E-14	-1.5E-14	2.71E-14
FAETP [1,4-DB eq]	3.8E-13	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	1.98E-11	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	4.58E-15	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	5.1E-14	1.57E-14	2.92E-15	4.54E-15	-9.67E-14	1.3E-15
AP [kg SO_2 eq]	1.29E-13	6.23E-14	8.66E-15	1.29E-14	-1.81E-13	4.53E-15
EP [kg PO_4 eq]	3.0E-14	4.98E-14	3.78E-16	2.96E-15	-2.96E-14	1.91E-15

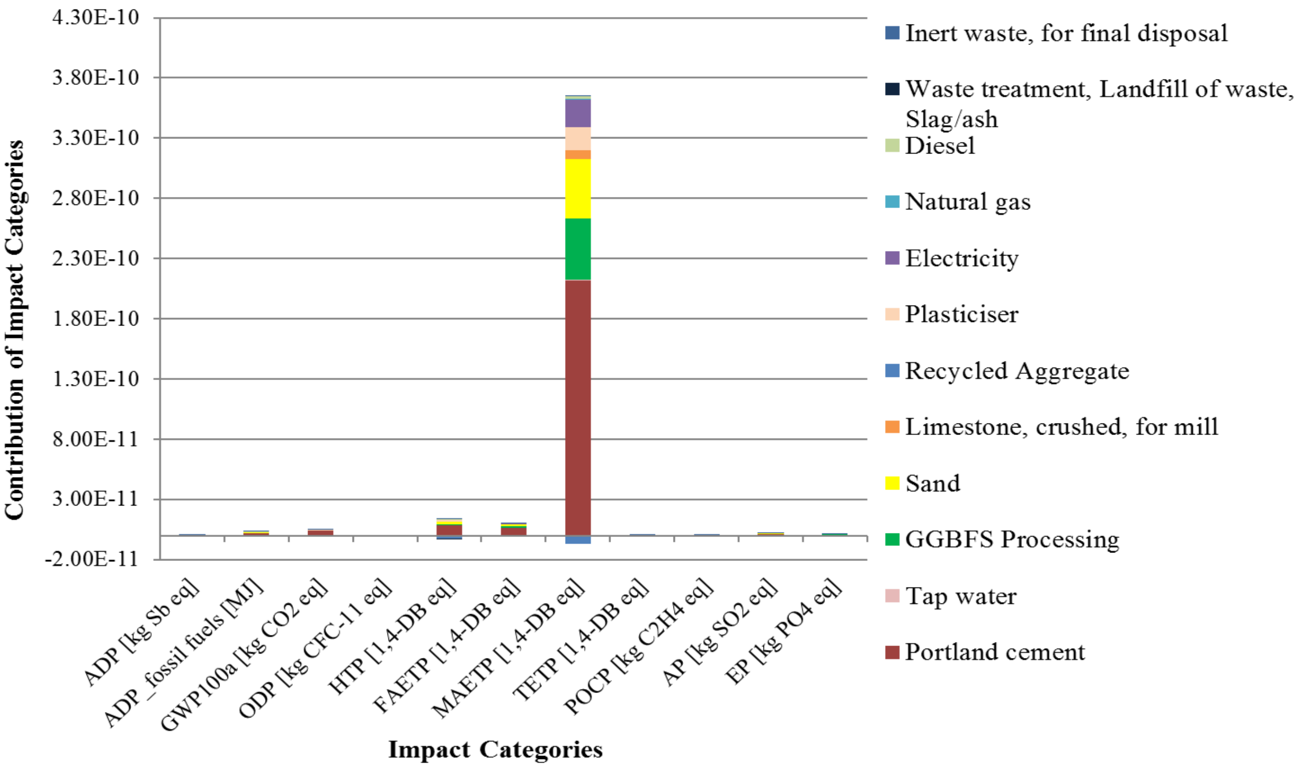

Figure AB.17. Normalized impact assessment results for Mixture-16

Table AB.18. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-17*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	5.12E-13	1.78E-15	1.72E-14	-7.03E-13	9.5E-14
ADP_fossil fuels [MJ]	3.25E-12	3.99E-15	5.74E-14	-1.76E-12	3.64E-13
GWP100a [kg CO_2 eq]	6.97E-12	3.18E-15	3.75E-14	-1.37E-12	1.31E-13
ODP [kg CFC-11 eq]	4.12E-14	7.25E-16	1.04E-15	-9.11E-16	2.05E-15
HTP [1,4-DB eq]	1.44E-11	3.53E-14	2.86E-13	-1.18E-11	1.44E-12
FAETP [1,4-DB eq]	1.14E-11	2.37E-14	1.26E-13	5.08E-13	4.55E-13
MAETP [1,4-DB eq]	3.67E-10	8.11E-13	7.42E-12	-3.61E-11	2.37E-11
TETP [1,4-DB eq]	3.43E-13	6.38E-16	1.29E-15	-2.05E-14	5.48E-15
POCP [kg C_2H_4 eq]	6.2E-13	8.82E-16	1.29E-14	-7.68E-13	6.1E-14
AP [kg SO_2 eq]	2.27E-12	2.29E-15	1.02E-13	-9.28E-13	1.55E-13
EP [kg PO_4 eq]	1.32E-12	1.62E-15	4.16E-14	-1.05E-13	3.59E-14

Table AB.18. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-17-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	1.91E-15

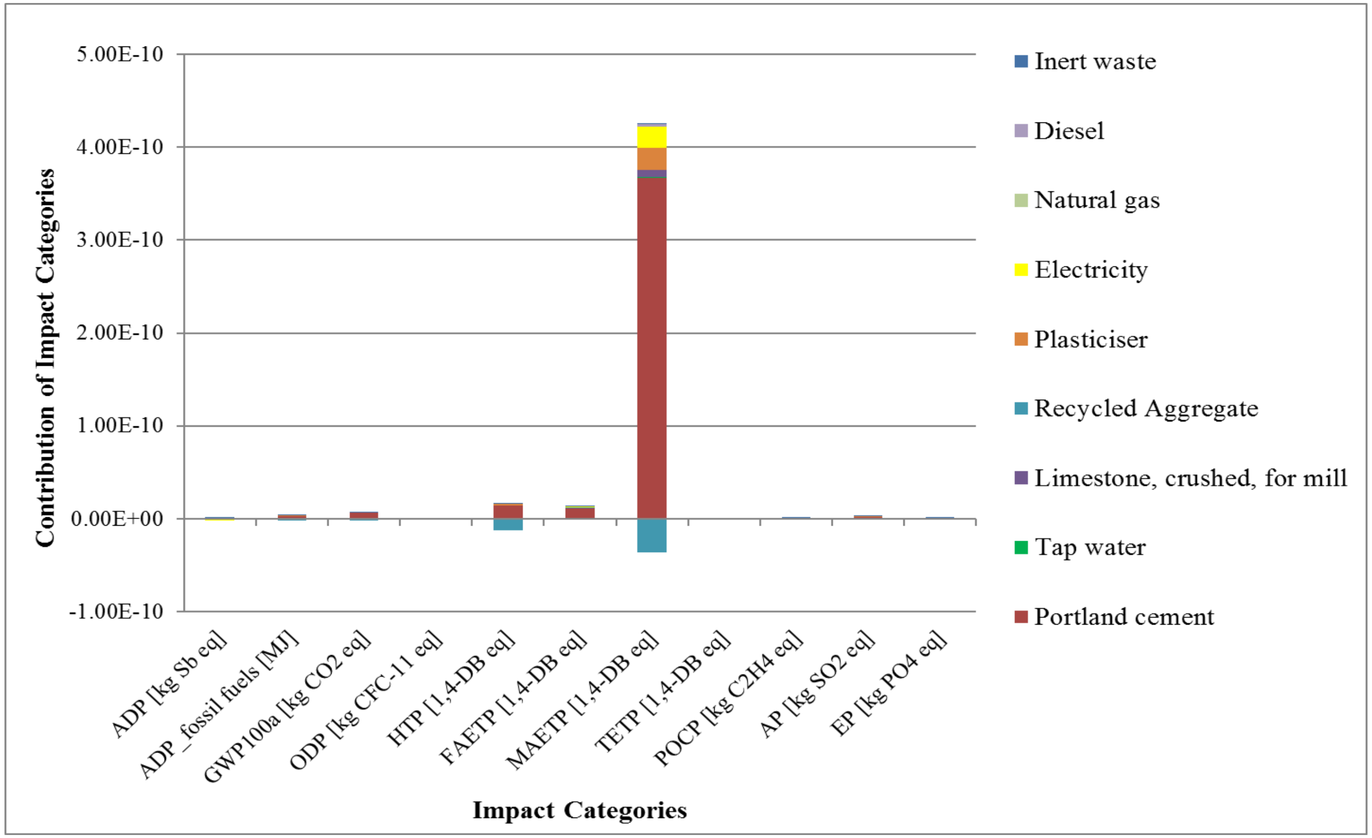

Figure AB.18. Normalized impact assessment results for Mixture-17

Table AB.19. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-18*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Limestone, crushed, for mill {CH}| market for limestone, crushed, for mill | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	4.72E-13	1.81E-15	1.93E-14	-1.66E-13	5.01E-14
ADP_fossil fuels [MJ]	3.0E-12	4.06E-15	6.43E-14	-4.17E-13	1.92E-13
GWP100a [kg CO_2 eq]	6.43E-12	3.24E-15	4.2E-14	-3.24E-13	6.91E-14
ODP [kg CFC-11 eq]	3.8E-14	7.38E-16	1.17E-15	-2.15E-16	1.08E-15
HTP [1,4-DB eq]	1.33E-11	3.59E-14	3.2E-13	-2.79E-12	7.62E-13
FAETP [1,4-DB eq]	1.06E-11	2.41E-14	1.41E-13	1.2E-13	2.4E-13
MAETP [1,4-DB eq]	3.39E-10	8.26E-13	8.31E-12	-8.55E-12	1.25E-11
TETP [1,4-DB eq]	3.17E-13	6.5E-16	1.44E-15	-4.86E-15	2.89E-15
POCP [kg C_2H_4 eq]	5.73E-13	8.99E-16	1.45E-14	-1.82E-13	3.22E-14
AP [kg SO_2 eq]	2.1E-12	2.33E-15	1.14E-13	-2.19E-13	8.18E-14
EP [kg PO_4 eq]	1.22E-12	1.65E-15	4.66E-14	-2.49E-14	1.89E-14

Table AB.19. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-18-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	1.91E-15

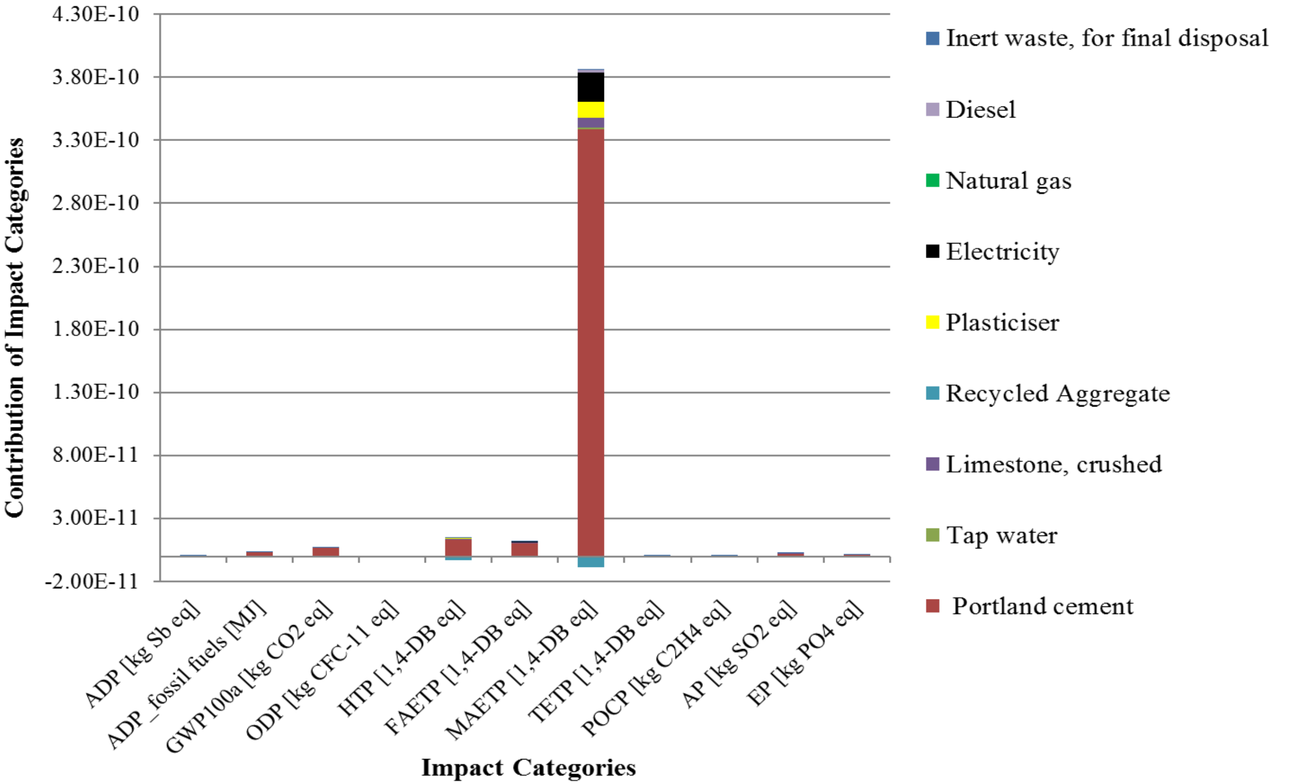

Figure AB.19. Normalized impact assessment results for Mixture-18

Table AB.20. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories_Mixture-19*

Mid-point Impact Category	Cement, Portland {Europe without Switzerland}| market for | Conseq, S	Tap water {GLO}| market group for | Conseq, S	Sand {GLO}| market for | Conseq, S	Recycled Aggregate	Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S
ADP [kg Sb eq]	6.46E-13	2.47E-15	1.41E-13	-1.28E-13	1.73E-13
ADP_fossil fuels [MJ]	4.11E-12	5.54E-15	2.92E-13	-3.2E-13	6.64E-13
GWP100a [kg CO_2 eq]	8.79E-12	4.42E-15	1.84E-13	-2.49E-13	2.39E-13
ODP [kg CFC-11 eq]	5.2E-14	1.01E-15	4.88E-15	-1.65E-16	3.74E-15
HTP [1,4-DB eq]	1.81E-11	4.9E-14	1.63E-12	-2.14E-12	2.64E-12
FAETP [1,4-DB eq]	1.44E-11	3.29E-14	8.87E-13	9.22E-14	8.32E-13
MAETP [1,4-DB eq]	4.63E-10	1.13E-12	3.6E-11	-6.56E-12	4.33E-11
TETP [1,4-DB eq]	4.33E-13	8.86E-16	1.04E-14	-3.73E-15	1.0E-14
POCP [kg C_2H_4 eq]	7.83E-13	1.23E-15	5.9E-14	-1.39E-13	1.11E-13
AP [kg SO_2 eq]	2.87E-12	3.17E-15	1.89E-13	-1.69E-13	2.83E-13
EP [kg PO_4 eq]	1.67E-12	2.25E-15	9.22E-14	-1.91E-14	6.55E-14

Table AB.20. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-19-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for granite crushing)**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-1.33E-16	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	1.57E-14	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	1.43E-14	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	1.01E-16	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	7.8E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	1.06E-13	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	4.65E-12	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	1.13E-15	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	3.2E-15	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	1.27E-14	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	1.02E-14	1.91E-15

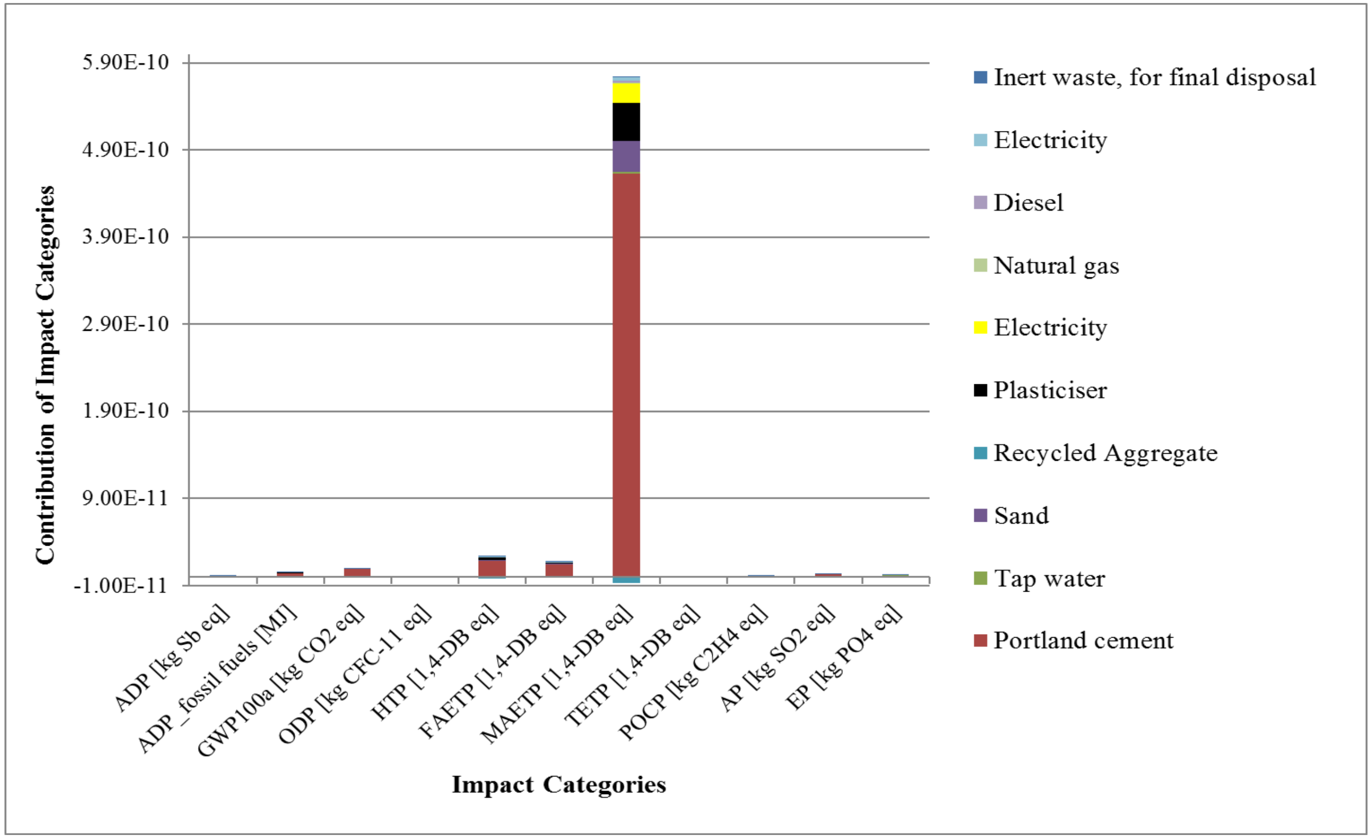

Figure AB.20. Normalized impact assessment results for Mixture-19

Table AB.21. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-20*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	4.84E-13	2.47E-15	1.15E-13	-3.02E-13	1.3E-13
ADP_fossil fuels [MJ]	3.08E-12	5.54E-15	2.39E-13	-7.57E-13	4.98E-13
GWP100a [kg CO_2 eq]	6.6E-12	4.42E-15	1.51E-13	-5.87E-13	1.79E-13
ODP [kg CFC-11 eq]	3.9E-14	1.01E-15	4.0E-15	-3.91E-16	2.8E-15
HTP [1,4-DB eq]	1.36E-11	4.9E-14	1.34E-12	-5.06E-12	1.98E-12
FAETP [1,4-DB eq]	1.08E-11	3.29E-14	7.27E-13	2.18E-13	6.24E-13
MAETP [1,4-DB eq]	3.47E-10	1.13E-12	2.95E-11	-1.55E-11	3.25E-11
TETP [1,4-DB eq]	3.25E-13	8.86E-16	8.55E-15	-8.81E-15	7.51E-15
POCP [kg C_2H_4 eq]	5.87E-13	1.23E-15	4.83E-14	-3.29E-13	8.36E-14
AP [kg SO_2 eq]	2.15E-12	3.17E-15	1.55E-13	-3.98E-13	2.12E-13
EP [kg PO_4 eq]	1.25E-12	2.25E-15	7.55E-14	-4.52E-14	4.91E-14

Table AB.21. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-20-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**Electricity, medium voltage {GLO}| market group for | Conseq, S (for granite crushing)**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-7.86E-17	-2.57E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	9.3E-15	-3.69E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	8.47E-15	-2.98E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	5.99E-17	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	4.61E-14	-1.64E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	6.24E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	2.74E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	6.65E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	1.89E-15	-1.06E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	7.52E-15	-1.98E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	6.0E-15	-3.23E-14	1.91E-15

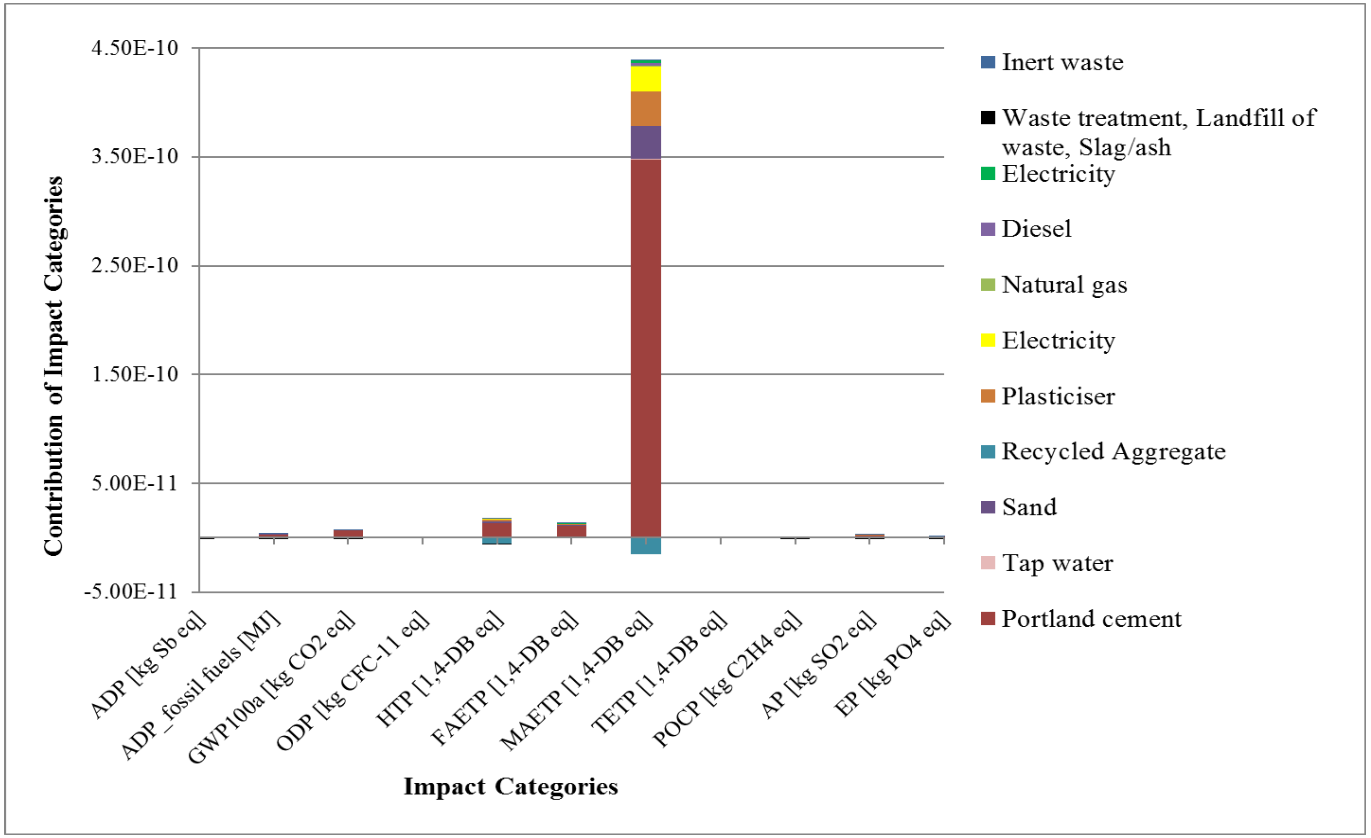

Figure AB.21. Normalized impact assessment results for Mixture-20

Table AB.22. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-21*

Mid-point Impact Category	**Cement, Portland {Europe without Switzerland}| market for | Conseq, S**	**Tap water {GLO}| market group for | Conseq, S**	**Sand {GLO}| market for | Conseq, S**	**Recycled Aggregate**	**Plasticiser, for concrete, based on sulfonated melamine formaldehyde {GLO}| production | Conseq, S**
ADP [kg Sb eq]	4.84E-13	2.47E-15	1.15E-13	-6.02E-13	1.3E-13
ADP_fossil fuels [MJ]	3.08E-12	5.54E-15	2.39E-13	-1.51E-12	4.98E-13
GWP100a [kg CO_2 eq]	6.6E-12	4.42E-15	1.51E-13	-1.17E-12	1.79E-13
ODP [kg CFC-11 eq]	3.9E-14	1.01E-15	4.0E-15	-7.81E-16	2.8E-15
HTP [1,4-DB eq]	1.36E-11	4.9E-14	1.34E-12	-1.01E-11	1.98E-12
FAETP [1,4-DB eq]	1.08E-11	3.29E-14	7.27E-13	4.35E-13	6.24E-13
MAETP [1,4-DB eq]	3.47E-10	1.13E-12	2.95E-11	-3.1E-11	3.25E-11
TETP [1,4-DB eq]	3.25E-13	8.86E-16	8.55E-15	-1.76E-14	7.51E-15
POCP [kg C_2H_4 eq]	5.87E-13	1.23E-15	4.83E-14	-6.58E-13	8.36E-14
AP [kg SO_2 eq]	2.15E-12	3.17E-15	1.55E-13	-7.96E-13	2.12E-13
EP [kg PO_4 eq]	1.25E-12	2.25E-15	7.55E-14	-9.04E-14	4.91E-14

Table AB.22. *Normalization Results for All Inputs and Outputs Regarding Midpoint Impact Categories _ Mixture-21-continued*

Mid-point Impact Category	**Electricity, medium voltage {GLO}| market group for | Conseq, S**	**Natural gas, high pressure {GLO}| market group for | Conseq, S**	**Diesel {Europe without Switzerland}| market for | Conseq, S**	**128 Waste treatment, Landfill of waste, Slag/ash, EU27**	**Inert waste, for final disposal {CH}| market for inert waste, for final disposal | Conseq, S**
ADP [kg Sb eq]	-6.51E-16	1.67E-16	1.79E-15	-2.57E-14	1.06E-15
ADP_fossil fuels [MJ]	7.7E-14	3.2E-14	6.02E-14	-3.69E-13	1.33E-14
GWP100a [kg CO_2 eq]	7.01E-14	2.17E-15	7.12E-15	-2.98E-13	4.48E-15
ODP [kg CFC-11 eq]	4.97E-16	2.66E-16	1.16E-15	0	2.55E-16
HTP [1,4-DB eq]	3.82E-13	2.77E-14	4.72E-14	-1.64E-14	2.71E-14
FAETP [1,4-DB eq]	5.17E-13	1.04E-14	2.43E-14	0	1.2E-14
MAETP [1,4-DB eq]	2.27E-11	4.58E-13	2.29E-12	0	4.74E-13
TETP [1,4-DB eq]	5.51E-15	6.58E-17	4.76E-16	0	1.83E-16
POCP [kg C_2H_4 eq]	1.57E-14	2.92E-15	4.54E-15	-1.06E-13	1.3E-15
AP [kg SO_2 eq]	6.23E-14	8.66E-15	1.29E-14	-1.98E-13	4.53E-15
EP [kg PO_4 eq]	4.98E-14	3.78E-16	2.96E-15	-3.23E-14	1.91E-15

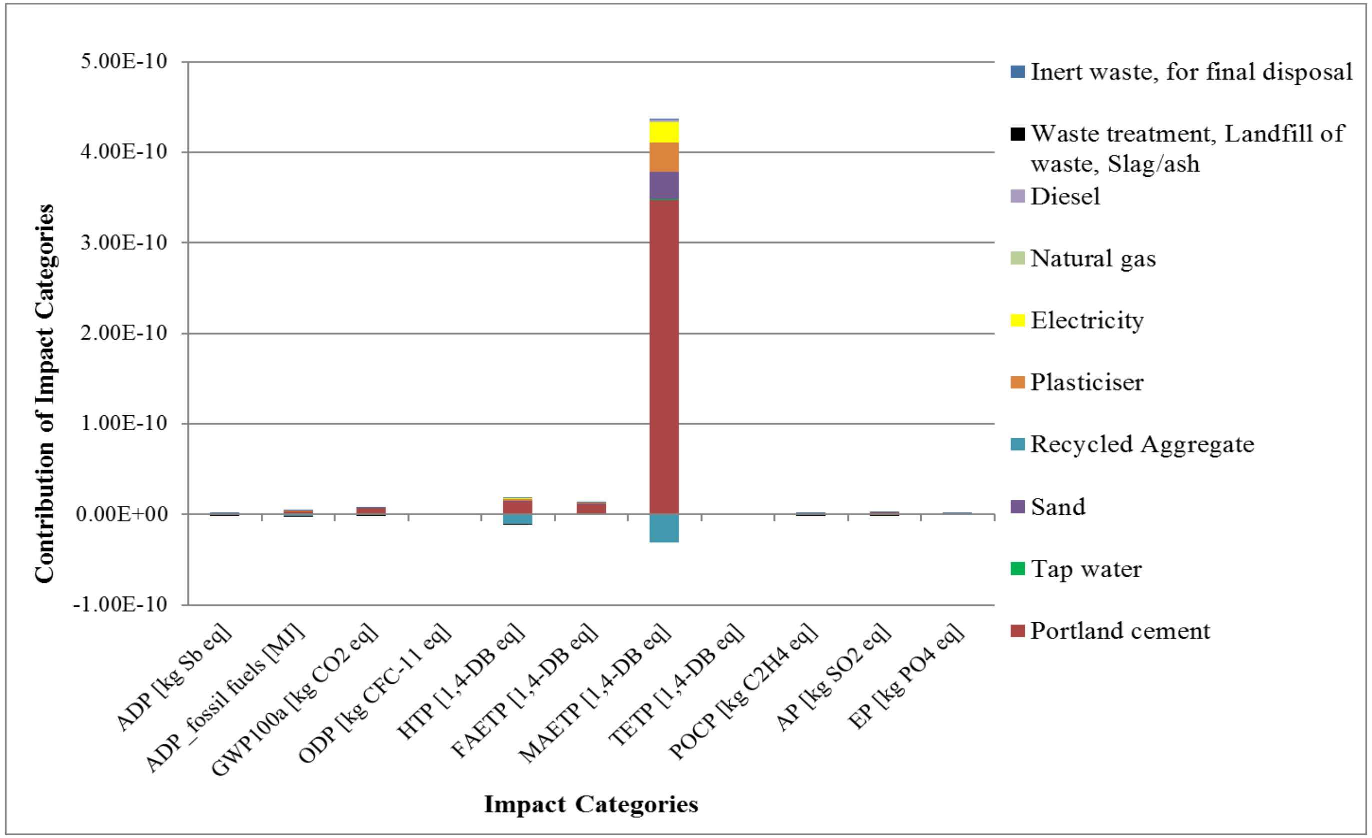

Figure AB.22. Normalized impact assessment results for Mixture-21

C. Total of Characterization Results for Control Mix and Concrete Mixtures

Table AC.1. *Total of Characterization Results for Control Mix and Concrete Mixtures*

Mid-point Impact Category	**Control Mix**	**Mixture-1**	**Mixture-2**	**Mixture-3**	**Mixture-4**
ADP [kg Sb eq]	2.01E-04	1.49E-04	1.65E-04	6.24E-05	5.62E-05
ADP_fossil fuels [MJ]	2.00E+03	1.61E+03	1.64E+03	9.10E+02	8.70E+02
GWP100a [kg CO_2 eq]	3.64E+02	3.06E+02	3.12E+02	2.06E+02	2.25E+02
ODP [kg CFC-11 eq]	1.52E-05	1.34E-05	1.37E-05	1.01E-05	1.09E-05
HTP [1,4-DB eq]	5.96E+01	4.86E+01	5.13E+01	2.41E+01	2.65E+01
FAETP [1,4-DB eq]	4.05E+01	3.52E+01	3.60E+01	2.73E+01	3.01E+01
MAETP [1,4-DB eq]	1.18E+05	1.03E+05	1.05E+05	7.35E+04	8.04E+04
TETP [1,4-DB eq]	4.73E-01	4.04E-01	4.16E-01	3.01E-01	3.44E-01
POCP [kg C_2H_4 eq]	3.63E-02	2.93E-02	2.93E-02	8.18E-03	5.67E-03
AP [kg SO_2 eq]	8.46E-01	7.15E-01	7.18E-01	4.21E-01	4.22E-01
EP [kg PO_4 eq]	3.06E-01	2.68E-01	2.71E-01	1.91E-01	2.08E-01

Table AC.1. *Total of Characterization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-5**	**Mixture-6**	**Mixture-7**	**Mixture-8**	**Mixture-9**
ADP [kg Sb eq]	1.75E-04	1.59E-04	1.49E-04	1.51E-04	2.04E-04
ADP_fossil fuels [MJ]	1.36E+03	1.17E+03	1.70E+03	1.73E+03	1.56E+03
GWP100a [kg CO_2 eq]	2.03E+02	1.62E+02	3.04E+02	3.07E+02	2.86E+02
ODP [kg CFC-11 eq]	9.81E-06	8.56E-06	1.47E-05	1.48E-05	1.24E-05
HTP [1,4-DB eq]	4.39E+01	3.88E+01	4.59E+01	4.70E+01	5.14E+01
FAETP [1,4-DB eq]	2.50E+01	2.14E+01	3.01E+01	3.08E+01	3.26E+01
MAETP [1,4-DB eq]	7.65E+04	6.69E+04	9.08E+04	9.28E+04	9.31E+04
TETP [1,4-DB eq]	2.76E-01	2.27E-01	3.82E-01	3.87E-01	3.89E-01
POCP [kg C_2H_4 eq]	2.27E-02	1.89E-02	3.47E-02	3.52E-02	2.66E-02
AP [kg SO_2 eq]	5.40E-01	4.58E-01	7.73E-01	7.89E-01	6.31E-01
EP [kg PO_4 eq]	1.83E-01	1.54E-01	2.37E-01	2.43E-01	2.36E-01

Table AC.1. *Total of Characterization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-10**	**Mixture-11**	**Mixture-12**	**Mixture-13**	**Mixture-14**
ADP [kg Sb eq]	1.62E-04	1.21E-04	9.63E-05	1.68E-04	1.81E-04
ADP_fossil fuels [MJ]	1.49E+03	1.31E+03	1.07E+03	1.47E+03	1.65E+03
GWP100a [kg CO_2 eq]	2.74E+02	2.20E+02	1.58E+02	2.51E+02	2.66E+02
ODP [kg CFC-11 eq]	1.11E-05	1.11E-05	9.47E-06	1.17E-05	1.27E-05
HTP [1,4-DB eq]	4.46E+01	4.10E+01	3.47E+01	4.59E+01	5.04E+01
FAETP [1,4-DB eq]	2.92E+01	3.07E+01	2.69E+01	3.02E+01	3.27E+01
MAETP [1,4-DB eq]	8.36E+04	9.41E+04	8.60E+04	8.94E+04	9.84E+04
TETP [1,4-DB eq]	3.55E-01	3.08E-01	2.37E-01	3.35E-01	3.50E-01
POCP [kg C_2H_4 eq]	2.70E-02	2.25E-02	1.74E-02	2.58E-02	3.06E-02
AP [kg SO_2 eq]	6.35E-01	5.73E-01	4.69E-01	6.15E-01	7.22E-01
EP [kg PO_4 eq]	2.27E-01	2.24E-01	1.90E-01	2.24E-01	2.48E-01

Table AC.1. *Total of Characterization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-15**	**Mixture-16**	**Mixture-17**	**Mixture-18**
ADP [kg Sb eq]	1.33E-04	8.96E-05	-1.56E-05	7.94E-05
ADP_fossil fuels [MJ]	8.86E+02	9.19E+02	7.98E+02	1.15E+03
GWP100a [kg CO_2 eq]	1.66E+02	1.73E+02	2.45E+02	2.64E+02
ODP [kg CFC-11 eq]	8.10E-06	8.54E-06	1.05E-05	9.75E-06
HTP [1,4-DB eq]	3.26E+01	2.87E+01	1.24E+01	3.11E+01
FAETP [1,4-DB eq]	2.08E+01	2.40E+01	3.10E+01	2.75E+01
MAETP [1,4-DB eq]	5.98E+04	6.95E+04	7.54E+04	7.33E+04
TETP [1,4-DB eq]	2.40E-01	2.55E-01	3.68E-01	3.53E-01
POCP [kg C_2H_4 eq]	1.38E-02	1.20E-02	-1.77E-03	1.70E-02
AP [kg SO_2 eq]	3.66E-01	4.03E-01	4.04E-01	5.17E-01
EP [kg PO_4 eq]	1.47E-01	1.70E-01	2.14E-01	2.09E-01

Table AC.1. *Total of Characterization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-19**	**Mixture-20**	**Mixture-21**
ADP [kg Sb eq]	1.75E-04	8.49E-05	2.23E-05
ADP_fossil fuels [MJ]	1.88E+03	1.10E+03	8.07E+02
GWP100a [kg CO_2 eq]	3.80E+02	2.57E+02	2.32E+02
ODP [kg CFC-11 eq]	1.45E-05	1.10E-05	1.09E-05
HTP [1,4-DB eq]	5.38E+01	3.21E+01	1.89E+01
FAETP [1,4-DB eq]	4.01E+01	3.09E+01	3.12E+01
MAETP [1,4-DB eq]	1.10E+05	8.21E+04	7.86E+04
TETP [1,4-DB eq]	5.01E-01	3.71E-01	3.61E-01
POCP [kg C_2H_4 eq]	3.10E-02	1.15E-02	-7.13E-04
AP [kg SO_2 eq]	7.82E-01	4.83E-01	3.86E-01
EP [kg PO_4 eq]	2.97E-01	2.16E-01	2.08E-01

D. Total of Normalization Results for Control Mix and Concrete Mixtures

Table AD.1. *Total of Normalization Results for Control Mix and Concrete Mixtures*

Mid-point Impact Category	**Control Mix**	**Mixture-1**	**Mixture-2**	**Mixture-3**	**Mixture-4**
ADP [kg Sb eq]	9.59E-13	7.11E-13	7.92E-13	2.98E-13	2.69E-13
ADP_fossil fuels [MJ]	5.27E-12	4.24E-12	4.32E-12	2.39E-12	2.29E-12
GWP100a [kg CO_2 eq]	8.7E-12	7.33E-12	7.46E-12	4.92E-12	5.39E-12
ODP [kg CFC-11 eq]	6.72E-14	5.9E-14	6.03E-14	4.46E-14	4.82E-14
HTP [1,4-DB eq]	2.31E-11	1.89E-11	1.99E-11	9.33E-12	1.03E-11
FAETP [1,4-DB eq]	1.71E-11	1.49E-11	1.52E-11	1.15E-11	1.27E-11
MAETP [1,4-DB eq]	6.07E-10	5.3E-10	5.39E-10	3.79E-10	4.15E-10
TETP [1,4-DB eq]	4.33E-13	3.69E-13	3.81E-13	2.76E-13	3.14E-13
POCP [kg C_2H_4 eq]	9.86E-13	7.95E-13	7.95E-13	2.24E-13	1.54E-13
AP [kg SO_2 eq]	3.54E-12	3.0E-12	3.01E-12	1.76E-12	1.77E-12
EP [kg PO_4 eq]	1.93E-12	1.69E-12	1.71E-12	1.21E-12	1.31E-12
Total	**6.69E-10**	**5.82E-10**	**5.93E-10**	**4.11E-10**	**4.5E-10**

Table AD.1. *Total of Normalization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-5**	**Mixture-6**	**Mixture-7**	**Mixture-8**	**Mixture-9**
ADP [kg Sb eq]	8.38E-13	7.59E-13	7.12E-13	7.23E-13	9.75E-13
ADP_fossil fuels [MJ]	3.59E-12	3.08E-12	4.47E-12	4.54E-12	4.11E-12
GWP100a [kg CO_2 eq]	4.85E-12	3.88E-12	7.26E-12	7.35E-12	6.84E-12
ODP [kg CFC-11 eq]	4.32E-14	3.77E-14	6.46E-14	6.53E-14	5.47E-14
HTP [1,4-DB eq]	1.7E-11	1.5E-11	1.78E-11	1.82E-11	1.99E-11
FAETP [1,4-DB eq]	1.06E-11	9.05E-12	1.27E-11	1.3E-11	1.38E-11
MAETP [1,4-DB eq]	3.95E-10	3.45E-10	4.69E-10	4.79E-10	4.8E-10
TETP [1,4-DB eq]	2.53E-13	2.08E-13	3.49E-13	3.54E-13	3.56E-13
POCP [kg C_2H_4 eq]	6.17E-13	5.14E-13	9.43E-13	9.57E-13	7.22E-13
AP [kg SO_2 eq]	2.26E-12	1.92E-12	3.24E-12	3.31E-12	2.64E-12
EP [kg PO_4 eq]	1.16E-12	9.74E-13	1.5E-12	1.53E-12	1.49E-12
Total	**4.36E-10**	**3.8E-10**	**5.18E-10**	**5.29E-10**	**5.31E-10**

Table AD.1. *Total of Normalization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-10**	**Mixture-11**	**Mixture-12**	**Mixture-13**	**Mixture-14**
ADP [kg Sb eq]	7.74E-13	5.8E-13	4.6E-13	8.05E-13	8.65E-13
ADP_fossil fuels [MJ]	3.92E-12	3.43E-12	2.81E-12	3.86E-12	4.33E-12
GWP100a [kg CO_2 eq]	6.56E-12	5.25E-12	3.77E-12	6.0E-12	6.37E-12
ODP [kg CFC-11 eq]	4.89E-14	4.91E-14	4.18E-14	5.15E-14	5.59E-14
HTP [1,4-DB eq]	1.73E-11	1.59E-11	1.35E-11	1.78E-11	1.96E-11
FAETP [1,4-DB eq]	1.24E-11	1.3E-11	1.14E-11	1.28E-11	1.38E-11
MAETP [1,4-DB eq]	4.32E-10	4.85E-10	4.44E-10	4.61E-10	5.08E-10
TETP [1,4-DB eq]	3.25E-13	2.82E-13	2.17E-13	3.07E-13	3.2E-13
POCP [kg C_2H_4 eq]	7.34E-13	6.11E-13	4.73E-13	7.02E-13	8.32E-13
AP [kg SO_2 eq]	2.66E-12	2.4E-12	1.96E-12	2.58E-12	3.03E-12
EP [kg PO_4 eq]	1.43E-12	1.42E-12	1.2E-12	1.41E-12	1.57E-12
Total	**4.78E-10**	**5.28E-10**	**4.8E-10**	**5.07E-10**	**5.59E-10**

Table AD.1. *Total of Normalization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-15**	**Mixture-16**	**Mixture-17**	**Mixture-18**
ADP [kg Sb eq]	6.38E-13	4.28E-13	-7.47E-14	3.8E-13
ADP_fossil fuels [MJ]	2.33E-12	2.42E-12	2.1E-12	3.03E-12
GWP100a [kg CO_2 eq]	3.97E-12	4.13E-12	5.86E-12	6.31E-12
ODP [kg CFC-11 eq]	3.57E-14	3.76E-14	4.63E-14	4.3E-14
HTP [1,4-DB eq]	1.26E-11	1.11E-11	4.83E-12	1.21E-11
FAETP [1,4-DB eq]	8.78E-12	1.01E-11	1.31E-11	1.17E-11
MAETP [1,4-DB eq]	3.08E-10	3.58E-10	3.89E-10	3.78E-10
TETP [1,4-DB eq]	2.2E-13	2.33E-13	3.36E-13	3.23E-13
POCP [kg C_2H_4 eq]	3.77E-13	3.26E-13	-4.83E-14	4.63E-13
AP [kg SO_2 eq]	1.54E-12	1.69E-12	1.69E-12	2.17E-12
EP [kg PO_4 eq]	9.31E-13	1.08E-12	1.35E-12	1.32E-12
Total	**3.39E-10**	**3.9E-10**	**4.18E-10**	**4.16E-10**

Table AD.1. *Total of Normalization Results for Control Mix and Concrete Mixtures-continued*

Mid-point Impact Category	**Mixture-19**	**Mixture-20**	**Mixture-21**
ADP [kg Sb eq]	8.37E-13	4.07E-13	1.06E-13
ADP_fossil fuels [MJ]	4.94E-12	2.89E-12	2.12E-12
GWP100a [kg CO_2 eq]	9.07E-12	6.14E-12	5.54E-12
ODP [kg CFC-11 eq]	6.37E-14	4.86E-14	4.82E-14
HTP [1,4-DB eq]	2.09E-11	1.24E-11	7.32E-12
FAETP [1,4-DB eq]	1.69E-11	1.31E-11	1.32E-11
MAETP [1,4-DB eq]	5.68E-10	4.24E-10	4.06E-10
TETP [1,4-DB eq]	4.58E-13	3.4E-13	3.3E-13
POCP [kg C_2H_4 eq]	8.42E-13	3.11E-13	-1.95E-14
AP [kg SO_2 eq]	3.28E-12	2.02E-12	1.62E-12
EP [kg PO_4 eq]	1.88E-12	1.36E-12	1.31E-12
Total	**6.27E-10**	**4.63E-10**	**4.38E-10**

E. Characterization Results for Building with Control Mix and Different Concrete Mixtures

Table AE.1. *Characterization Results for Building with Control Mix*

Mid-point Impact Category	**Control Mix**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	5.82E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	5.81E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	1.06E+02	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	4.42E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.73E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	1.17E+01	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	3.41E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.37E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	1.05E-02	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.45E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	8.87E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.1. *Characterization Results for Building with Control Mix-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.13E-07	2.04E-03
ADP_fossil fuels [MJ]	0.00E+00	4.80E+01	1.60E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.08E+00	5.50E+02
ODP [kg CFC-11 eq]	0.00E+00	7.05E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.45E-01	5.19E+02
FAETP [1,4-DB eq]	0.00E+00	1.40E-01	2.46E+02
MAETP [1,4-DB eq]	0.00E+00	4.64E+02	1.13E+06
TETP [1,4-DB eq]	0.00E+00	1.55E-03	2.25E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.42E-04	1.49E-01
AP [kg SO_2 eq]	0.00E+00	2.06E-02	2.51E+00
EP [kg PO_4 eq]	0.00E+00	4.96E-03	7.23E-01

Table AE.2. *Characterization Results for Building with Mixture-1 (Building_M1)*

Mid-point Impact Category	**Mixture-1**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.31E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.67E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	8.90E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.88E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.41E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	1.02E+01	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.98E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.17E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	8.47E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.07E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	7.77E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.2. *Characterization Results for Building with Mixture-1 (Building_M1)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.31E-07	2.02E-03
ADP_fossil fuels [MJ]	0.00E+00	5.07E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.25E+00	5.34E+02
ODP [kg CFC-11 eq]	0.00E+00	7.44E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.69E-01	5.16E+02
FAETP [1,4-DB eq]	0.00E+00	1.47E-01	2.45E+02
MAETP [1,4-DB eq]	0.00E+00	4.90E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.63E-03	2.23E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.72E-04	1.47E-01
AP [kg SO_2 eq]	0.00E+00	2.18E-02	2.48E+00
EP [kg PO_4 eq]	0.00E+00	5.23E-03	7.12E-01

Table AE.3. *Characterization Results for Building with Mixture-2 (Building_M2)*

Mid-point Impact Category	**Mixture-2**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.81E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.76E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	9.06E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.96E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.49E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	1.04E+01	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	3.03E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.21E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	8.47E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.08E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	7.85E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.3. *Characterization Results for Building with Mixture-2 (Building_M2)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.34E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.12E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.29E+00	5.35E+02
ODP [kg CFC-11 eq]	0.00E+00	7.52E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.74E-01	5.16E+02
FAETP [1,4-DB eq]	0.00E+00	1.49E-01	2.45E+02
MAETP [1,4-DB eq]	0.00E+00	4.95E+02	1.13E+06
TETP [1,4-DB eq]	0.00E+00	1.65E-03	2.23E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.78E-04	1.47E-01
AP [kg SO_2 eq]	0.00E+00	2.20E-02	2.48E+00
EP [kg PO_4 eq]	0.00E+00	5.29E-03	7.13E-01

Table AE.4. *Characterization Results for Building with Mixture-3 (Building_M3)*

Mid-point Impact Category	**Mixture-3**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.81E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.64E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	5.97E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.93E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	6.97E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	7.91E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.13E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	8.73E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	2.39E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.22E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	5.55E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.4. *Characterization Results for Building with Mixture-3 (Building_M3)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.27E-07	2.00E-03
ADP_fossil fuels [MJ]	0.00E+00	5.01E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.21E+00	5.04E+02
ODP [kg CFC-11 eq]	0.00E+00	7.35E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.64E-01	5.08E+02
FAETP [1,4-DB eq]	0.00E+00	1.45E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	4.83E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.61E-03	2.20E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.65E-04	1.41E-01
AP [kg SO_2 eq]	0.00E+00	2.15E-02	2.39E+00
EP [kg PO_4 eq]	0.00E+00	5.16E-03	6.90E-01

Table AE.5. *Characterization Results for Building with Mixture-4 (Building_M4)*

Mid-point Impact Category	**Mixture-4**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.63E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.52E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	6.54E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.17E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	7.68E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.74E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.33E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	9.96E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	1.64E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.22E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.03E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.5. *Characterization Results for Building with Mixture-4 (Building_M4)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.38E-07	2.00E-03
ADP_fossil fuels [MJ]	0.00E+00	5.18E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.33E+00	5.10E+02
ODP [kg CFC-11 eq]	0.00E+00	7.61E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.80E-01	5.09E+02
FAETP [1,4-DB eq]	0.00E+00	1.51E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	5.00E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.67E-03	2.21E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.85E-04	1.40E-01
AP [kg SO_2 eq]	0.00E+00	2.22E-02	2.39E+00
EP [kg PO_4 eq]	0.00E+00	5.35E-03	6.95E-01

Table AE.6. *Characterization Results for Building with Mixture-5 (Building_M5)*

Mid-point Impact Category	**Mixture-5**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	5.08E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.96E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	5.88E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.84E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.27E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	7.25E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.22E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	8.01E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	6.58E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.57E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	5.30E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.6. *Characterization Results for Building with Mixture-5 (Building_M5)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.54E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.42E+01	1.58E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.48E+00	5.04E+02
ODP [kg CFC-11 eq]	0.00E+00	7.96E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	5.02E-01	5.14E+02
FAETP [1,4-DB eq]	0.00E+00	1.57E-01	2.42E+02
MAETP [1,4-DB eq]	0.00E+00	5.23E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.75E-03	2.19E+00
POCP [kg C_2H_4 eq]	0.00E+00	6.11E-04	1.45E-01
AP [kg SO_2 eq]	0.00E+00	2.33E-02	2.43E+00
EP [kg PO_4 eq]	0.00E+00	5.59E-03	6.88E-01

Table AE.7. *Characterization Results for Building with Mixture-6 (Building_M6)*

Mid-point Impact Category	**Mixture-6**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.60E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.39E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	4.71E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.48E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.12E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	6.20E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	1.94E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	6.59E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	5.48E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.33E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	4.47E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.7. *Characterization Results for Building with Mixture-6 (Building_M6)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.50E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.36E+01	1.58E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.44E+00	4.92E+02
ODP [kg CFC-11 eq]	0.00E+00	7.88E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.97E-01	5.13E+02
FAETP [1,4-DB eq]	0.00E+00	1.56E-01	2.41E+02
MAETP [1,4-DB eq]	0.00E+00	5.18E+02	1.11E+06
TETP [1,4-DB eq]	0.00E+00	1.73E-03	2.18E+00
POCP [kg C_2H_4 eq]	0.00E+00	6.05E-04	1.44E-01
AP [kg SO_2 eq]	0.00E+00	2.30E-02	2.40E+00
EP [kg PO_4 eq]	0.00E+00	5.54E-03	6.79E-01

Table AE.8. *Characterization Results for Building with Mixture-7 (Building_M7)*

Mid-point Impact Category	**Mixture-7**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.32E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.93E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	8.81E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	4.25E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.33E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.73E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.63E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.11E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	1.01E-02	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.24E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.89E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.8. *Characterization Results for Building with Mixture-7 (Building_M7)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.22E-07	2.02E-03
ADP_fossil fuels [MJ]	0.00E+00	4.93E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.16E+00	5.33E+02
ODP [kg CFC-11 eq]	0.00E+00	7.24E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.57E-01	5.15E+02
FAETP [1,4-DB eq]	0.00E+00	1.43E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	4.76E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.59E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.56E-04	1.49E-01
AP [kg SO_2 eq]	0.00E+00	2.12E-02	2.49E+00
EP [kg PO_4 eq]	0.00E+00	5.09E-03	7.03E-01

Table AE.9. *Characterization Results for Building with Mixture-8 (Building_M8)*

Mid-point Impact Category	**Mixture-8**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.39E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	5.01E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	8.92E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	4.29E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.36E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.92E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.69E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.12E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	1.02E-02	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.29E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	7.04E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.9. *Characterization Results for Building with Mixture-8 (Building_M8)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.20E-07	2.02E-03
ADP_fossil fuels [MJ]	0.00E+00	4.90E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.14E+00	5.34E+02
ODP [kg CFC-11 eq]	0.00E+00	7.19E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.54E-01	5.15E+02
FAETP [1,4-DB eq]	0.00E+00	1.42E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.73E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.58E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.53E-04	1.49E-01
AP [kg SO_2 eq]	0.00E+00	2.10E-02	2.50E+00
EP [kg PO_4 eq]	0.00E+00	5.05E-03	7.05E-01

Table AE.10. *Characterization Results for Building with Mixture-9 (Building_M9)*

Mid-point Impact Category	**Mixture-9**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	5.92E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.53E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	8.30E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.60E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.49E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	9.46E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.70E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.13E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	7.70E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.83E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.86E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.10. *Characterization Results for Building with Mixture-9 (Building_M9)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.28E-07	2.04E-03
ADP_fossil fuels [MJ]	0.00E+00	5.03E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.23E+00	5.28E+02
ODP [kg CFC-11 eq]	0.00E+00	7.38E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.66E-01	5.16E+02
FAETP [1,4-DB eq]	0.00E+00	1.46E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.85E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.62E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.67E-04	1.46E-01
AP [kg SO_2 eq]	0.00E+00	2.16E-02	2.45E+00
EP [kg PO_4 eq]	0.00E+00	5.19E-03	7.03E-01

Table AE.11. *Characterization Results for Building with Mixture-10 (Building_M10)*

Mid-point Impact Category	**Mixture-10**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.69E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.32E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.96E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.21E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.29E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.48E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.43E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.03E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	7.82E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.84E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.57E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.11. *Characterization Results for Building with Mixture-10 (Building_M10)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.36E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.15E+01	1.58E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.30E+00	5.24E+02
ODP [kg CFC-11 eq]	0.00E+00	7.56E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.77E-01	5.14E+02
FAETP [1,4-DB eq]	0.00E+00	1.50E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	4.97E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.66E-03	2.21E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.81E-04	1.47E-01
AP [kg SO_2 eq]	0.00E+00	2.21E-02	2.45E+00
EP [kg PO_4 eq]	0.00E+00	5.31E-03	7.00E-01

Table AE.12. *Characterization Results for Building with Mixture-11 (Building_M11)*

Mid-point Impact Category	**Mixture-11**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	3.52E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.79E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	6.38E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.23E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.19E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.90E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.73E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	8.92E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	6.51E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.66E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.50E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.12. *Characterization Results for Building with Mixture-11 (Building_M11)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.30E-07	2.01E-03
ADP_fossil fuels [MJ]	0.00E+00	5.05E+01	1.58E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.24E+00	5.08E+02
ODP [kg CFC-11 eq]	0.00E+00	7.41E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.68E-01	5.13E+02
FAETP [1,4-DB eq]	0.00E+00	1.47E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.88E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.63E-03	2.20E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.70E-04	1.45E-01
AP [kg SO_2 eq]	0.00E+00	2.17E-02	2.44E+00
EP [kg PO_4 eq]	0.00E+00	5.21E-03	6.99E-01

Table AE.13. *Characterization Results for Building with Mixture-12 (Building_M12)*

Mid-point Impact Category	**Mixture-12**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.79E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.10E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	4.57E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.75E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.01E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	7.79E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.50E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	6.87E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	5.04E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.36E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	5.51E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.13. *Characterization Results for Building with Mixture-12 (Building_M12)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.29E-07	2.01E-03
ADP_fossil fuels [MJ]	0.00E+00	5.04E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.23E+00	4.90E+02
ODP [kg CFC-11 eq]	0.00E+00	7.40E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.67E-01	5.12E+02
FAETP [1,4-DB eq]	0.00E+00	1.46E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	4.87E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.62E-03	2.18E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.69E-04	1.44E-01
AP [kg SO_2 eq]	0.00E+00	2.16E-02	2.41E+00
EP [kg PO_4 eq]	0.00E+00	5.20E-03	6.89E-01

Table AE.14. *Characterization Results for Building with Mixture-13 (Building_M13)*

Mid-point Impact Category	**Mixture-13**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	4.88E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.26E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.28E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.39E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.33E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.75E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.59E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	9.73E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	7.49E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.78E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.48E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.14. *Characterization Results for Building with Mixture-13 (Building_M13)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.38E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.19E+01	1.58E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.33E+00	5.17E+02
ODP [kg CFC-11 eq]	0.00E+00	7.61E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.80E-01	5.15E+02
FAETP [1,4-DB eq]	0.00E+00	1.51E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	5.01E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.67E-03	2.21E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.85E-04	1.46E-01
AP [kg SO_2 eq]	0.00E+00	2.23E-02	2.45E+00
EP [kg PO_4 eq]	0.00E+00	5.35E-03	6.99E-01

Table AE.15. *Characterization Results for Building with Mixture-14 (Building_M14)*

Mid-point Impact Category	**Mixture-14**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	5.25E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	4.77E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.73E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.68E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.46E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	9.49E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.85E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.01E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	8.87E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.09E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	7.19E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.15. *Characterization Results for Building with Mixture-14 (Building_M14)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.41E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	5.22E+01	1.59E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.35E+00	5.22E+02
ODP [kg CFC-11 eq]	0.00E+00	7.67E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.84E-01	5.16E+02
FAETP [1,4-DB eq]	0.00E+00	1.52E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	5.04E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.68E-03	2.21E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.89E-04	1.48E-01
AP [kg SO_2 eq]	0.00E+00	2.24E-02	2.48E+00
EP [kg PO_4 eq]	0.00E+00	5.39E-03	7.07E-01

Table AE.16. *Characterization Results for Building with Mixture-15 (Building_M15)*

Mid-point Impact Category	**Mixture-15**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	3.87E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.57E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	4.82E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.35E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	9.45E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	6.02E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	1.73E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	6.96E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	4.01E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.06E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	4.27E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.16. *Characterization Results for Building with Mixture-15 (Building_M15)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.17E-07	2.02E-03
ADP_fossil fuels [MJ]	0.00E+00	4.87E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.12E+00	4.93E+02
ODP [kg CFC-11 eq]	0.00E+00	7.14E-07	2.16E-04
HTP [1,4-DB eq]	0.00E+00	4.51E-01	5.11E+02
FAETP [1,4-DB eq]	0.00E+00	1.41E-01	2.41E+02
MAETP [1,4-DB eq]	0.00E+00	4.70E+02	1.11E+06
TETP [1,4-DB eq]	0.00E+00	1.57E-03	2.18E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.49E-04	1.43E-01
AP [kg SO_2 eq]	0.00E+00	2.09E-02	2.38E+00
EP [kg PO_4 eq]	0.00E+00	5.02E-03	6.77E-01

Table AE.17. *Characterization Results for Building with Mixture-16 (Building_M16)*

Mid-point Impact Category	**Mixture-16**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.60E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.67E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	5.01E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.48E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	8.33E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	6.95E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.01E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	7.38E-02	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	3.47E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.17E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	4.93E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.17. *Characterization Results for Building with Mixture-16 (Building_M16)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.07E-07	2.01E-03
ADP_fossil fuels [MJ]	0.00E+00	4.71E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.02E+00	4.94E+02
ODP [kg CFC-11 eq]	0.00E+00	6.91E-07	2.16E-04
HTP [1,4-DB eq]	0.00E+00	4.36E-01	5.10E+02
FAETP [1,4-DB eq]	0.00E+00	1.37E-01	2.42E+02
MAETP [1,4-DB eq]	0.00E+00	4.55E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.52E-03	2.19E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.31E-04	1.42E-01
AP [kg SO_2 eq]	0.00E+00	2.02E-02	2.39E+00
EP [kg PO_4 eq]	0.00E+00	4.86E-03	6.83E-01

Table AE.18. *Characterization Results for Building with Mixture-17 (Building_M17)*

Mid-point Impact Category	**Mixture-17**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	-4.53E-06	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.31E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.11E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.04E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	3.61E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.99E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.19E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.07E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	-5.14E-04	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.17E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.21E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.18. *Characterization Results for Building with Mixture-17 (Building_M17)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.22E-07	1.98E-03
ADP_fossil fuels [MJ]	0.00E+00	4.93E+01	1.56E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.16E+00	5.16E+02
ODP [kg CFC-11 eq]	0.00E+00	7.24E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.56E-01	5.05E+02
FAETP [1,4-DB eq]	0.00E+00	1.43E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.76E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.59E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.56E-04	1.38E-01
AP [kg SO_2 eq]	0.00E+00	2.12E-02	2.39E+00
EP [kg PO_4 eq]	0.00E+00	5.09E-03	6.96E-01

Table AE.19. *Characterization Results for Building with Mixture-18 (Building_M18)*

Mid-point Impact Category	**Mixture-18**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.30E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.34E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.66E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	2.83E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	9.03E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	7.99E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.12E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.02E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	4.94E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.50E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.06E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.19. *Characterization Results for Building with Mixture-18 (Building_M18)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.36E-07	2.00E-03
ADP_fossil fuels [MJ]	0.00E+00	5.15E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.31E+00	5.21E+02
ODP [kg CFC-11 eq]	0.00E+00	7.57E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.77E-01	5.11E+02
FAETP [1,4-DB eq]	0.00E+00	1.50E-01	2.43E+02
MAETP [1,4-DB eq]	0.00E+00	4.98E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.66E-03	2.21E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.82E-04	1.44E-01
AP [kg SO_2 eq]	0.00E+00	2.21E-02	2.42E+00
EP [kg PO_4 eq]	0.00E+00	5.32E-03	6.95E-01

Table AE.20. *Characterization Results for Building with Mixture-19 (Building_M19)*

Mid-point Impact Category	**Mixture-19**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	5.08E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	5.45E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	1.10E+02	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	4.19E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	1.56E+01	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	1.16E+01	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	3.19E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.45E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	8.98E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	2.27E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	8.61E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.20. *Characterization Results for Building with Mixture-19 (Building_M19)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.26E-07	2.03E-03
ADP_fossil fuels [MJ]	0.00E+00	4.99E+01	1.60E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.21E+00	5.55E+02
ODP [kg CFC-11 eq]	0.00E+00	7.33E-07	2.18E-04
HTP [1,4-DB eq]	0.00E+00	4.63E-01	5.17E+02
FAETP [1,4-DB eq]	0.00E+00	1.45E-01	2.46E+02
MAETP [1,4-DB eq]	0.00E+00	4.82E+02	1.13E+06
TETP [1,4-DB eq]	0.00E+00	1.61E-03	2.26E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.64E-04	1.48E-01
AP [kg SO_2 eq]	0.00E+00	2.14E-02	2.50E+00
EP [kg PO_4 eq]	0.00E+00	5.15E-03	7.21E-01

Table AE.21. *Characterization Results for Building with Mixture-20 (Building_M20)*

Mid-point Impact Category	**Mixture-20**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.47E-05	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	3.18E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	7.45E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.20E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	9.28E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	8.95E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.38E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.08E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	3.32E-03	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.40E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.26E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.21. *Characterization Results for Building with Mixture-20 (Building_M20)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.14E-07	2.00E-03
ADP_fossil fuels [MJ]	0.00E+00	4.82E+01	1.57E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.09E+00	5.19E+02
ODP [kg CFC-11 eq]	0.00E+00	7.08E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.46E-01	5.11E+02
FAETP [1,4-DB eq]	0.00E+00	1.40E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.66E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.55E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.44E-04	1.42E-01
AP [kg SO_2 eq]	0.00E+00	2.07E-02	2.41E+00
EP [kg PO_4 eq]	0.00E+00	4.97E-03	6.97E-01

Table AE.22. *Characterization Results for Building with Mixture-21 (Building_M21)*

Mid-point Impact Category	**Mixture-21**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	6.45E-06	1.89E-06	5.86E-11	6.11E-08	1.98E-03
ADP_fossil fuels [MJ]	2.34E+02	1.33E+04	4.95E-04	3.61E+01	1.99E+03
GWP100a [kg CO_2 eq]	6.73E+01	2.59E+02	4.28E-05	2.18E+00	1.80E+02
ODP [kg CFC-11 eq]	3.17E-06	2.02E-04	4.51E-12	4.33E-07	1.11E-05
HTP [1,4-DB eq]	5.47E+00	2.96E+01	1.50E-05	6.91E-01	4.71E+02
FAETP [1,4-DB eq]	9.05E+00	3.10E+01	1.86E-05	6.45E-02	2.04E+02
MAETP [1,4-DB eq]	2.28E+04	1.07E+05	6.18E-02	2.65E+02	9.87E+05
TETP [1,4-DB eq]	1.05E-01	9.66E-02	6.07E-08	2.07E-03	2.01E+00
POCP [kg C_2H_4 eq]	-2.08E-04	9.13E-02	9.55E-09	2.83E-04	4.66E-02
AP [kg SO_2 eq]	1.12E-01	1.20E+00	2.15E-07	4.71E-03	1.05E+00
EP [kg PO_4 eq]	6.02E-02	2.19E-01	1.17E-07	7.47E-04	4.10E-01

Table AE.22. *Characterization Results for Building with Mixture-21 (Building_M21)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	3.12E-07	1.99E-03
ADP_fossil fuels [MJ]	0.00E+00	4.79E+01	1.56E+04
GWP100a [kg CO_2 eq]	0.00E+00	3.07E+00	5.12E+02
ODP [kg CFC-11 eq]	0.00E+00	7.03E-07	2.17E-04
HTP [1,4-DB eq]	0.00E+00	4.43E-01	5.07E+02
FAETP [1,4-DB eq]	0.00E+00	1.39E-01	2.44E+02
MAETP [1,4-DB eq]	0.00E+00	4.62E+02	1.12E+06
TETP [1,4-DB eq]	0.00E+00	1.54E-03	2.22E+00
POCP [kg C_2H_4 eq]	0.00E+00	5.40E-04	1.39E-01
AP [kg SO_2 eq]	0.00E+00	2.06E-02	2.38E+00
EP [kg PO_4 eq]	0.00E+00	4.94E-03	6.94E-01

F. Normalization Results for Building with Control Mix and Different Concrete Mixtures

Table AF.1. *Normalization Results for Building with Control Mix*

Mid-point Impact Category	Control Mix	Energy Consumption	Water Consumption	Transportation	Other Building Materials
ADP [kg Sb eq]	2.78E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.53E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.52E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.95E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	6.70E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.97E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.76E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.26E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.86E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	1.03E-12	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	5.60E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.1. *Normalization Results for Building with Control Mix-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.50E-15	9.74E-12
ADP_fossil fuels [MJ]	0.00E+00	1.26E-13	4.20E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.37E-14	1.31E-11
ODP [kg CFC-11 eq]	0.00E+00	3.11E-15	9.63E-13
HTP [1,4-DB eq]	0.00E+00	1.73E-13	2.01E-10
FAETP [1,4-DB eq]	0.00E+00	5.90E-14	1.04E-10
MAETP [1,4-DB eq]	0.00E+00	2.39E-12	5.83E-09
TETP [1,4-DB eq]	0.00E+00	1.42E-15	2.06E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.47E-14	4.06E-12
AP [kg SO_2 eq]	0.00E+00	8.64E-14	1.05E-11
EP [kg PO_4 eq]	0.00E+00	3.13E-14	4.57E-12

Table AF.2. *Normalization Results for Building with Mixture-1 (Building_M1)*

Mid-point Impact Category	**Mixture-1**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.06E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.23E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.13E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.71E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.48E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.32E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.54E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.07E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.31E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	8.69E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.91E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.2. *Normalization Results for Building with Mixture-1 (Building_M1)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.58E-15	9.67E-12
ADP_fossil fuels [MJ]	0.00E+00	1.33E-13	4.18E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.78E-14	1.28E-11
ODP [kg CFC-11 eq]	0.00E+00	3.28E-15	9.61E-13
HTP [1,4-DB eq]	0.00E+00	1.82E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.23E-14	1.04E-10
MAETP [1,4-DB eq]	0.00E+00	2.53E-12	5.80E-09
TETP [1,4-DB eq]	0.00E+00	1.49E-15	2.04E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.56E-14	4.00E-12
AP [kg SO_2 eq]	0.00E+00	9.12E-14	1.04E-11
EP [kg PO_4 eq]	0.00E+00	3.31E-14	4.50E-12

Table AF.3. *Normalization Results for Building with Mixture-2 (Building_M2)*

Mid-point Impact Category	**Mixture-2**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.30E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.25E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.16E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.75E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.77E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.42E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.56E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.10E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.30E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	8.72E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.96E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.3. *Normalization Results for Building with Mixture-2 (Building_M2)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.60E-15	9.69E-12
ADP_fossil fuels [MJ]	0.00E+00	1.35E-13	4.18E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.86E-14	1.28E-11
ODP [kg CFC-11 eq]	0.00E+00	3.32E-15	9.61E-13
HTP [1,4-DB eq]	0.00E+00	1.84E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.30E-14	1.04E-10
MAETP [1,4-DB eq]	0.00E+00	2.55E-12	5.81E-09
TETP [1,4-DB eq]	0.00E+00	1.51E-15	2.04E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.57E-14	4.01E-12
AP [kg SO_2 eq]	0.00E+00	9.21E-14	1.04E-11
EP [kg PO_4 eq]	0.00E+00	3.34E-14	4.51E-12

Table AF.4. *Normalization Results for Building with Mixture-3 (Building_M3)*

Mid-point Impact Category	**Mixture-3**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	8.64E-14	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	6.94E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.43E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.29E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	2.71E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.35E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.10E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	7.99E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	6.49E-14	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	5.12E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.51E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.4. *Normalization Results for Building with Mixture-3 (Building_M3)-continued*

<table>
<tr><th>Mid-point Impact Category</th><th>Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U</th><th>Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U</th><th>Total</th></tr>
<tr><td>ADP [kg Sb eq]</td><td>0.00E+00</td><td>1.56E-15</td><td>9.55E-12</td></tr>
<tr><td>ADP_fossil fuels [MJ]</td><td>0.00E+00</td><td>1.32E-13</td><td>4.12E-11</td></tr>
<tr><td>GWP100a [kg CO_2 eq]</td><td>0.00E+00</td><td>7.68E-14</td><td>1.21E-11</td></tr>
<tr><td>ODP [kg CFC-11 eq]</td><td>0.00E+00</td><td>3.24E-15</td><td>9.57E-13</td></tr>
<tr><td>HTP [1,4-DB eq]</td><td>0.00E+00</td><td>1.80E-13</td><td>1.97E-10</td></tr>
<tr><td>FAETP [1,4-DB eq]</td><td>0.00E+00</td><td>6.15E-14</td><td>1.03E-10</td></tr>
<tr><td>MAETP [1,4-DB eq]</td><td>0.00E+00</td><td>2.49E-12</td><td>5.76E-09</td></tr>
<tr><td>TETP [1,4-DB eq]</td><td>0.00E+00</td><td>1.48E-15</td><td>2.01E-12</td></tr>
<tr><td>POCP [kg C_2H_4 eq]</td><td>0.00E+00</td><td>1.54E-14</td><td>3.84E-12</td></tr>
<tr><td>AP [kg SO_2 eq]</td><td>0.00E+00</td><td>9.00E-14</td><td>1.00E-11</td></tr>
<tr><td>EP [kg PO_4 eq]</td><td>0.00E+00</td><td>3.26E-14</td><td>4.36E-12</td></tr>
</table>

Table AF.5. *Normalization Results for Building with Mixture-4 (Building_M4)*

Mid-point Impact Category	**Mixture-4**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	7.79E-14	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	6.64E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.56E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.40E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	2.98E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.70E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.20E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.12E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	4.47E-14	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	5.13E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.81E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.5. *Normalization Results for Building with Mixture-4 (Building_M4)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.62E-15	9.54E-12
ADP_fossil fuels [MJ]	0.00E+00	1.36E-13	4.12E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.95E-14	1.22E-11
ODP [kg CFC-11 eq]	0.00E+00	3.35E-15	9.58E-13
HTP [1,4-DB eq]	0.00E+00	1.86E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	6.37E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.58E-12	5.77E-09
TETP [1,4-DB eq]	0.00E+00	1.53E-15	2.02E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.59E-14	3.82E-12
AP [kg SO_2 eq]	0.00E+00	9.32E-14	1.00E-11
EP [kg PO_4 eq]	0.00E+00	3.38E-14	4.39E-12

Table AF.6. *Normalization Results for Building with Mixture-5 (Building_M5)*

Mid-point Impact Category	**Mixture-5**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.43E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.04E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.41E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.25E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	4.94E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.07E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.15E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	7.33E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.79E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	6.56E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.35E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.6. *Normalization Results for Building with Mixture-5 (Building_M5)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.69E-15	9.71E-12
ADP_fossil fuels [MJ]	0.00E+00	1.43E-13	4.16E-11
GWP100a [kg CO_2 eq]	0.00E+00	8.31E-14	1.20E-11
ODP [kg CFC-11 eq]	0.00E+00	3.51E-15	9.57E-13
HTP [1,4-DB eq]	0.00E+00	1.95E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.66E-14	1.02E-10
MAETP [1,4-DB eq]	0.00E+00	2.70E-12	5.77E-09
TETP [1,4-DB eq]	0.00E+00	1.60E-15	2.01E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.66E-14	3.95E-12
AP [kg SO_2 eq]	0.00E+00	9.75E-14	1.02E-11
EP [kg PO_4 eq]	0.00E+00	3.53E-14	4.35E-12

Table AF.7. *Normalization Results for Building with Mixture-6 (Building_M6)*

Mid-point Impact Category	**Mixture-6**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.20E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	8.92E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.13E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.09E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	4.36E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	2.62E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.00E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	6.03E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.49E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	5.57E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	2.83E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.7. *Normalization Results for Building with Mixture-6 (Building_M6)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.67E-15	9.68E-12
ADP_fossil fuels [MJ]	0.00E+00	1.41E-13	4.14E-11
GWP100a [kg CO_2 eq]	0.00E+00	8.23E-14	1.18E-11
ODP [kg CFC-11 eq]	0.00E+00	3.47E-15	9.55E-13
HTP [1,4-DB eq]	0.00E+00	1.93E-13	1.99E-10
FAETP [1,4-DB eq]	0.00E+00	6.59E-14	1.02E-10
MAETP [1,4-DB eq]	0.00E+00	2.67E-12	5.75E-09
TETP [1,4-DB eq]	0.00E+00	1.58E-15	1.99E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.65E-14	3.92E-12
AP [kg SO_2 eq]	0.00E+00	9.65E-14	1.01E-11
EP [kg PO_4 eq]	0.00E+00	3.50E-14	4.29E-12

Table AF.8. *Normalization Results for Building with Mixture-7 (Building_M7)*

Mid-point Impact Category	**Mixture-7**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.06E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.30E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.11E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.87E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.17E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.69E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.36E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.01E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.73E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	9.39E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.35E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.8. *Normalization Results for Building with Mixture-7 (Building_M7)-continued*

Mid-point Impact Category	Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U	Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U	Total
ADP [kg Sb eq]	0.00E+00	1.54E-15	9.67E-12
ADP_fossil fuels [MJ]	0.00E+00	1.30E-13	4.18E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.56E-14	1.27E-11
ODP [kg CFC-11 eq]	0.00E+00	3.19E-15	9.62E-13
HTP [1,4-DB eq]	0.00E+00	1.77E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.06E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.46E-12	5.79E-09
TETP [1,4-DB eq]	0.00E+00	1.45E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.51E-14	4.05E-12
AP [kg SO_2 eq]	0.00E+00	8.87E-14	1.05E-11
EP [kg PO_4 eq]	0.00E+00	3.22E-14	4.44E-12

Table AF.9. *Normalization Results for Building with Mixture-8 (Building_M8)*

Mid-point Impact Category	Mixture-8	Energy Consumption	Water Consumption	Transportation	Other Building Materials
ADP [kg Sb eq]	2.10E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.32E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.13E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.89E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.29E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.77E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.39E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.03E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.78E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	9.59E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.45E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.9. *Normalization Results for Building with Mixture-8 (Building_M8)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.53E-15	9.67E-12
ADP_fossil fuels [MJ]	0.00E+00	1.29E-13	4.18E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.51E-14	1.28E-11
ODP [kg CFC-11 eq]	0.00E+00	3.17E-15	9.63E-13
HTP [1,4-DB eq]	0.00E+00	1.76E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.02E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.44E-12	5.79E-09
TETP [1,4-DB eq]	0.00E+00	1.44E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.50E-14	4.05E-12
AP [kg SO_2 eq]	0.00E+00	8.81E-14	1.05E-11
EP [kg PO_4 eq]	0.00E+00	3.19E-14	4.45E-12

Table AF.10. *Normalization Results for Building with Mixture-9 (Building_M9)*

Mid-point Impact Category	**Mixture-9**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.83E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.19E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.98E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.59E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.78E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.00E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.39E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.03E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.09E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	7.67E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.33E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.10. *Normalization Results for Building with Mixture-9 (Building_M9)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.57E-15	9.75E-12
ADP_fossil fuels [MJ]	0.00E+00	1.32E-13	4.17E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.71E-14	1.26E-11
ODP [kg CFC-11 eq]	0.00E+00	3.25E-15	9.60E-13
HTP [1,4-DB eq]	0.00E+00	1.81E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.18E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.50E-12	5.79E-09
TETP [1,4-DB eq]	0.00E+00	1.48E-15	2.04E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.54E-14	3.98E-12
AP [kg SO_2 eq]	0.00E+00	9.04E-14	1.03E-11
EP [kg PO_4 eq]	0.00E+00	3.28E-14	4.44E-12

Table AF.11. *Normalization Results for Building with Mixture-10 (Building_M10)*

Mid-point Impact Category	Mixture-10	Energy Consumption	Water Consumption	Transportation	Other Building Materials
ADP [kg Sb eq]	2.24E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.14E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.90E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.42E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.01E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.59E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.25E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.42E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.13E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	7.71E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.15E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.11. *Normalization Results for Building with Mixture-10 (Building_M10)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.61E-15	9.69E-12
ADP_fossil fuels [MJ]	0.00E+00	1.35E-13	4.17E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.90E-14	1.25E-11
ODP [kg CFC-11 eq]	0.00E+00	3.33E-15	9.58E-13
HTP [1,4-DB eq]	0.00E+00	1.85E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.33E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.57E-12	5.78E-09
TETP [1,4-DB eq]	0.00E+00	1.52E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.58E-14	3.99E-12
AP [kg SO_2 eq]	0.00E+00	9.26E-14	1.03E-11
EP [kg PO_4 eq]	0.00E+00	3.36E-14	4.43E-12

Table AF.12. *Normalization Results for Building with Mixture-11 (Building_M11)*

Mid-point Impact Category	**Mixture-11**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.68E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	9.96E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.52E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.42E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	4.61E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.76E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.41E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	8.16E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.77E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	6.97E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.11E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.12. *Normalization Results for Building with Mixture-11 (Building_M11)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.58E-15	9.63E-12
ADP_fossil fuels [MJ]	0.00E+00	1.33E-13	4.15E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.75E-14	1.21E-11
ODP [kg CFC-11 eq]	0.00E+00	3.27E-15	9.58E-13
HTP [1,4-DB eq]	0.00E+00	1.81E-13	1.99E-10
FAETP [1,4-DB eq]	0.00E+00	6.21E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.52E-12	5.79E-09
TETP [1,4-DB eq]	0.00E+00	1.49E-15	2.01E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.55E-14	3.95E-12
AP [kg SO_2 eq]	0.00E+00	9.08E-14	1.02E-11
EP [kg PO_4 eq]	0.00E+00	3.29E-14	4.42E-12

Table AF.13. *Normalization Results for Building with Mixture-12 (Building_M12)*

Mid-point Impact Category	**Mixture-12**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.33E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	8.15E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.09E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.21E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	3.91E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.30E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.29E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	6.28E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.37E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	5.70E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.48E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.13. *Normalization Results for Building with Mixture-12 (Building_M12)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.57E-15	9.60E-12
ADP_fossil fuels [MJ]	0.00E+00	1.33E-13	4.13E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.73E-14	1.17E-11
ODP [kg CFC-11 eq]	0.00E+00	3.26E-15	9.56E-13
HTP [1,4-DB eq]	0.00E+00	1.81E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	6.19E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.51E-12	5.78E-09
TETP [1,4-DB eq]	0.00E+00	1.49E-15	1.99E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.55E-14	3.91E-12
AP [kg SO_2 eq]	0.00E+00	9.06E-14	1.01E-11
EP [kg PO_4 eq]	0.00E+00	3.29E-14	4.36E-12

Table AF.14. *Normalization Results for Building with Mixture-13 (Building_M13)*

Mid-point Impact Category	**Mixture-13**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.33E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.12E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.74E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.49E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.16E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.70E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.34E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	8.90E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.04E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	7.47E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.10E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.14. *Normalization Results for Building with Mixture-13 (Building_M13)-continued*

<table>
<tr><th>Mid-point Impact Category</th><th>Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U</th><th>Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U</th><th>Total</th></tr>
<tr><td>ADP [kg Sb eq]</td><td>0.00E+00</td><td>1.62E-15</td><td>9.70E-12</td></tr>
<tr><td>ADP_fossil fuels [MJ]</td><td>0.00E+00</td><td>1.36E-13</td><td>4.16E-11</td></tr>
<tr><td>GWP100a [kg CO_2 eq]</td><td>0.00E+00</td><td>7.96E-14</td><td>1.24E-11</td></tr>
<tr><td>ODP [kg CFC-11 eq]</td><td>0.00E+00</td><td>3.36E-15</td><td>9.59E-13</td></tr>
<tr><td>HTP [1,4-DB eq]</td><td>0.00E+00</td><td>1.86E-13</td><td>2.00E-10</td></tr>
<tr><td>FAETP [1,4-DB eq]</td><td>0.00E+00</td><td>6.38E-14</td><td>1.03E-10</td></tr>
<tr><td>MAETP [1,4-DB eq]</td><td>0.00E+00</td><td>2.58E-12</td><td>5.78E-09</td></tr>
<tr><td>TETP [1,4-DB eq]</td><td>0.00E+00</td><td>1.53E-15</td><td>2.02E-12</td></tr>
<tr><td>POCP [kg C_2H_4 eq]</td><td>0.00E+00</td><td>1.59E-14</td><td>3.98E-12</td></tr>
<tr><td>AP [kg SO_2 eq]</td><td>0.00E+00</td><td>9.33E-14</td><td>1.03E-11</td></tr>
<tr><td>EP [kg PO_4 eq]</td><td>0.00E+00</td><td>3.38E-14</td><td>4.42E-12</td></tr>
</table>

Table AF.15. *Normalization Results for Building with Mixture-14 (Building_M14)*

Mid-point Impact Category	**Mixture-14**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.51E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.25E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.85E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.62E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	5.67E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.02E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.47E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.28E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.41E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	8.77E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	4.54E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.15. *Normalization Results for Building with Mixture-14 (Building_M14)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.63E-15	9.71E-12
ADP_fossil fuels [MJ]	0.00E+00	1.37E-13	4.18E-11
GWP100a [kg CO_2 eq]	0.00E+00	8.01E-14	1.25E-11
ODP [kg CFC-11 eq]	0.00E+00	3.38E-15	9.60E-13
HTP [1,4-DB eq]	0.00E+00	1.88E-13	2.00E-10
FAETP [1,4-DB eq]	0.00E+00	6.42E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.60E-12	5.80E-09
TETP [1,4-DB eq]	0.00E+00	1.54E-15	2.02E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.60E-14	4.02E-12
AP [kg SO_2 eq]	0.00E+00	9.39E-14	1.04E-11
EP [kg PO_4 eq]	0.00E+00	3.41E-14	4.47E-12

Table AF.16. *Normalization Results for Building with Mixture-15 (Building_M15)*

Mid-point Impact Category	**Mixture-15**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.85E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	6.76E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.15E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.04E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	3.67E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	2.55E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	8.94E-11	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	6.37E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.09E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	4.45E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	2.70E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.16. *Normalization Results for Building with Mixture-15 (Building_M15)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.52E-15	9.65E-12
ADP_fossil fuels [MJ]	0.00E+00	1.28E-13	4.12E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.46E-14	1.18E-11
ODP [kg CFC-11 eq]	0.00E+00	3.15E-15	9.54E-13
HTP [1,4-DB eq]	0.00E+00	1.75E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	5.98E-14	1.02E-10
MAETP [1,4-DB eq]	0.00E+00	2.42E-12	5.74E-09
TETP [1,4-DB eq]	0.00E+00	1.44E-15	2.00E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.49E-14	3.88E-12
AP [kg SO_2 eq]	0.00E+00	8.75E-14	9.96E-12
EP [kg PO_4 eq]	0.00E+00	3.17E-14	4.28E-12

Table AF.17. *Normalization Results for Building with Mixture-16 (Building_M16)*

Mid-point Impact Category	**Mixture-16**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.24E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	7.01E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.20E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.09E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	3.23E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	2.94E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.04E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	6.76E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	9.45E-14	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	4.90E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.12E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.17. *Normalization Results for Building with Mixture-16 (Building_M16)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.47E-15	9.59E-12
ADP_fossil fuels [MJ]	0.00E+00	1.24E-13	4.12E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.22E-14	1.18E-11
ODP [kg CFC-11 eq]	0.00E+00	3.05E-15	9.55E-13
HTP [1,4-DB eq]	0.00E+00	1.69E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	5.79E-14	1.02E-10
MAETP [1,4-DB eq]	0.00E+00	2.35E-12	5.75E-09
TETP [1,4-DB eq]	0.00E+00	1.39E-15	2.00E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.44E-14	3.87E-12
AP [kg SO_2 eq]	0.00E+00	8.47E-14	1.00E-11
EP [kg PO_4 eq]	0.00E+00	3.07E-14	4.32E-12

Table AF.18. *Normalization Results for Building with Mixture-17 (Building_M17)*

Mid-point Impact Category	**Mixture-17**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	-2.16E-14	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	6.08E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.70E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.34E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	1.40E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.80E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.13E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.76E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	-1.40E-14	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	4.91E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.93E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.18. *Normalization Results for Building with Mixture-17 (Building_M17)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.54E-15	9.44E-12
ADP_fossil fuels [MJ]	0.00E+00	1.30E-13	4.11E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.56E-14	1.23E-11
ODP [kg CFC-11 eq]	0.00E+00	3.19E-15	9.57E-13
HTP [1,4-DB eq]	0.00E+00	1.77E-13	1.96E-10
FAETP [1,4-DB eq]	0.00E+00	6.06E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.46E-12	5.76E-09
TETP [1,4-DB eq]	0.00E+00	1.45E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.51E-14	3.76E-12
AP [kg SO_2 eq]	0.00E+00	8.86E-14	1.00E-11
EP [kg PO_4 eq]	0.00E+00	3.21E-14	4.40E-12

Table AF.19. *Normalization Results for Building with Mixture-18 (Building_M18)*

Mid-point Impact Category	**Mixture-18**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.10E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	8.79E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.83E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.25E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	3.50E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.38E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.10E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.37E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	1.34E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	6.28E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.83E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.19. *Normalization Results for Building with Mixture-18 (Building_M18)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.61E-15	9.57E-12
ADP_fossil fuels [MJ]	0.00E+00	1.36E-13	4.14E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.91E-14	1.25E-11
ODP [kg CFC-11 eq]	0.00E+00	3.34E-15	9.56E-13
HTP [1,4-DB eq]	0.00E+00	1.85E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	6.33E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.57E-12	5.76E-09
TETP [1,4-DB eq]	0.00E+00	1.52E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.58E-14	3.91E-12
AP [kg SO_2 eq]	0.00E+00	9.27E-14	1.01E-11
EP [kg PO_4 eq]	0.00E+00	3.36E-14	4.39E-12

Table AF.20. *Normalization Results for Building with Mixture-19 (Building_M19)*

Mid-point Impact Category	**Mixture-19**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	2.43E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	1.43E-12	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	2.63E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.85E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	6.05E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	4.91E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.65E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	1.33E-13	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	2.44E-13	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	9.50E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	5.44E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.20. *Normalization Results for Building with Mixture-19 (Building_M19)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.56E-15	9.71E-12
ADP_fossil fuels [MJ]	0.00E+00	1.31E-13	4.20E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.66E-14	1.33E-11
ODP [kg CFC-11 eq]	0.00E+00	3.23E-15	9.62E-13
HTP [1,4-DB eq]	0.00E+00	1.79E-13	2.01E-10
FAETP [1,4-DB eq]	0.00E+00	6.14E-14	1.04E-10
MAETP [1,4-DB eq]	0.00E+00	2.49E-12	5.82E-09
TETP [1,4-DB eq]	0.00E+00	1.47E-15	2.06E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.53E-14	4.02E-12
AP [kg SO_2 eq]	0.00E+00	8.98E-14	1.05E-11
EP [kg PO_4 eq]	0.00E+00	3.26E-14	4.55E-12

Table AF.21. *Normalization Results for Building with Mixture-20 (Building_M20)*

Mid-point Impact Category	**Mixture-20**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	1.18E-13	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	8.37E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.78E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.41E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	3.60E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.79E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.23E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.86E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	9.03E-14	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	5.86E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.96E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.21. *Normalization Results for Building with Mixture-20 (Building_M20)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.50E-15	9.58E-12
ADP_fossil fuels [MJ]	0.00E+00	1.27E-13	4.14E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.39E-14	1.24E-11
ODP [kg CFC-11 eq]	0.00E+00	3.12E-15	9.58E-13
HTP [1,4-DB eq]	0.00E+00	1.73E-13	1.98E-10
FAETP [1,4-DB eq]	0.00E+00	5.92E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.40E-12	5.77E-09
TETP [1,4-DB eq]	0.00E+00	1.42E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.48E-14	3.86E-12
AP [kg SO_2 eq]	0.00E+00	8.67E-14	1.01E-11
EP [kg PO_4 eq]	0.00E+00	3.14E-14	4.40E-12

Table AF.22. *Normalization Results for Building with Mixture-21 (Building_M21)*

Mid-point Impact Category	**Mixture-21**	**Energy Consumption**	**Water Consumption**	**Transportation**	**Other Building Materials**
ADP [kg Sb eq]	3.08E-14	9.06E-15	2.80E-19	2.92E-16	9.45E-12
ADP_fossil fuels [MJ]	6.16E-13	3.51E-11	1.30E-18	9.49E-14	5.23E-12
GWP100a [kg CO_2 eq]	1.61E-12	6.20E-12	1.02E-18	5.22E-14	4.30E-12
ODP [kg CFC-11 eq]	1.40E-14	8.90E-13	1.99E-20	1.91E-15	4.90E-14
HTP [1,4-DB eq]	2.12E-12	1.15E-11	5.83E-18	2.68E-13	1.83E-10
FAETP [1,4-DB eq]	3.83E-12	1.31E-11	7.87E-18	2.73E-14	8.61E-11
MAETP [1,4-DB eq]	1.18E-10	5.53E-10	3.19E-16	1.37E-12	5.09E-09
TETP [1,4-DB eq]	9.58E-14	8.84E-14	5.55E-20	1.90E-15	1.84E-12
POCP [kg C_2H_4 eq]	-5.65E-15	2.48E-12	2.60E-19	7.70E-15	1.27E-12
AP [kg SO_2 eq]	4.69E-13	5.01E-12	9.01E-19	1.97E-14	4.39E-12
EP [kg PO_4 eq]	3.81E-13	1.38E-12	7.37E-19	4.72E-15	2.59E-12

Table AF.22. *Normalization Results for Building with Mixture-21 (Building_M21)-continued*

Mid-point Impact Category	**Waste concrete {Europe without Switzerland}| treatment of waste concrete, inert material landfill | Alloc Rec, U**	**Waste concrete gravel {CH}| treatment of, sorting plant | Alloc Def, U**	**Total**
ADP [kg Sb eq]	0.00E+00	1.49E-15	9.49E-12
ADP_fossil fuels [MJ]	0.00E+00	1.26E-13	4.11E-11
GWP100a [kg CO_2 eq]	0.00E+00	7.34E-14	1.22E-11
ODP [kg CFC-11 eq]	0.00E+00	3.10E-15	9.58E-13
HTP [1,4-DB eq]	0.00E+00	1.72E-13	1.97E-10
FAETP [1,4-DB eq]	0.00E+00	5.88E-14	1.03E-10
MAETP [1,4-DB eq]	0.00E+00	2.39E-12	5.77E-09
TETP [1,4-DB eq]	0.00E+00	1.41E-15	2.03E-12
POCP [kg C_2H_4 eq]	0.00E+00	1.47E-14	3.77E-12
AP [kg SO_2 eq]	0.00E+00	8.61E-14	9.98E-12
EP [kg PO_4 eq]	0.00E+00	3.12E-14	4.39E-12