ENVIRONMENTAL IMPACT COMPARISON FOR DIFFERENT PERSONAL CARE PRODUCTS IN SELECTED ACCOMMODATION SECTOR: A CASE STUDY FOR STUDENT DORMITORIES

by

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ABSTRACT

ENVIRONMENTAL IMPACT COMPARISON FOR DIFFERENT PERSONAL CARE PRODUCTS IN SELECTED ACCOMMODATION SECTOR: A CASE STUDY FOR STUDENT DORMITORIES

Life Cycle Assessment (LCA) studies on the ecological impacts of personal care products (PCPs) are increasing in order to have reliable data used in the evaluation of sustainability concepts. The need for eco-friendly product design and raise environmental awareness among consumers are new trends in PCPs sector. Despite the fact that the production stages of liquid soap, bar soap, shampoo and shower gel have environmental footprints, dramatic environmental impacts come from their usage in hand wash and shower. In this study; environmental impacts of PCPs have been analyzed with GaBi 6.0 Software, EcoInvent Database and CML Assessment Methodology. The combined environmental impacts at use phase in Bogazici University's Dormitories have been identified using detailed data from industry and consumer-behavior approaches. Seasonal population difference and daily routine changes have also been considered in use stage scenarios. As a result of this study; it is seen that using personal care products have remarkable ecotoxicity potentials due to the packaging materials of products and wastewater released from showers and sinks. The easiest way to dealing with wastewater has been accepted as prevention of waste production. The gray water recovery systems lead to the prevention of the wastewater occurance in use stage of PCPs and also give opportunities to save clean water. The installation of the gray water recovery systems for all dormitories benefits the Bogazici University's water consumption rates and wastewater pollution loads, at the same time it affects the product's ecological loads in use phase.

ÖZET

SEÇİLMİŞ KONAKLAMA SEKTÖRÜNDE FARKLI KİŞİSEL BAKIM ÜRÜNLERİ İÇİN ÇEVRESEL ETKİ KARŞILAŞTIRMASI: ÖĞRENCİ YURTLARI İÇİN ÖRNEK BİR ÇALIŞMA

Sürdürülebilirlik kavramlarının değerlendirilmesinde güvenilir verilerin elde edilmesi için kişisel bakım ürünlerinin ekolojik etkileriyle ilgili Yaşam Döngüsü Değerlendirmesi (YDD) çalışmaları artmaktadır. Çevre dostu ürün tasarımına duyulan ihtiyaç ve tüketiciler arasında çevre bilincini artırmak, kişisel bakım ürünleri sektöründe yeni eğilimlerdir. Sıvı sabun, katı sabun, şampuan ve duş jeli ürünlerinin üretim aşamalarında çevresel ayak izleri bulunmasına rağmen, kullanım aşamalarında, el yıkama ve duş alma esnasında, göze çarpan çevresel etkiler oluşur. Bu çalışmada; kişisel bakım ürünlerinin çevresel etkileri GaBi 6.0 Yazılımı, EcoInvent Veritabanı ve CML Değerlendirme Metodolojisi kullanılarak analiz edilmiştir. Boğaziçi Üniversitesi yurtlarındaki kişisel bakım ürünleri kullanımı sonucu oluşan birleşik çevresel etkiler; endüstriyel üretim bilgileri ve tüketici davranışları yaklaşımlarından elde edilen ayrıntılı veriler kullanılarak belirlenmiştir. Kullanım aşamasındaki senaryolarda dönemsel nüfus farkı ve günlük rutin değişiklikler de dikkate alınmıştır. Bu çalışmanın sonucunda; kişisel bakım ürünleri kullanmanın, ürünlerin ambalaj malzemeleri ile duş ve lavabolardan kaynaklanan atık sulardan dolayı ekolojik kirlilik potansiyeline sahip olduğu görülmektedir. Atık su ile başa çıkmanın en kolay yolu atık üretiminin önlenmesi yöntemi olarak kabul edilmektedir. Gri su geri kazanım sistemleri, kişisel bakım ürünlerinin kullanım aşamasında atık suların önlenmesini sağlamakta ve aynı zamanda temiz su tasarrufu için fırsatlar sunmaktadır. Boğaziçi Üniversitesi yurt binaları için gri su geri dönüşüm sistemlerinin kurulması, üniversitenin su tüketim oranlarına ve atık su kirlilik yüklerine fayda sağlayacak, aynı zamanda söz konusu kişisel bakım ürünlerinin kullanım aşamasındaki ekolojik yüklerini de etkileyecektir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	Explanation	Unit
COD	Chemical Oxygen Demand	mg/L
BOD	Biological Oxygen Demand	mg/L
TSS	Total Suspended Solids	mg/L
TP	Total Phosphorus	mg/L
TN	Total Nitrogen	mg/L
GWP	Global Warming Potential	kg CO_2 Equivalent

Abbreviation	Explanation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PCP	Personal Care Products
AASHE	The Association for the Advancement of Sustainability in Higher Education
STARS	The Sustainability Tracking, Assessment & Rating System
SETAC	Society of Environmental Toxicology and Chemistry
ISO	International Standard Organization
IPCC	The Intergovernmental Panel on Climate Change
ISTKA	Istanbul Development Agency
LEED	Leadership in Energy and Environmental Design
USGBC	Unites States Green Building Council
MBR	Membrane Bioreactors
MCR	Membrane Chemical Reactors
GROW	Green Roof Water Recycling System
UN SDGs	United Nations Sustainable Development Goals
EPA	United States Environmental Protection Agency

1. INTRODUCTION

The life-cycle environmental impacts of consumer products are mostly argued for sustainable product design, environmental consumer information, and product policy making; indicating a very high demand for environmental data. With the presence of recognized tools for environmental decision support, as life-cycle assessment (LCA), assessments on the ecological impacts of personal care products (PCPs) are increasing. The main reason for this is the producers' willingness to have eco-friendly approaches in their marketing strategies. The application of such consumer products also generally raises concerns about environmental impacts associated with extensive water use, organic load (as Chemical Oxygen Demand, Biological Oxygen Demand, Total Phosphorus and Total Nitrogen) to wastewater stream, and packaging-waste generation.

In this study; a wide range of environmental impacts have been analyzed using detailed data from industry and consumer-behavior studies to identify the importance of chemicals/raw materials selection at the production stage and their final impacts at use phase in selected service buildings which are Bogazici University's Dormitories. Bogazici University is one of the leading universities in Turkey that involves 'green campus' targets in their strategical plan and also their vision. The vision of the university is achieving international excellence in education and research and becoming a "green", sustainable university. Universities are key points in regional development plans both with resource conservation applications and with a possible reduction in wastes and emissions they generate (Bogazici University's Strategical Plan 2015-2019, Strategical Target No: 14).

The development of water conservation and wastewater reduction technologies for Bogazici University's Dormitories are in the scope of 'Green and Sustainable Campus Program' of Rectorate. The wastewater characteristics and chemical consumption information have been used for continual improvement in Green and Sustainable Campus Program by controlling the impacts of dormitory resident activities. The importance of the water reuse/recycle/recovery in campus sustainability have been standardized clearly with the technical approach of The Association for the Advancement of Sustainability in Higher Education (AASHE)'s The Sustainability Tracking, Assessment & Rating System (STARS) Checklist (STARS Technical Manual v2.1.3, 2017).

2. LITERATURE REVIEW

2.1. Life Cycle Assessment Of Personal Care Products

2.1.1. Introduction

Life Cycle Assessment (LCA) is used to evaluate the environmental impacts of products. It allows for more informed decisions through a better understanding of human and ecological health and environmental impacts of products, processes, and activities (SETAC, 1993). Originally LCA has been developed in 1960s by using the efficiency researches in industrial processes in terms of energy consumption and 'net energy analysis' that assumed to be direct and indirect depletion for a process. In 1970s, the first emission related study is done by U.S. National Science Foundation to inspect substitute methods for packaging. Recently international organizations such as SETAC and International Standard Organization (ISO) defined LCA approach as the UNI EN ISO 14040 is "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle." (ISO 14044; 2006).

Life-cycle inventory (LCI) is a "cradle to grave" analysis of the significant system inputs and outputs. The inventory comprises the collection of the inputs (materials and resources) and outputs for the product throughout its life cycle. The aim is to gather all environmental data for undiscovered products, to evaluate the ecological significance of different life-cycle stages of products, to compare the environmental footprints of products serving equal applications, and to present recommendations for different stockholders along the products' life cycles (Burgess and Brennan, 2001). Regulated by the ISO 14040:2006 series standards, LCA consists in four distinct phases:

- Goal and scope definition (study model which defines the methodological framework which all other LCA phases must comply with)
- Inventory of all the inputs and outputs related to the product system
- Assessment of the potential impacts associated with these inputs and outputs
- Interpretation of the inventory data and impact assessment results related to the goal and scope of the study.

Different softwares can be used in order to accomplish a life cycle assessment. For example; a version of SimaPro software has been used in a consulting company's work with Impact 2002+ and the EcoInvent Unit process libraries which are the primary and globally used tools. This methodology allows the results to be presented as both mid-point characterizations as well as end-point damage assessments (Ka-le-pa Tech, 2009). Additionally; in Annette Koehler's study "Comparing the Environmental Footprint of Consumer Products: The Relevance of Different Life Cycle Phases" following LCA methods are used: the products' carbon footprints are calculated using IPCC global-warming potential (GWP) with a 100-year time frame, the products' direct and indirect energy performance are derived by the fossil cumulative-energy demand (CEDfossil). The overall environmental footprint has assessed with the Eco-indicator 99 (EI99) methodology (Koehler et al., 2009).

The CML methodology which is developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands is the most widely-used and often considered the most complete methodology. This methodology groups the life cycle impact consequences into midpoint categories, according to common mechanisms or groupings.

2.1.2. Goal and Scope Definition

The goal of life cycle assessment studies is to evaluate the degree of inequality and guide future studies in order to focus important ecological issues in selected production facility; in formulation, packaging, use and disposal stages. The system boundaries and functional unit are defined to provide the goal and scope of an LCA. The functional unit is, not only the magnitude of product, the baseline of optimal products to be compared (Consoli et al., 1993).

2.1.3. Life Cycle Inventory and Impact Assessment

Life Cycle Inventory (LCI) represents the data collection, data calculation and data allocation steps to identify the product's input/output values within the system. There are three main impact categories that should be taken into account when considering the scope of an LCA study: resource use, human health consequences, and ecological consequences. Impact categories cover climate change, stratospheric ozone depletion, photo oxidant formation (smog), eutrophication, acidification, water use, noise, etc. (Pennington et al., 2004). LCIA is conducted within the series of steps as described below;

- Selection and definition of impact categories: The impact categories are selected and identified to describe the impacts caused by the considered product, products or services based on results of inventory analysis (ISO 14043, 2000).
- Classification: Inventory results are assigned to different impact categories, based on the expected types of impacts on the environment (ISO 14043, 2000).
- Characterization: Potential environmental impacts of emissions are calculated by using science-based conversion factors, called characterization factors or equivalency factors for each impact category. This way different substances emitted can be transformed into the same unit (ISO 14043, 2000).
- Normalization: Individual impacts are combined into a dimensionless final score in a form suitable for weighting to compare all environmental impacts using the same scale (ISO 14043, 2000).
- Weighting: Weighting, also referred as valuation assigns weights or relative values to the different impact categories based on their perceived importance or relevance. In other words, weighting determines which potential impacts are more important than the others (ISO 14043, 2000).
- Interpretation; A systematic evaluation of the needs and opportunities which covers conclusions, recommendations, reporting and identification of the important environmental issues consistent with the goal and scope of the study (ISO 14043, 2000)

2.1.4. Production Stage

2.1.4.1. Raw Materials. The environmental impacts of raw materials acquisition and supply stages develop with increasing numbers of chemical ingredients. “Comparing the Environmental Footprint of Consumer Products: The Relevance of Different Life Cycle Phases” study by Annette Koehler points out the noticeable increase in energy related results in raw materials supply stage. With the increase of the PCPs water content, raw materials becomes less effective and the packaging values come to be more important (Koehler et al., 2009).

A sustainability consulting company compares various types of soaps; the raw materials examine the ingredients used to make soaps including various alternative recipes. The following basic recipes are considered; Bar Soap made from 100% Tallow, Bar Soap made from 100% Crude Coconut Oil, Bar Soap made from 100 % Palm Oil, Bar Soap from 50% Palm Oil and 50% Coconut Oil, Bar Soap from 50% Palm Oil and 50% Animal Fat, Liquid Soap from 100% Soybean Oil. In end-point results;

even with the negative impacts in certain categories, the damage review shows that overall, the bar soap from 100% Animal Fat has lower impacts. This is due to the fact that in the EcoInvent Unit Process Library values used in this research, only the energy input to render tallow is considered. Tallow is a byproduct of meat packing where the animal husbandry and the process of slaughtering are not included, since the raw material is considered as waste (Ka-le-pa Tech, 2009).

For shampoo, one of the main components is water which is delivered as tap water by the local municipal utility. Further on the shampoo consists of several complex surfactant mixtures which basically descend from palm kernel, palm and coconut oil. Processes involved in the production of these surfactants are amongst others sulfating and ethoxylation. Ingredients with a major environmental load are surfactants such as cocoamidopropyl betaine and fatty alkanolamides, and also the controlling viscosity agent (in this case propylene glycol) and finally sodium benzoate and sodium laureth sulphate. For all substances, global warming, non-renewable energy and land occupation are the impact categories with higher values. Respiratory inorganics have also relevant contribution of environmental impact for most substances (European Commission Joint Research Center, 2012).

2.1.4.2. Manufacturing. For PCPs; manufacturing stage of solid products like bar soaps has the contribution of product formulation to energy, carbon, and overall environmental footprints. Other products that formulated by pure mixing of raw chemical ingredients and therefore considerably less energy-consuming.

In comparison for various PCPs which performed by a sustainability consulting company in 2009; using data for soap making equipment and some order of magnitude thermal calculations, the amount of energy to make 3.7 kg (1 gallon) of soap was used. Less energy is required to heat liquid fats to the necessary temperatures. In addition to this, the packaging for the products is included. Examining the impacts associated with the manufacturing of the soaps of interest, but the most significant impacts come from the water used during the hand washing phase of the life cycle (Ka-le-pa Tech, 2009).

The manufacturing process done in plant for shampoos consists basically of mixing and pumping the ingredients delivered into mixing vessels. Once the product is fabricated, filling is the final step. A cleaning process is involved after each basin. Several stock solutions are generated before the prepared mixtures are pumped together with all remaining ingredients in vessels. The final product is delivered afterwards to the filling station. There is a cleaning step involved after each batch which

requires only water as cleaning agent. Electricity, natural gas and water are basically needed for production. Further on there are direct CO_2 and NOx emissions to air to be considered (Henkel, 2008).

2.1.5. Packaging Stage

In the packaging stage, materials and package manufacturing have been taken into account. It is considered that plastic package manufacturing is made through injection. For different plastic materials, the same process of injection casting for PVC, PE and PP covers have been examined, although there are little differences in the inputs required to produce 1 kg of covered product of each material, e.g. amount of energy needed (Henkel, 2008).

The impacts due to product packaging are compared the damage assessment of three bar soap recipes and one liquid soap recipe used for 1000 hand washing lasting approximately 30 seconds each. It is notable that liquid soap has large contributions from packaging and soap manufacturing. The disparity between liquid soap and bar soap is due to the quantity of product per functional unit. While 2.75 packages of bar soap are required, 10 packages of liquid soap are required for 1000 hand washes. This represents a significant difference in raw materials input (Koehler et al., 2009).

2.1.6. Transportation; Distribution of Products Stage

Products are packaged according to consumer specifications. They may be placed in protective plastic bags, either manually or by using an automated system, to ensure that the quality of the product during shipping. Lastly, they are placed in cardboard boxes and shipped to client distribution centers to be sold in markets. Air emissions from distributor vehicles result in search for alternative fuel sources.

2.1.7. Consumer Use Stage

In common, PCPs expose parallel environmental profiles because of similar consumer usage, packaging systems, and chemical compositions. For instance; although environmental footprint of producing 1 kg of bar soap performs worse than that of liquid soap, hand-washing with bar soap overall demonstrates to be superior to liquid soap for all indicators in the case study.

In dormitory buildings, personal choices influence water consumption and wastewater characterization. Dormitory provides an excellent venue for controlled study of the selected products use and also for campus sustainability.

As it is understood from the study of The Agricultural University of Norway; a gray water recovery system reduces water consumption by 30% and eliminates pollution. The system is relatively simple with separation of toilet wastewater (black water) and water from sinks and showers (gray water) afterwards a reliable filtration of gray water for producing a water quality suitable for irrigation or groundwater recharge. Important parameters for wastewater and gray water recovery will be Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Phosphorus (TP) and Total Nitrogen (TN) (Jenssen, 2005).

The product-specific data collected from producing industries and their environmental effects have been analyzed in “Comparing the Environmental Footprint of Consumer Products: The Relevance of Different Life Cycle Phases” by Annette Koehler. Liquid and bar soap products are selected and industrial data are taken from two different corporations. Change in consumer practices was modeled in alternative scenarios by altering different use-related factors, including applied product quantity, temperature and amount of water used, use of refillable packaging and mobility choices. Data on average product dosage and application frequencies are collected from the manufacturers’ consumer-behavior studies (Koehler et al., 2009).

For shampoos; a study which is made by a well-known shampoo producer shows that the use phase has the most significant impact on water usage. During the use phase, parameters temperature and water usage are the main drivers for the emission released. The functional unit for this shampoo is defined as one application in shower; 7g of product. In order to wash the hair a consumer needs shampoo, water and a heating technology to heat the water up to a convenient temperature. The provision of the shampoo is part of the implemented downstream processes. The water is considered to be provided by a local municipal utility as tap water. The heating technology is mapped based on statistical data describing the share of different energy carriers (Henkel, 2008).

The use phase generates wastewater and solid waste which consists of the primary packaging materials. It has estimated the content of the waste water regarding certain surfactants and also biological oxygen demand and chemical oxygen demand. This estimation led to the conclusion that the applied amount of shampoo per hair wash does not influence the composition of the waste water

negatively. Therefore the waste water from the use phase is treated like normal domestic waste water (Henkel, 2008).

2.2. Sustainable and Green Campus Notion

In Regional Development Plan of Istanbul for 2023; conservation of resources and environment, development and encouragement of active waste management, providing energy efficiency and extension of cleaner energy usage, development and protection of historical and cultural heritage by considering asset value, economic and social development dimensions have been focused with the aim of 'Regional and Cultural Sustainability Growth Axis Strategies'. Universities with a sustainable reduction in the emissions contribute the city and the 'sustainable lifestyle for the students' that is a transport way for future generations to understand sustainability approach. It is important to develop the use of renewable energy and energy efficient technologies, waste management strategies, water recycling, water conservation practices for university campuses located in Istanbul by ensuring the negative impact on the amount of waste in the city (ISTKA, 2018).

In Bogazici University, with green campus notion, the environmental technology improvements, energy efficiency innovations and sustainable development will be achieved in such areas. In selected buildings of campus, the development of water recycling and water conservation projects, energy efficiency and related units to ensure the insulation of boilers, lighting units to suit the needs of the application, providing natural ventilation and lighting, such as the need to minimize the benefits of green building practices that take place. The participation of administrative staff and students has been provided and their training has been succeeding by information distribution. Student clubs, activities and questionnaires on sustainable campus life have been performed for student involvement. In the scope of waste management, several meetings were held with building representatives on hazardous, toner and recyclable wastes (Green Campus Program, 2018)

The Association for the Advancement of Sustainability in Higher Education (AASHE) is an organization which universities in USA and Canada work together on behalf of constructing a sustainable future. Sustainability Tracking Assessment & Rating System (STARS) is a credit and tracking system made by AASHE which provides improvements in sustainability concepts. Regarding to STARS Version 2.1 Technical Manual; conservation of water has to be succeeded in directly related credits; OP Credit 3: Building Operations and Maintenance, OP Credit 4: Building Design and Construction, OP Credit 22: Water Use. These credits are also matched with Leadership

in Energy and Environmental Design (LEED) Standards of Unites States Green Building Council (USGBC) (AASHE and USGBC, 2018).

According to AASHE's Sustainable Campus Index 2018; water conservation and effective rainwater and wastewater management also reduce the need for effluent discharge into local surface water supplies, which helps improve the health of local water ecosystems. Besides water conservation, recycling and reuse practices are important in protecting limited groundwater supplies. (AASHE, 2018).

2.2.1. Water Conservation in Dormitories

It is obvious that researchers recently have concentrated on new technologies for better conservation of water resources due to the growing population, the contamination of both surface and groundwater and the climate change which creates a requirement for such environmentally sustainable applications. In regions where people faced with water scarcity; treatment of wastewater and recovery options become vitally important.

According to World Health Organization (WHO); it is recommended to wash hands with soap and water when hands are visibly dirty or visibly soiled with all body fluids or after using the toilet. The United Nation's Sustainable Development Goal 6 Synthesis Report 2018 on Water and Sanitation emphasize that unfortunately billions of people still lack safe water, sanitation and handwashing facilities. Only 27 per cent of population in least developed countries has access to soap and water for handwashing on premises. For showering case, Taking shower in two days, four days or whenever people feel theirselves unconfortable is recommended. According to the research studied by Dermatologiest Dr. Joshua Zeichner, it is revealed that people are taking too much shower. Frequent showering (especially with hot water) can dry the skin and discomfort; however, it can kill the good bacteria naturally found in the skin and make people more susceptible to diseases.

The United Nation's Sustainable Development Goals Index and Dashboards figure the member countries' improvements in the direction of succeeded the SDGs and specify the need for urgent progress. The global SDG Index score and scores by goal have been explicated as the percentage of country specific achievements. The difference between 100 and countries' scores have known as the range in percentage that needs to be completed to achieving the SDGs and goals. The same set of

indicators has been used for all countries to produce comparable scores and rankings (United Nations Sustainable Development Goals, 2018).

According to United Nation's Sustainable Development Goals; Goal 6 is named as 'Ensure availability and sustainable management of water and sanitation for all'. The goal has eight targets and eleven indicators as listed below (Table 2.1).

Table 2.1. SDG #6: Ensure Availability and Sustainable Management of Water and Sanitation for All and Turkey's 2018 Performance (United Nations Sustainable Development Goals, 2018).

TARGETS	INDICATORS	PERFORMANCE
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services	N/A
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water	44.3%
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated	N/A
	6.3.2 Proportion of bodies of water with good ambient water quality	N/A
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time	N/A
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	27.5%
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0-100)	N/A
	6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation	NA
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time	N/A
6.A By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	6.A.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan	N/A

Table 2.1. Continued.

6.B Support and strengthen the participation of local communities in improving water and sanitation management	6.B.1	
	Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management	N/A

The importance of gray water recovery linked to Target 6.3 which considers improving sanitation and wastewater treatment infrastructures in cities and encouraging reuse of treated wastewater. This goal and targets aim to ensure public access to healthy, safe, drinkable and usable water as a precious resource for human. Unfortunately, global statistics shows that recycling and reuse options are not preferable nonetheless mostly untreated wastewater has been released into nature. With regards to SDG Index and Dashboards Reports in 2017 and 2018; better management options and innovative wastewater treatment concepts are needed. Since over 80 per cent of countries have insufficient finance to meet national water, sanitation and hygiene targets. Smart technologies could improve all aspects of water resources and water, sanitation and hygiene management (Christensen & Gordon, 2018).

Turkey's overall score in SDGs has been recorded as 66.0 (14.2% lower than region average which is 76.9). Moreover, in SDG Global Rank, Turkey has been ranked in 79th out of 156. The specific score for Goal #6: Clean water and sanitation has been recorded as 67.7 out of 100. Ukraine has achieved the Goal #6 with its 96.6 score, this score has been seen as the highest score within this goal and below targets (The interactive 2018 SDG Dashboards).

Concerning waste generation, water and resources consumption and energy needs; university campuses are similar to building sites and cities with their contribution to environmental quality. Green campus notion within the campus buildings aims to encourage the construction of energy and resource effective buildings. Water conservation is possible by choosing proper systems and by supplying adequate flexibility between these systems. Gray water recovery in dormitories keep academic members and students in countenance to improve resources conservation methods and recycling applications (M. Alshuwaikhat and Abubakar, 2008).

Different treatment and recovery technologies are available for water recycling. A life cycle assessment has been done in Imperial College London compares four mainly used gray water recovery systems including reed beds, membrane bioreactors (MBR), membrane chemical reactors (MCR) and an innovative green roof water recycling system (GROW). The outcomes demonstrate

that overall GROW has relatively better performance than the remaining three technologies. MCR has the greatest environmental effect. The other two technologies which mainly depend on natural treatment processes have the lower impact. Due to electricity and chemicals consumption (i.e. TiO_2 to assist BOD removal in the MCR and NaOH, HCl for cleaning and stoppage of membrane fouling) use phase has higher impact. Additional researches exposed that for GROW systems nearly 90% of the use phase contribution comes directly from electricity consumption. For the reed beds, nearly 80% contribution comes from the construction phase. Sand, gravel, LDPE and PVC materials are the main contributors (Memon et al., 2007).

3. MATERIALS AND METHODS

3.1. Introduction

The data obtained from personal care products' manufacturers are used to specify the organic pollution load of wastewater released from dormitories in Bogazici University. Regarding to the products' life cycle assessment studies and consumer habit approaches, gray water recovery systems are suggested.

The consumer behavior approach and the product use patterns show variations. Although the production stages of selected product groups have a contribution to environmental footprints, considerable impacts are caused in the consumer use phase. University dormitories are the most problematic areas, where PCPs lead to excess amount of chemical pollution load in the wastewater treatment facilities.

The aim of this study is to evaluate the degree of inequality and to guide future production technologies in order to integrate eco-design concepts in selected production facility. 'Environmental footprints of university residents' have been evaluated considering seasonal PCPs' consumption with comparison of different products and scenarios. The product' data has been collected from industry and consumer use data has been gathered from student dormitory. Ten dormitories in Bogazici University's Campus have been evaluated and suggestions have been made to design gray water treatment systems. Collected and treated gray water are used for indoor purposes and also for irrigation purposes in university. The gray water recovery definitely benefits the university's water consumption rates and wastewater loads, at the same time it affects the product's water footprint in use phase.

3.2. Data Collection

Energy, resources and other inputs, products, byproducts, wastes, air emissions and wastewater discharges have been examined within the scope of the study. Data from manufacturers have been collected punctiliously and some assumptions have been made to complete the overall system assessments. All data is based on the defined functional unit of the study.

The required data for life cycle assessment of selected products have been gathered individually by; field trips, actual industry situations, literature based approaches and country specific assumptions. Industrial data have covered raw materials amount, energy consumption, waste production and management of residues.

The selection of functional units for each products have been summarized in Table 3.1.

Table 3.1. The selection of functional units for each products.

Functional unit	Liquid soap product	Shampoo product	Shower gel product	Bar soap product
Weight	400 mL – 425 g	400 mL – 412 g	250 mL – 257 g	200 g
Dosage	4 mL / use	10.5 g / use	12.9 g / use	2 g / use
Number of use	100 use / 400 mL product	39 use / 400 mL product	20 use / 250 mL product	100 use / 200 g product

In order to make reasonable assumptions on consumer habits; “Personal Care Products’ Consumption Survey” have been performed among dormitory residents. With reference to the survey; approximately 47% of residents use liquid soap while 15% of residents use bar soap in hand washing, 38% of them use both. Dormitory residents almost spend their half day in their rooms and 41% of residents wash their hands every 2 hours. Liquid soap users press the soap dispenser at least twice and bar soap users prefer bar soap not only for hand wash, for body wash too. Every resident use shampoo and 91% of residents prefer shower gel.

The cultural diversity becomes an issue while making assumptions on personal care and hygiene habits within a multi-nationality student community. The personal care and hygiene terms indicate various meanings throughout the world. Despite that differenciation, personal care and hygiene are known as the most effective ways of having healthy living conditions.

In this study, to point out dramatic environmental impact assessment results, independent from cultural divisions it is assummed that every resident have a high sense of personal care and hygiene. The functional unit of the study is defined as “‘an average university resident’s (as average consumers) PCPs consumption for one school term”. The average consumer term is interpreted as "reasonably well informed and reasonably observant and forethoughtful, taking into account social and cultural factors" by The European Court of Justice (Overview of the Consumer Protection Act, 2007).

Bogazici University's full capacity dormitory population and the survey results which have been performed among students are used in order to make assumptions of consumer use habits. "High Season" has been defined as one term of academic calendar as six months (Fall and Winter months); it is assumed that dormitories are at full capacity during high season. "Low Season" has been defined as summer term and holidays as six months (Spring and Summer months); it is assumed that the population drop by 1/4th of high season. While the population in dormitories decreases, the need for shower increases during summer months. This fact has been taken into consideration in shampoo and shower gel consumption scenarios (Table 3.2).

Table 3.2. The assumptions based on industrial data and consumer behavior.

Functional unit	Liquid soap product	Shampoo product	Shower gel product	Bar soap product
Weight	400 mL – 425 g	400 mL – 412 g	250 mL – 257 g	200 g
Dosage	4 mL / use	10.5 g / use	12.9 g / use	2 g / use
Number of use	100 use / 400 mL product	39 use / 400 mL product	20 use / 250 mL product	100 use / 200 g product
Water temperature	38	38	38	38
High season, people	2699	4089	3721	1390
Assumptions	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days	Hair wash every 2 days, 6 months = 90 days	Shower every 2 days, 6 months = 90 days	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days
High season, product amount	34004	9660	16810	17517
Low season, people	676	1024	932	348
Assumptions	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days	Hair wash every day, 6 months = 180 days	Shower every day, 6 months = 180 days	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days
Low season, product amount	8516	4839	8418	4385
Literature assumptions	Not a specific number for hand washing	Hair wash in a week is recommendable	Body wash every day is recommendable	Not a specific number for hand washing

3.3. Design of Gray Water Recovery System

When it is considered as domestic wastewater flow; there are two groups of wastewater streams known as black and gray water. Black water is sewage which contains faeces, urine and transport water. Gray water can be segregated as low-polluted part of domestic wastewater which originated from showers, hand washing sinks and washing machines. Mostly kitchen sinks are not included in gray water recovery systems because of food residues (Metcalf&Eddy).

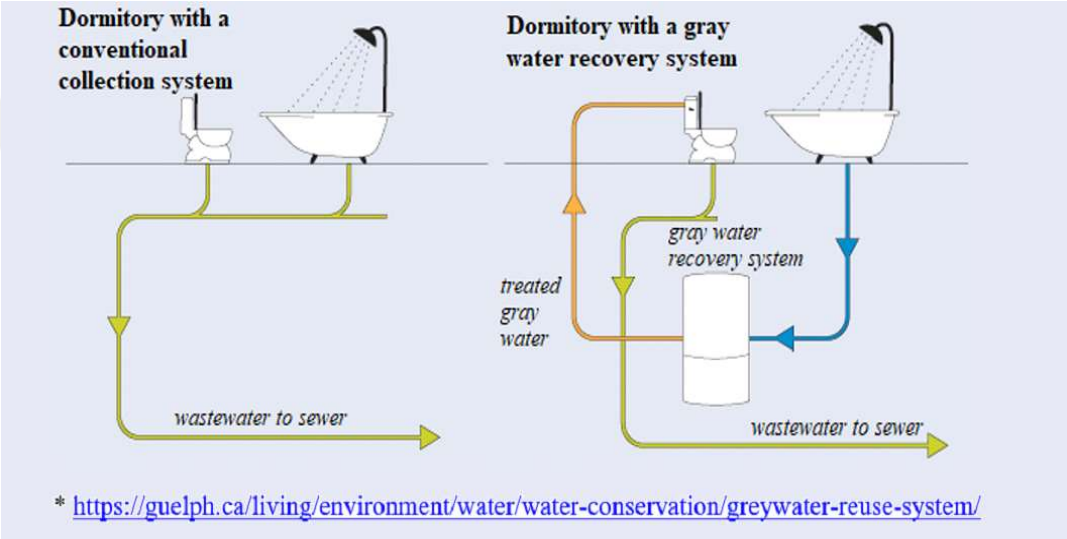

Figure 3.1. Illustration of collection systems with and without gray water recovery system.

In order to design the gray water recovery system for dormitories; gray water characterization and system's capacity calculations have been done. Gray water contaminants have been compared with literature data in Table 3.3 (Üstün and Tırpancı, 2015).

Gray water has been categorized as low contaminated and highly contaminated according to consumer habits and living standards. Also collection systems are known as effective in recovery opportunities; collecting washing machine, kitchen and dishwasher's wastewater together with sink, bathtub and shower cause increase in contamination of gray water.

Table 3.3. Characterization of Untreated Gray Water.

Parameters	Sample from dormitory	Low contaminated gray water	High contaminated gray water
pH	7.2	6.4-8.1	5.2-10.0
BOD_5, mg/L	237	59-424	48-890

Table 3.3. Continued.

Total COD, mg/L	590	100-645	361-1815
TKN, mg/L	8.7	<0.1-15.0	<0.1-4.6
TSS, mg/L	172	30-303	35-625
Total coliform / 100mL	1000	10^1-10^5	10^2-10^6
Fecal coliform / 100mL	>240	10^1-10^5	10^2-10^6
BOD_5/COD Ratio	0.4	0.5-0.6	0.1-0.4

The BOD_5/COD ratio is between 0.3-0.8 for domestic wastewater. For dormitory sample the BOD_5/COD ratio is calculated as 0.4. This value is close to lower ratio because of the high soaps, shampoos and shower gels content of gray water which are slowly biodegradable (Metcalf&Eddy). As it is graphically shown in Figure 3.2; collecting gray water generated from shower and sink hypothetically make 40% of water reuse opportunity.

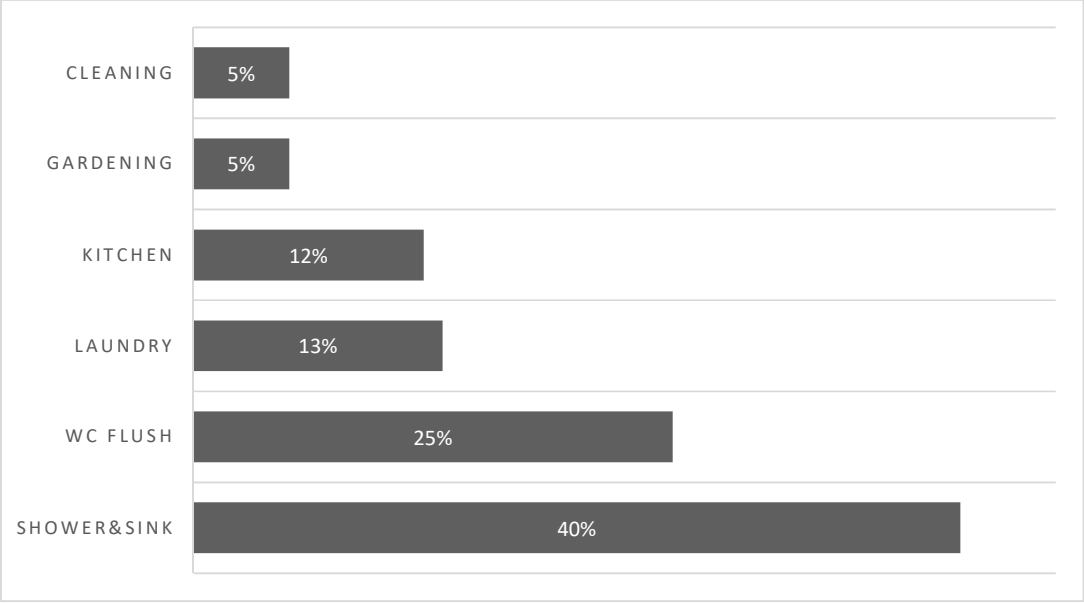

Figure 3.2. Household water use percentages (tırpancı, 2015).

Membrane Bioreactors (MBR) System is chosen for gray water recovery. MBR is favorable with its volume expansivity and effluent quality almost free from microorganisms. The effluent water of existing gray water recovery system which placed in 4th North Dormitory is used as flush water in toilets since 2014. There is still the chance to use this water as irrigation water and cleaning purposes. Effluent standards for treated gray water are given in Table 3.4.

Table 3.4. Gray water reuse effluent standards according to use purpose.

Parameters	Dormitory Effluent	EPA Guidelines For Water Reuse (EPA/600/R-12/618 | September 2012)			Turkish Water Pollution Control Regulation (Official Gazette No: 25687/Date: 31.12.2004)
		Urban reuse, irrigation, toilet flushing etc.	Agricultural reuse, food crops not commercially processed	Agricultural reuse, food crops commercially processed	Irrigation
pH	7.5	6-9	6-9	6-9	6.5-8.5
BOD_5, mg/L	7	≤10	≤10	≤30	≤100
TSS, mg/L	0	≤5	≤5	≤30	≤45
Fecal coliform / 100mL	0	NA	NA	<200	≤100

Since 2014, periodical analyses have been performed on gray water treatment system in Bogazici University's 4th Dormitory in North Campus by the manufacturer of the system; UTES Corporation (Table3.5). Recycled water amount has been measured approximately 15.2%.

Table 3.5. Analyze Results of Gray Water Treatment System (2014-2018 average).

Parameter	Unit	Influent water	Effluent water
pH		7.2	7.5
BOD5	mg/l	237	7
TSS	mg/l	172	0
Dissolved oxygen	%	8	9.4
Total coliform	adet/ 100mL	1000	0
Fecal coliform	adet/ 100mL	>240	0

In order to design a system in 4th Dormitory in North Campus; the required flow rate of system has been based on assumptions taken from literature. For dormitories, typical wastewater flow rate has been found as between 75-190 L/capita.day (LCD); it has assumed as 80 LCD for this study. The capacity of 4th Dormitory that has been taken from dormitory directorate as 252 people. MBR unit with its permeability 0.02 μ has been installed with a flow rate of 1 m^3/h (16 m^3/day).

4. IMPACT ASSESSMENT FOR SELECTED PERSONAL CARE PRODUCTS

This part has been performed by using GaBi 6.0 Software program and EcoInvent version v3.5 database. All raw materials necessary for production and packaging phases have been determined. Flow diagram of production processes, transportation of raw materials and packaging materials have been created in program. Environmental impacts have been evaluated by considering results of product inventories. Within the scope of this study; characterization, normalization and classification procedures have been done for environmental impact assessment. The classification of emission and contaminating factors are given in table below as a part of this LCA study.

Table 4.1. Classification of Environmental Impact Categories.

Impact category	Impact area	Lca inventory examples (i.e. Classification)	Characterization factors as baseline	Definition of characterization factor
Global warming	Global	Carbondioxide (CO_2) Nitrogendioxide (NO_2) Clorofluorocarbons (CFCs) Hydroclorofluorocarbons (HFCs), Methylbromide (CH_3Br)	Global warming potential [kg CO_2-Equiv.]	LCI data have been converted into CO_2 equivalent. Global warming potentials may be 100 years potentials.
Ozone layer depletion	Global	Clorofluorocarbons (CFCs) Hydroclorofluorocarbons (HFCs), Halons Methylbromide (CH_3Br)	Ozone layer depletion [kg R11-Equiv.]	LCI data have been converted into triclorofluoromethane (CFC-11) equivalent.
Acidification	Local/ Regional	Sulfuroxides (SOx) Nitrogenoxides (NOx) Hydrochloric Acid (HCl) Hydrofluoric Acid (HF) Ammonia (NH_4)	Acidification potential [kg SO_2-Equiv.]	LCI data have been converted into Hydrogen Ion (H^+) equivalent.
Eutrophication	Local	Phosphate (PO_4) Nitrogenoxides (NOx) Nitrogendioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication potential [kg Phosphate-Equiv.]	LCI data have been converted into Phosphate (PO_4) equivalent.
Photochemical smog	Local	Hydrocarbons except methane (NMHC)	Photochemical smog potential	LCI data have been converted into Ethane (C_2H_6) equivalent.
Terrestrial toxicity	Local	Highly concentrated chemicals that fatally toxic to rodents	Terrestrial ecotoxicity potential [kg DCB-Equiv.]	LC50 data have been converted to equivalents.

Table 4.1. Continued.

Aquatic toxicity	Local	Highly concentrated chemicals that fatally toxic to fish	Aquatic ecotoxicity potential [kg DCB-Equiv.]	LC50 data have been converted to equivalents.
Human health	Global / Regional / Local	Emissions to air, water and soil	Human Health Toxicity Potential [kg DCB-Equiv.]	LC50 data have been converted to equivalents.
Resources consumption	Global / Regional / Local	Fossil fuels and minerals that have been utilized	Resources consumption potential	LCI data have been converted into Resources Consumed equivalent.
Land use	Global / Regional / Local	Landfill area occupied for waste disposal	Land propriety	Solid waste amounts have been calculated with their volumes.
Water consumption	Regional / Local	Water that has been used or consumed	Water scarcity	LCI data have been converted into water reserves.

International methodologies have been used to assess impacts. CML Methodology groups the life cycle impact consequences into midpoint categories, according to common mechanisms. Recources Consumption, Acidification, Eutrophication, Global Warming, Ozone Layer Depletion, Human Toxicity, Fresh Water Ecotoxicity, Marine Ecotoxicity, Terrestrial Ecotoxicity and Photochemical Oxidation Potentials have been identified by using CML Methodology.

Table 4.2. Product properties.

Functional unit	Liquid soap product	Shampoo product	Shower gel product	Bar soap product
Weight	400 mL – 425 g	400 mL – 412 g	250 mL – 257 g	200 g
Dosage	4 mL / use	10.5 g / use	12.9 g / use	2 g / use
Number of use	100 use / 400 mL product	39 use / 400 mL product	20 use / 250 mL product	100 use / 200 g product
EU-EcoLabel Criteria (f.u. = 1 g of Active Content. AC = weight of organic ingredients in the product calculated on the basis of the complete formulation of the product.)				
Critical Dilution Volume (CDV_{tox})	20000 l/f.u	20000 l/f.u	20000 l/f.u	3500 l/f.u
Content of ingredients exceeding 0.010% by weight and not readily biodegradable	< 30 mg/f.u	< 30 mg/f.u	< 30 mg/f.u	< 15 mg/f.u
Content of ingredients not anaerobically biodegradable	< 25 mg/f.u	< 25 mg/f.u	< 25 mg/f.u	< 15 mg/f.u

The system boundary is defined as a supply-chain system, including all stages from raw material extraction to the end-of-life treatment of the product. Additionally, selected system boundary should be consistent with goal and scope of the study (Escamilla et al., 2012). The system consist of following subsystems; raw materials which are used for production and transportation of them, manufacturing processes, packaging, use of product, transportation of wastes after usage and end of life.

4.1. Selected Liquid Soap Product

Within the scope of this study raw materials acquisition, production, use and disposal phases of selected liquid soap product have been analyzed. Functional unit for liquid soap product is 0.425 kg as one bottle of product.

Within the life cycle assessment of liquid soap product, the main environmental impacts have been seen in the raw materials acquisition phase. After that, the packaging phase follows with its high usage of plastics and chemicals. Raw material changes in recipes according to European Union EcoLabel Criteria have been assessed and the product improvements have been suggested. Olive oil, Cocamide Mea and Glycerin ingredients relatively have contribution to environmental foot print of liquid soap production. With respect to EU EcoLabel Criteria and related calculations, the CDVtox of the liquid soap product is below 20000L/f.u which mean that the chemicals included in the formulation of this product do not give rise to aquatic toxicity in production and use phases. When the biodegradability of chemical substances in product has been thought, it is observed that all surfactants are readily biodegradable and below 0.03g/g AC in formulation (2014/893/EU: Commission Decision, EU Ecolabel for rinse-off cosmetic products).

In order to select correct data within the system, raw materials composition of product has been listed and different ways have been followed. Chemicals which are included in EcoInvent database have been used directly. For the ones which have not been placed in database; approximations have been done according to chemical structures and production technologies. The chemicals used in selected liquid soap production are given in table below with their CAS numbers and roles in formulation.

Table 4.3. The chemicals used in selected liquid soap production.

Raw materials	Cas number	Environmental hazards	Role in formulation	The selected data from ecoinvent
Trilon EDTA Powder	64-02-8	Possibly hazardous short term degradation products are not likely. Long term degradation products may arise.	Chelating agent	EDTA production
Sodium Lauret Sulphate (SLES)	68891-38-3	Acutely toxic to aquatic life. Readily biodegradable. Significant accumulation in organisms is not to be expected.	Anionic surfactant	Sodium sulphate, powder, production mix, at plant
Cocoamidoprophyl Betaine	61789-40-0	Readily biodegradable.	Seconder amphoteric surfactant & foam booster	Fatty acid/ production, from vegetable oil
Comperlan COD (Cocamide DEA & Glycerin)	68603-42-9	Readily biodegradable.	Seconder amphoteric surfactant	Fatty acid/ production, from vegetable oil
Cibafast H Liquid (Sodium Benzotriazolyl, butylphenol sulfonate)	92484-48-5, 143-22-6		Uv absorber	Triethyleneglycol production
Microcare CB (Benzyl Alcohol, Triethylene Glycol)	100-51-6, 55965-84-9	Readily biodegradable.	Preservative	Biocides, for paper production, unspecified, at plant
Sodium Chloride	7647-14-5	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise. The product itself and its products of degradation are not toxic.	Thickening agent	Sodium chloride, powder/production
Citric Acid	77-92-9	Readily biodegradable.	Acidity adjustment	Fatty acid/ production, from vegetable oil
CI 19140	1934-21-0	Toxicity to daphnia and other aquatic invertebrates EC50 - Daphnia - 5.706,55 mg/l - 48 h	Coloring agent	Chemical organic/ production
CI 17200	3567-66-6	Toxicity to daphnia and other aquatic invertebrates EC50 - Daphnia - 5.706,55 mg/l - 48 h	Coloring agent	Chemical organic/ production
CI 61570	3443-90-1	Toxicity to daphnia and other aquatic invertebrates EC50 - Daphnia - 5.706,55 mg/l - 48 h	Coloring agent	Chemical organic/ production

Table 4.3. Continued.

Picholine	Mixture		Perfume	Fatty acid/ production, from vegetable oil
Olivem (Olive Oil Esther)	226708-41-4	Readily Biodegradable	Additive	Fatty acid/ production, from vegetable oil

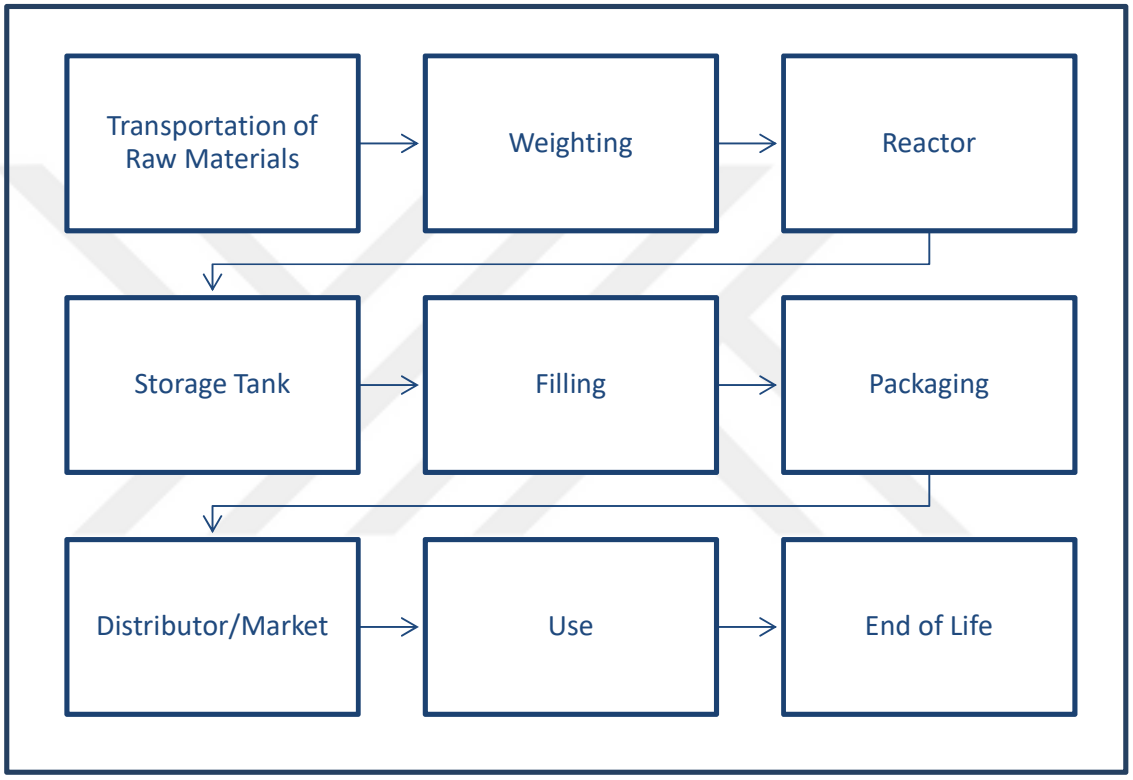

Figure 4.1. Process diagram for liquid soap product.

In this study, raw materials, raw materials transportation from their producers to the plant and the final product transportation from the plan to the consumer, the energy and water consumed at the plan during the production stage and the packaging and production wastes at the end of the life were taken into account.

Here in Figure 4.2; each category of environmental impacts is shown as percentage distributions according to the LCA stages. When the results are examined, firstly raw materials and end-of-life stages are seen as the stages that stand out in impact categories. While the effect of the use phase of ozone layer depletion is observed, it is seen that the raw material acquisition phase has more effect on all remaining environmental impact categories.

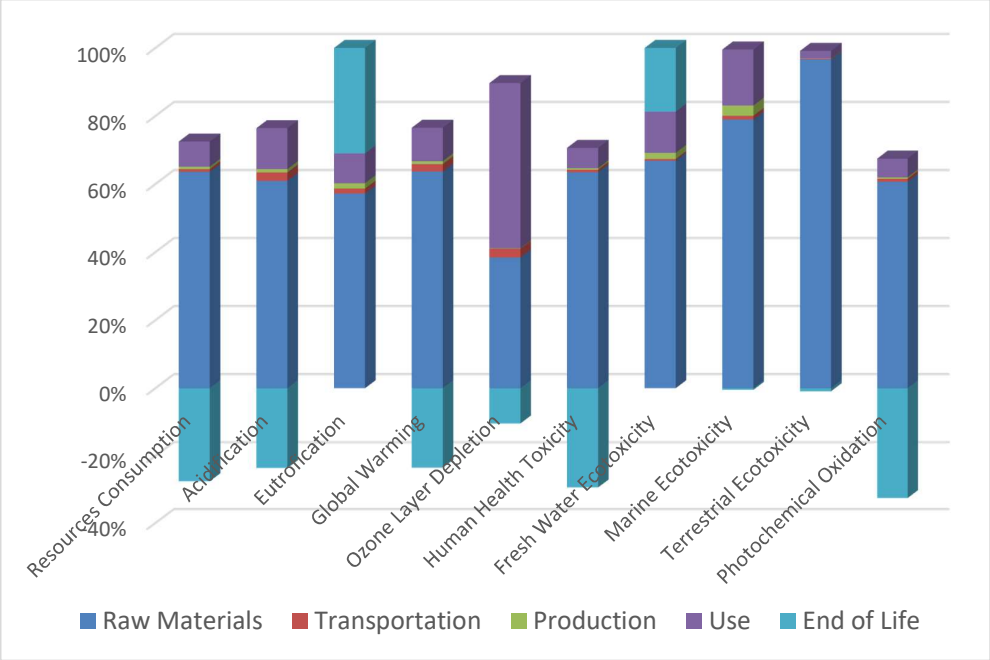

Figure 4.2. Characterization of environmental impact categories in liquid soap life cycle.

Above stated environmental impact categories have been compared by normalization process. Normalization is a process which refers the whole world's consumption averages in terms of their environmental impacts. In results; sea, fresh water and terrestrial ecotoxicity are three major impact categories and the highest environmental pollution load comes from raw materials acquisition phase (Figure 4.3).

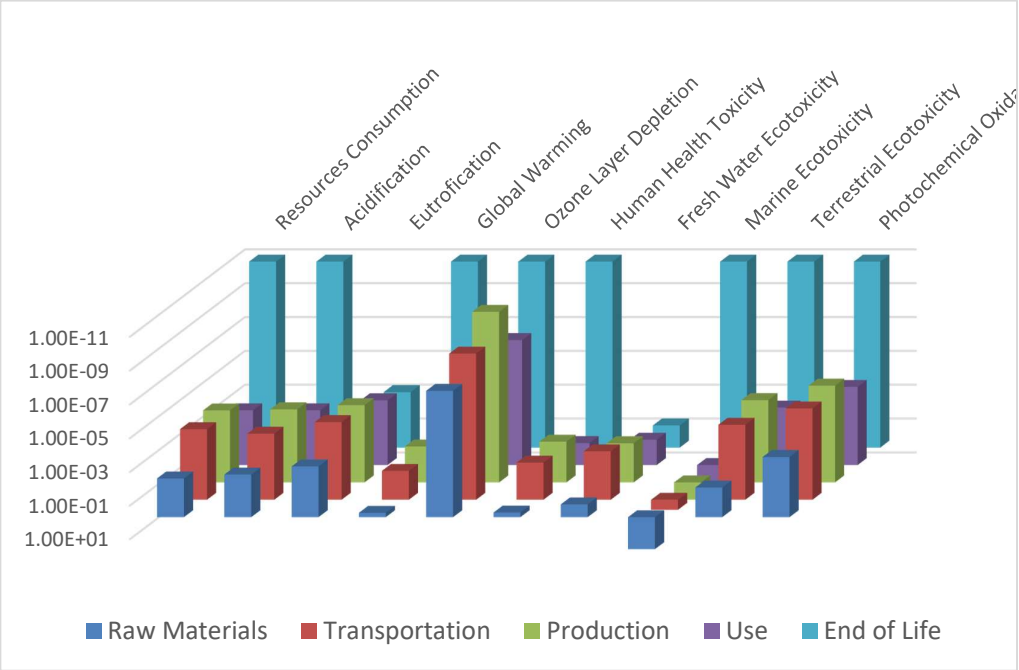

Figure 4.3. Normalization of environmental impact categories in liquid soap life cycle.

4.1.1. Resources Consumption

Resource consumption, which is the category of impact expressing the consumption of natural resources (petroleum, iron ore, etc.), is given in Figure 4.4. for the production of one bottle of liquid soap. The biggest impact is the raw material stage. The reason for this is the consumption of the raw materials used during production. The negative result of the end-of-life stage results from packaging recoveries in the scenario. Because at this point, there will be no resources for the packaging which is needed during production and this will decrease the value in this effect category.

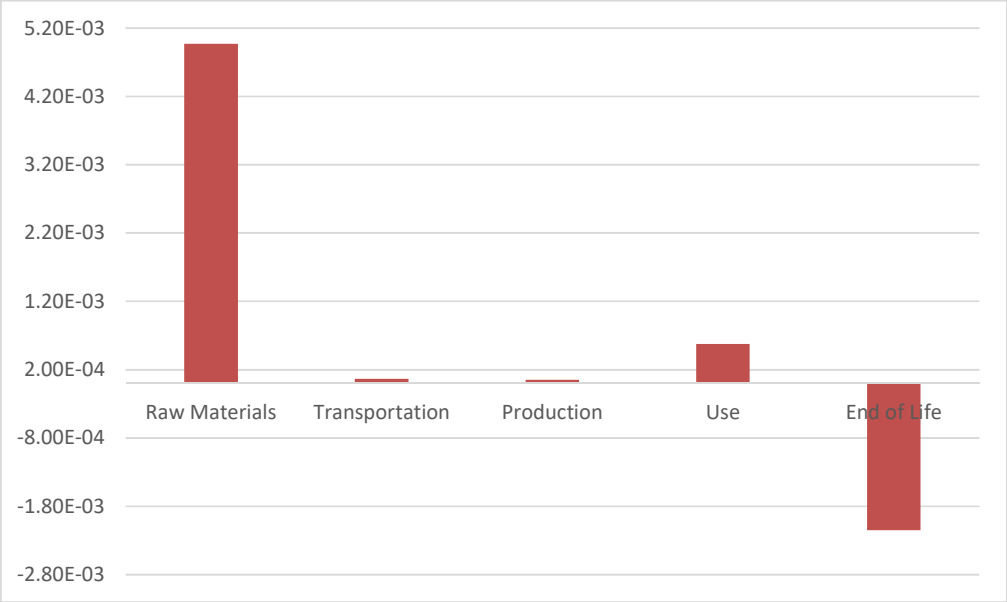

Figure 4.4. Resources consumption impact in liquid soap life cycle.

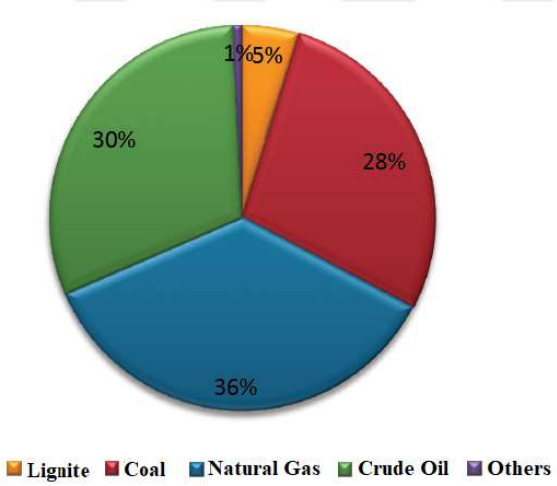

Figure 4.5. Decomposition of substances that affect resource consumption.

4.1.2. Environmental Impact Assessment of Raw Materials

The environmental loads of the raw materials used in the production are compared with each other in Figure 4.6. According to the results, the main effects of DEA & glycerin on olive oil and cocamide are found in all raw materials.

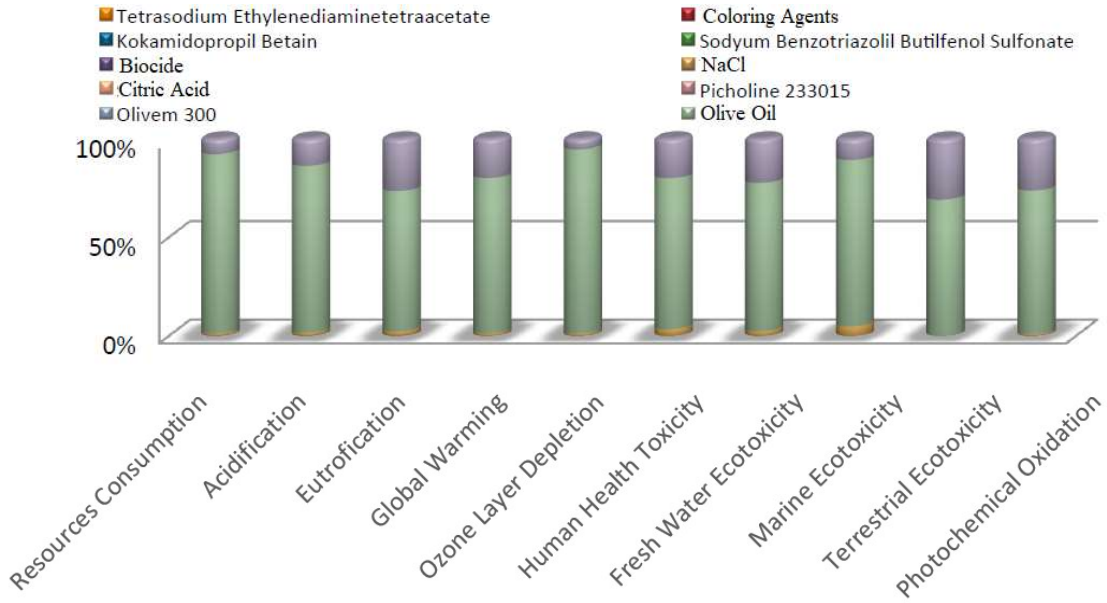

Figure 4.6. Comparison of raw materials according to environmental impact categories.

4.1.3. Global Warming Potential

The global warming potential, in other words, the distribution of the environmental impact of carbon footprint by LCA stages is given in Figure 4.7.

According to the results, the raw material stage is the hot spot. The effects of olive oil and Cocamide DEA & Glycerin raw materials on the recipe are prominent. The effect in the use phase is caused by the consumer habits, ie the amount of water used. End-of-life negative effects refer to benefits from recycling. At the end, the carbon footprint causing global warming was found to be caused by carbon dioxide gas (Figure 4.8).

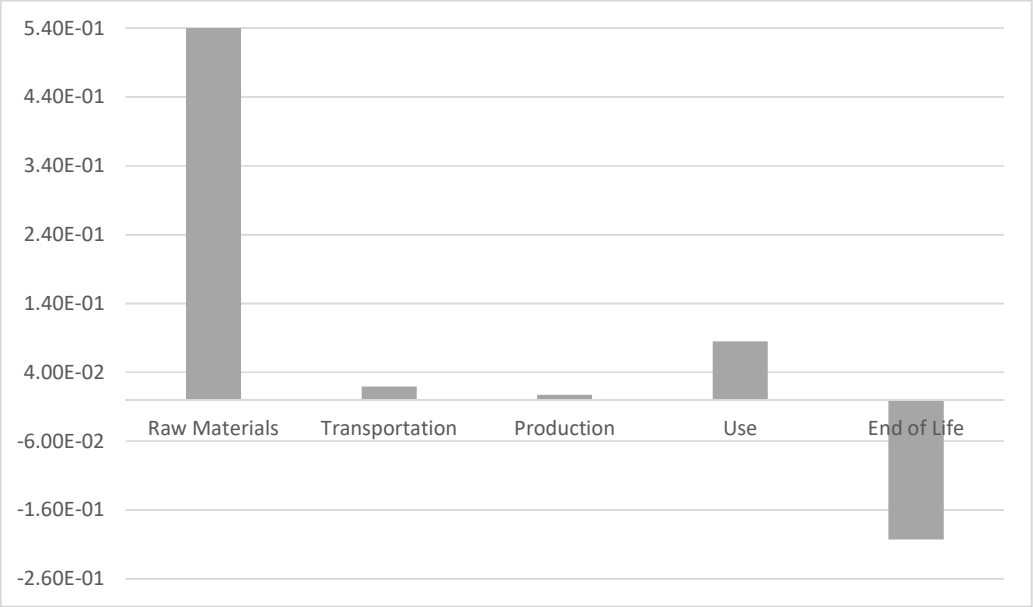

Figure 4.7. Global warming potential in liquid soap life cycle.

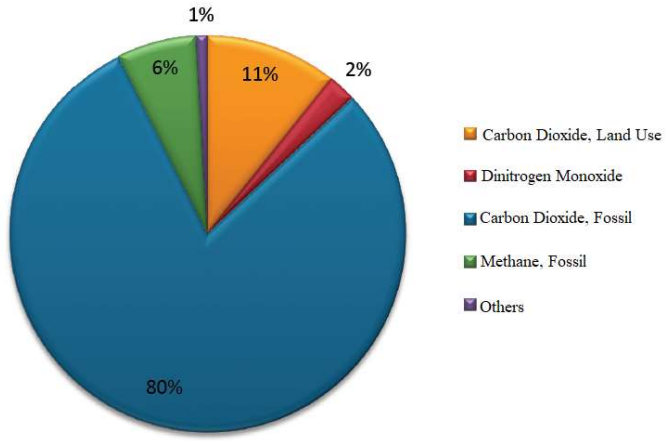

Figure 4.8. Separation of substances affecting global warming.

4.1.4. Acidification Potential

As it is seen in Figure 4.9; the acidification potential which expresses the toxic effect of acid on soil, surface/ground water, organisms, ecosystems and materials, it is seen that the raw materials acquisition phase of 1 bottle of liquid soap production has higher impact. Sulfur dioxide emissions from the production of raw materials are the main reason for this.

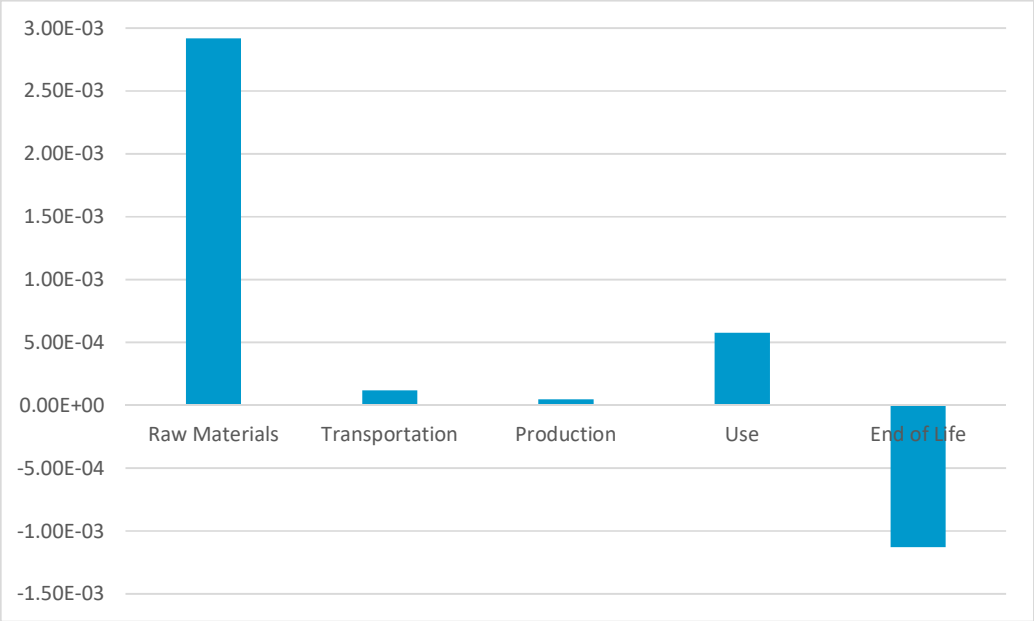

Figure 4.9. Acidification potential in liquid soap life cycle.

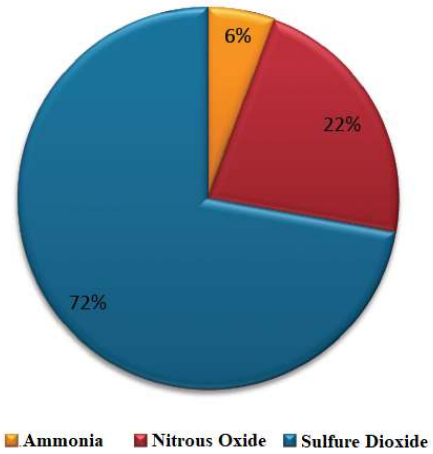

Figure 4.10. Decomposition of substances affecting acidification.

4.1.5. Eutrophication Potential

When eutrophication which is defined as impacts of excessive release of nutrients to air, water and soil is examined, it is observed that raw materials and end-of-life stages contribute the most. The impact of end-of-life stage is due to increased eutrophication after discharge of wastewater to wetland after use. The impact of the use of olive oil in the raw material stage is prominent (Figure 4.11).

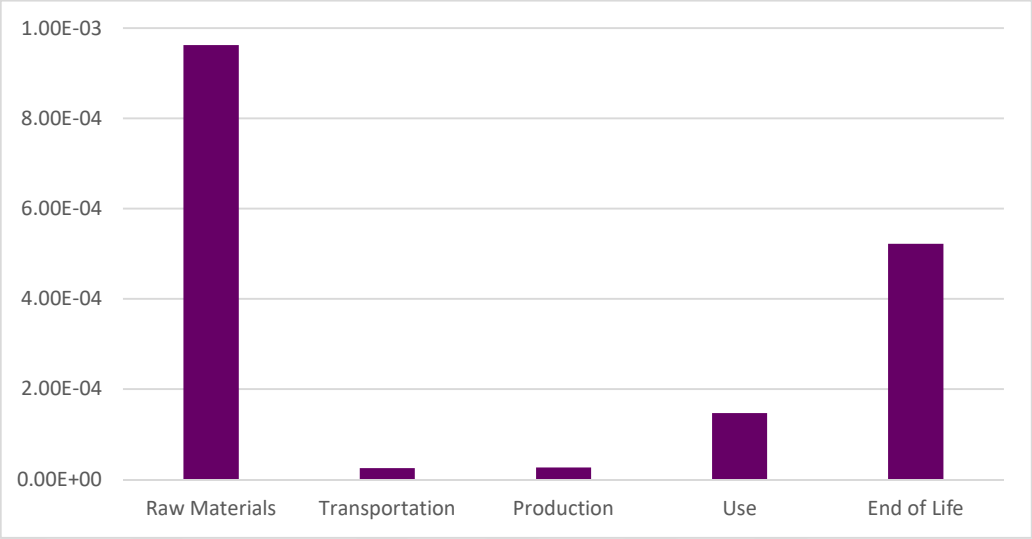

Figure 4.11. Eutrophication potential in liquid soap life cycle.

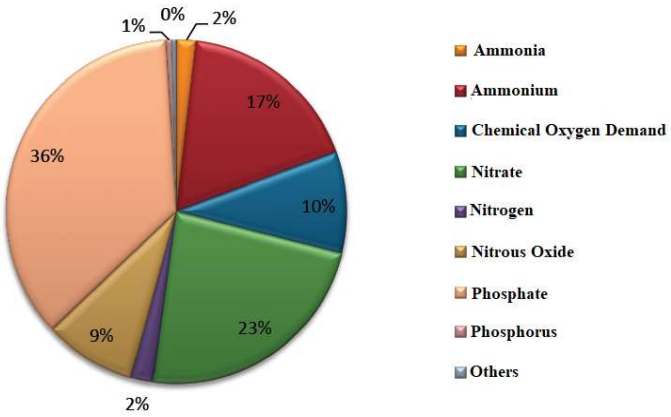

Figure 4.12. Decomposition of substances affecting eutrophication.

4.1.6. Ozone Layer Depletion Potential

This impact, which expresses the decrease in the amount of ozone in the stratosphere and the depletion of the ozone layer due to the effects of human gases, such as CFC, HCFC, chlorine and bromine, is seen to be more effective in the use phase (Figure 4.13). The major reason for this is the emissions during water consumption. The impact on the raw material stage is due to the emissions generated during the production of energy used in the production of raw materials.

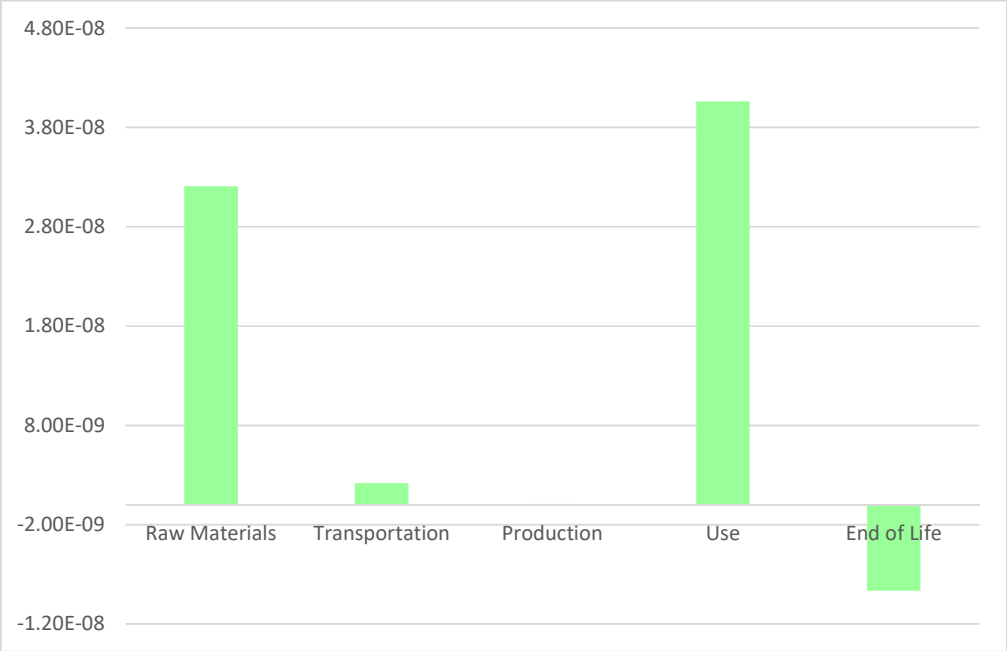

Figure 4.13. Ozone layer depletion potential in liquid soap life cycle.

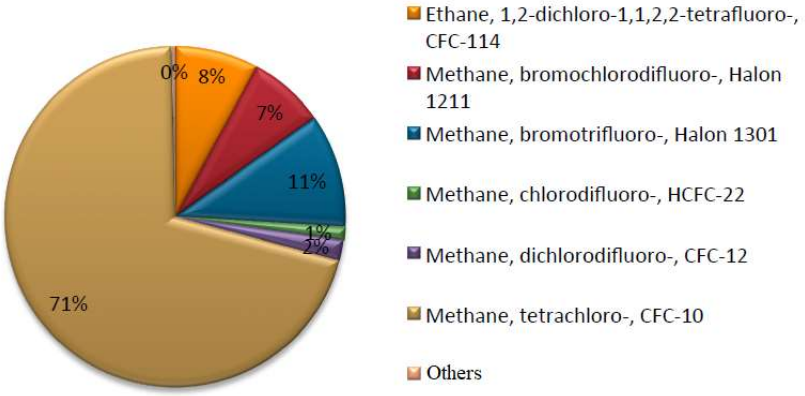

Figure 4.14. Decomposition of substances affecting ozone layer depletion.

4.1.7. Human Health Toxicity Potential

Human health toxicity, which expresses the toxic effect on human health caused by the release of various chemicals to the environment, is mainly due to the raw material stage (Figure 4.15). This is due to the chemical and hazardous metal emissions that occur in the raw material production processes.

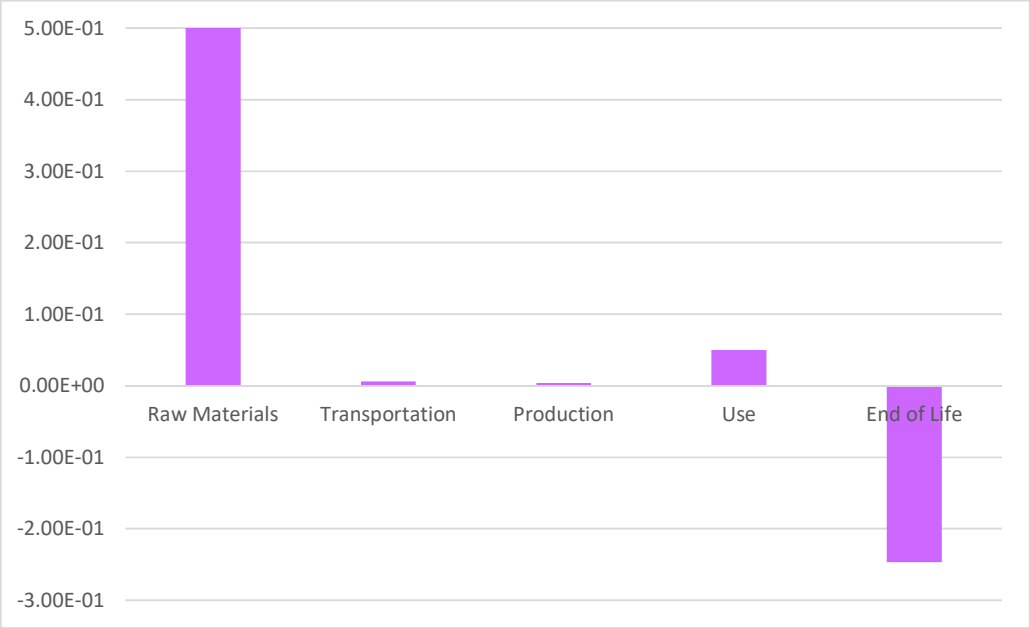

Figure 4.15. Human health toxicity potential in liquid soap life cycle.

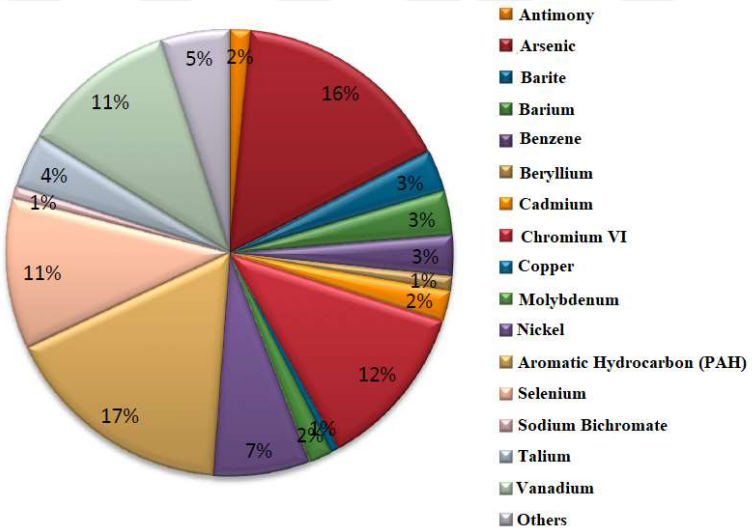

Figure 4.16. Decomposition of substances affecting human health toxicity.

4.1.8. Fresh Water Ecotoxicity Potential

This impact, which expresses the harm to the freshwater ecosystem as a result of the mixture of toxic substance-induced emissions to air, water or soil, is due to more raw material stage than other impact categories (Figure 4.17). This is due to the emissions during the production of the energy used during the production of raw materials. The effect of olive oil is prominent.

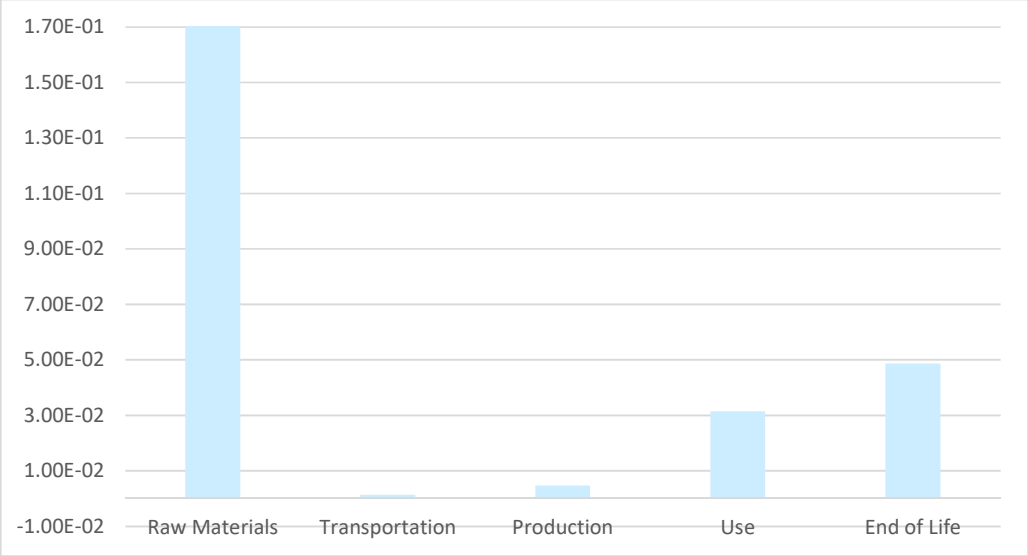

Figure 4.17. Fresh water ecotoxicity potential in liquid soap life cycle.

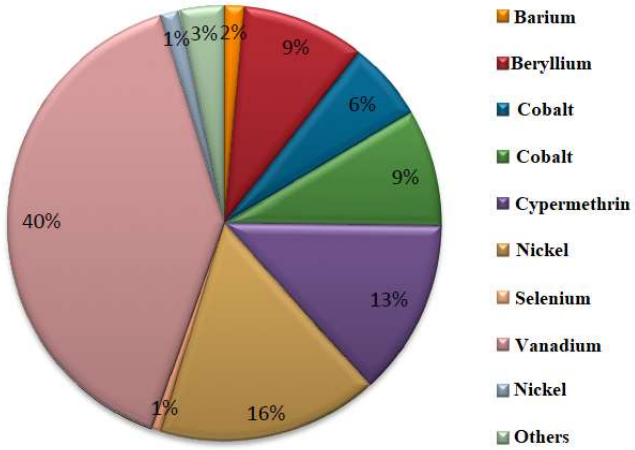

Figure 4.18. Decomposition of substances affecting fresh water ecotoxicity.

4.1.9. Marine Ecotoxicity Potential

This impact, which expresses the harm to the sea ecosystem is due to raw materials, use and end of life impacts. The impact in the raw material stage is caused by emissions to the environment during the production of raw materials and the effects of olive oil, Cocamide DEA & Glycerin on the recipe are prominent. (Figure 4.19). The classification of the causative agents was given in Figure 4.20 and the effect was mostly caused by beryllium and vanadium.

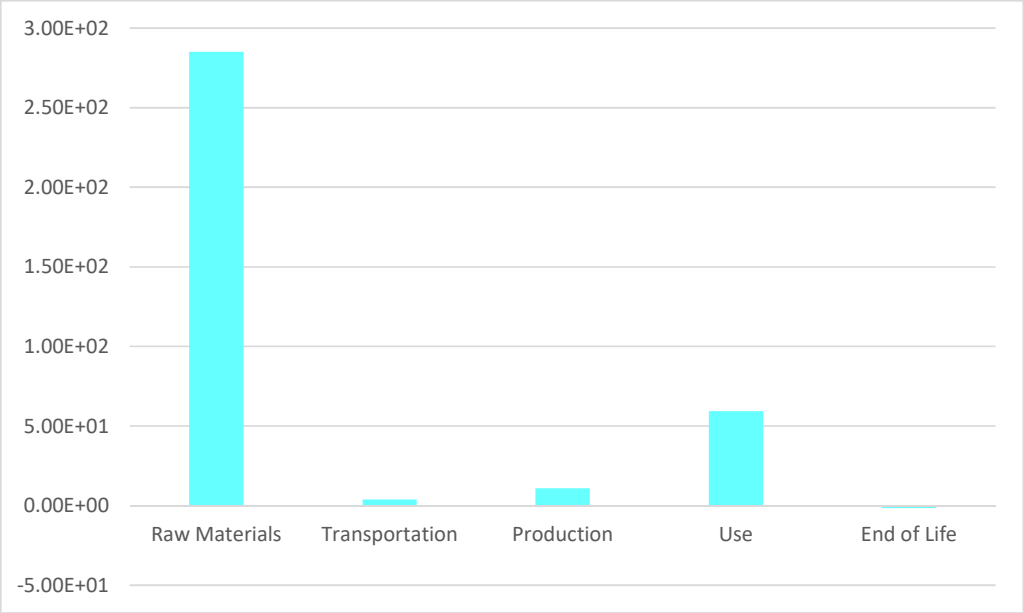

Figure 4.19. Marine ecotoxicity potential in liquid soap life cycle.

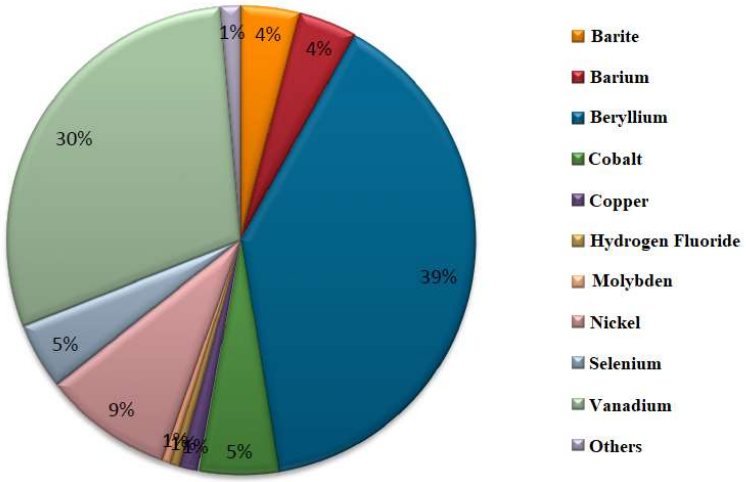

Figure 4.20. Decomposition of substances affecting marine ecotoxicity.

4.1.10. Terrestrial Ecotoxicity Potential

This impact, which expresses the impacts of toxic substances released to the environment on the terrestrial ecosystem, is of raw material origin (Figure 4.21). The reason for this impact in the raw material acquisition is due to the emissions from the production of raw materials.

Olive oil found in the product contains 68% and then Cocamide DEA & Glycerin has the most effect with 31%. The classification of the causative agents was given in Figure 4.22 and most of the effect was caused by cypermethrin.

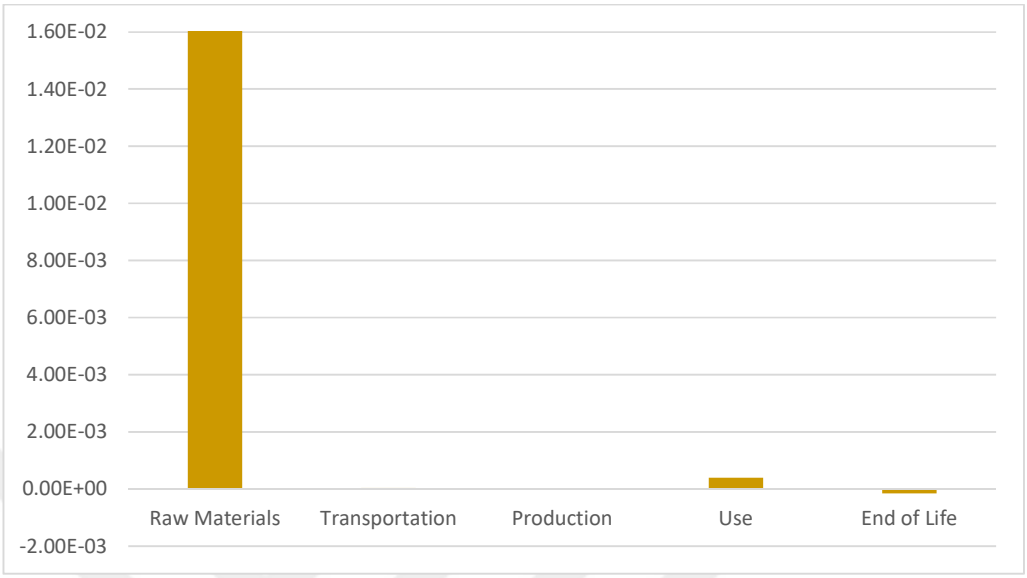

Figure 4.21. Terrestrial ecotoxicity potential in liquid soap life cycle.

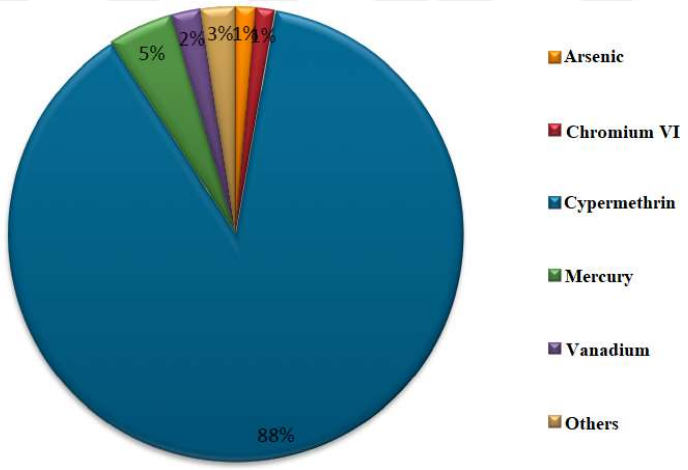

Figure 4.22. Decomposition of substances affecting terrestrial ecotoxicity.

4.1.11. Photochemical Oxidation Potential

The raw material stage is important in this impact category, which defines the formation of reactive substances that damage agricultural products, human health and ecosystems. Emissions during the production of raw materials and during the production phase are the main reason for this (Figure 4.23).

The decomposition of the substances causing this impact is given in Figure 4.24 and most of the impact is from carbon monoxide. As in the other impact categories, the benefits resulting from the end-of-life scenario result in recycling and reuse.

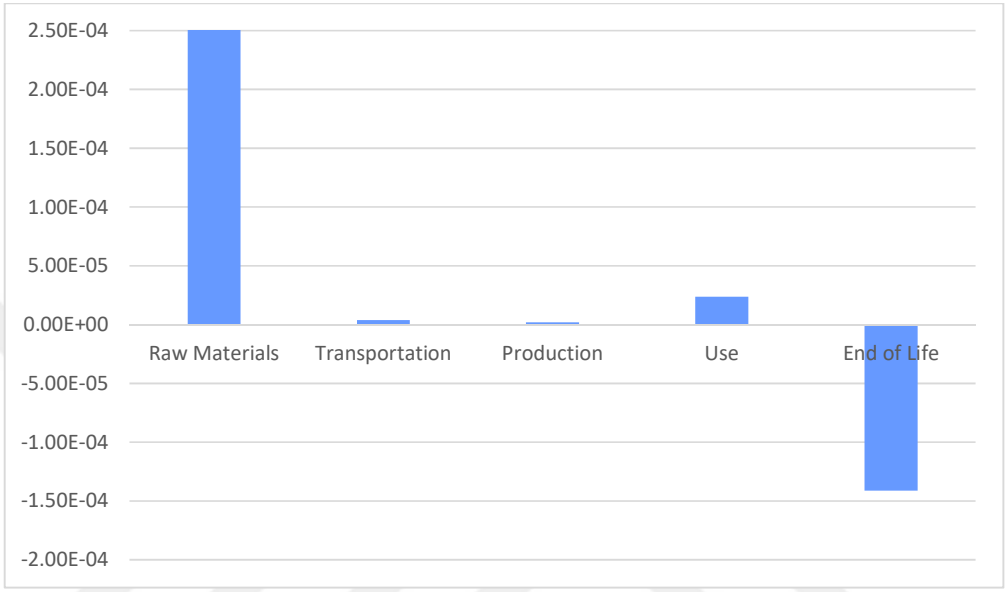

Figure 4.23. Photochemical oxidation potential in liquid soap life cycle.

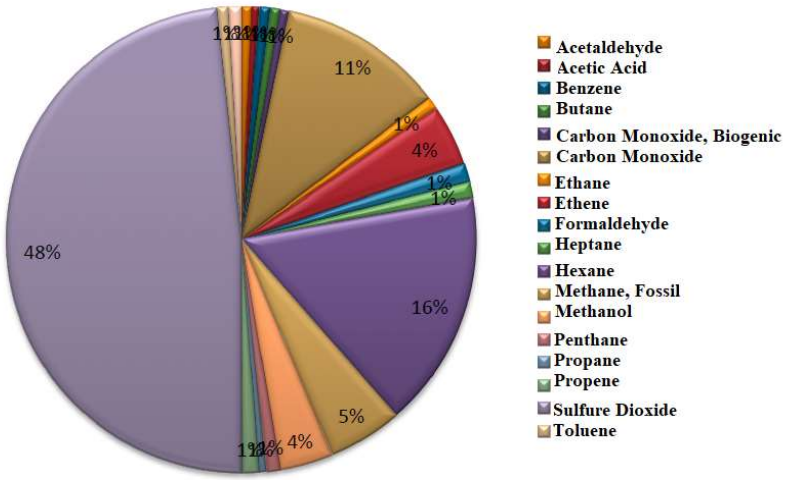

Figure 4.24. Decomposition of substances affecting photochemical oxidation.

4.2. Selected Handmade Bar Soap Product

Within the scope of this study raw materials acquisition, production, use and disposal phases of selected bar soap product have been analyzed. Functional unit for bar soap product is 200 g as one bar of product.

Within the life cycle assessment of bar soap product, main environmental impacts have seen in use and production phase. Raw materials used in saponification step and steam generator's energy need have negative contribution to global warming potential of handmade soap bar.

In order to select correct data within the system, raw materials composition of product has been listed and different ways have been followed. Chemicals which are included in EcoInvent database have been used directly. For the ones which are not placed in database; approximations have been done according to chemical structures and production technologies. The chemicals used in selected liquid soap production are given in table below with their CAS numbers and roles in formulation.

Table 4.4. The Chemicals Used In Selected Bar Soap Production.

Raw materials	Cas number	Environmental hazards	Role in formulation	The selected data from ecoinvent
Olive Pomace Oil			Oil	Vegetable oil, from waste cooking oil, at plant
Sodium Chloride	7647-14-5	Possibly hazardous short term degradation products are not likely. The product itself and its products of degradation are not toxic.	Thickening agent	Sodium chloride, powder
Sodium Hydroxide	1310-73-2	No Bioaccumulation	Caustic	Sodium hydroxide, 50% in H2O, production mix, at plant
Citronella Oil	8000-29-1		Perfume	Fatty alcohol, petrochemical, at plant
Isobornyl Acetate	125-12-12		Perfume	3-methyl-1-butyl acetate

Table 4.4. Continued.

Diphenyl Oxide	101-84-8		Perfume	Diphenylether-compounds, at regional storehouse
Pine Oil 70	8002-09-3		Perfume	Fatty alcohol, from palm oil
Silicate				Sodium silicate, furnace process, pieces, at plant

As a result of the life cycle assessment, it was determined that the highest environmental impact was caused by the user. This information needs to be communicated within the framework of the social responsibility of educating the consumer. Handmade solid soap's carbon footprint was found as 0.929 kg CO_2eq.

In case the consumer effect is not handled, the recipe stands out as in other chemical industry products. In this case, the carbon footprint is calculated as 0.379 kg CO_2eq per functional unit. A large part of this value comes from the raw material stage. Prina oil and caustic are the main ingredients of soap production. It is recommended to provide these raw materials from more sensitive sources.

The proposal to be made over the bill is the R & D work to be carried out on the prescription. Changes to the prescription without lowering product quality are assessed on the basis of a clean production label, EU Ecolabel. The following results were obtained in the evaluation of the product composition:

- The chemicals used in prescription were below Critical Dilution Volume (CDV). This shows the minimum effect to the environment and living things.

- All chemicals in the prescription are degredable in both aerobic and anaerobic environments.

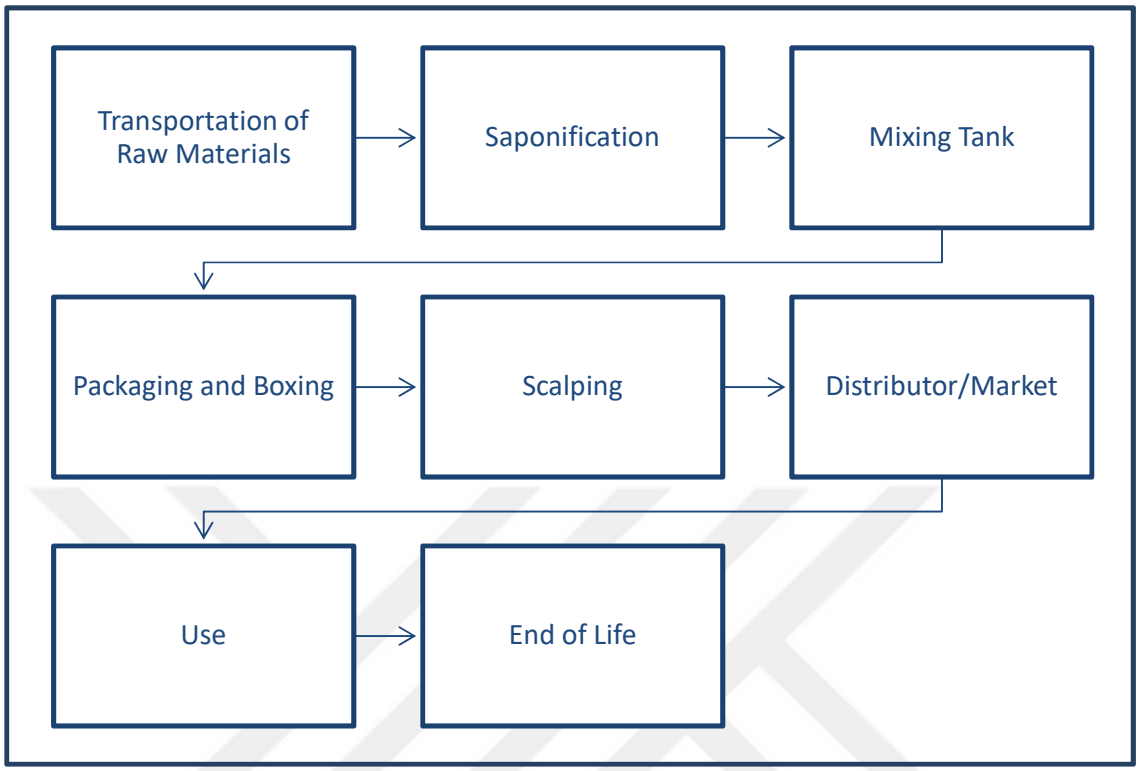

Figure 4.25. Process diagram for bar soap product.

In this study, raw materials used in the raw material stage, raw materials transportation stage from the producer to the factory and the final product transportation from the factory to the consumer, the energy and water consumed at the factory during the production stage and the packaging and production wastes at the end of the life were taken into account.

Here in Figure 4.26; each category of environmental impacts is shown as percentage distributions according to the LCA stages. When the results are examined, respectively, usage, production and raw material stages are seen as the stages that stand out in the effect categories. While environmental impacts such as resource consumption, acidification, global warming and ozone depletion are prominent in the process of use, human health toxicity, freshwater ecotoxicity, production of marine ecotoxicity and photochemical oxidation, raw material in terrestrial ecotoxicity and end of life in eutrophication come to the fore.

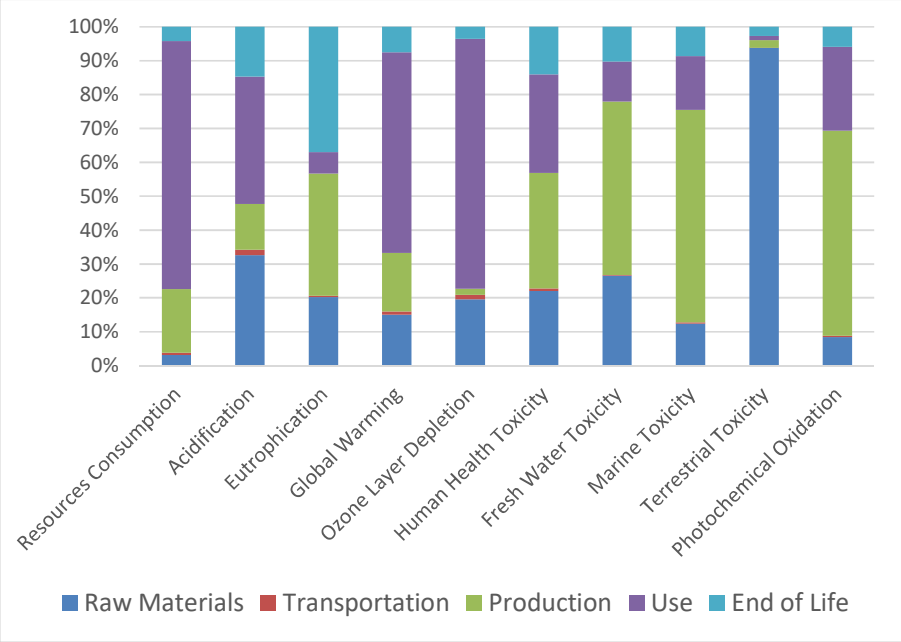

Figure 4.26. Characterization of environmental impact categories in bar soap life cycle.

Above stated environmental impact categories have been compared by normalization process (Figure 4.27). Normalization is a process which refers the whole world's consumption averages in terms of their environmental impacts. In results; sea, fresh water and terrestrial ecotoxicity are three major impact categories and the highest environmental pollution load comes from production, use and raw materials acquisition phase.

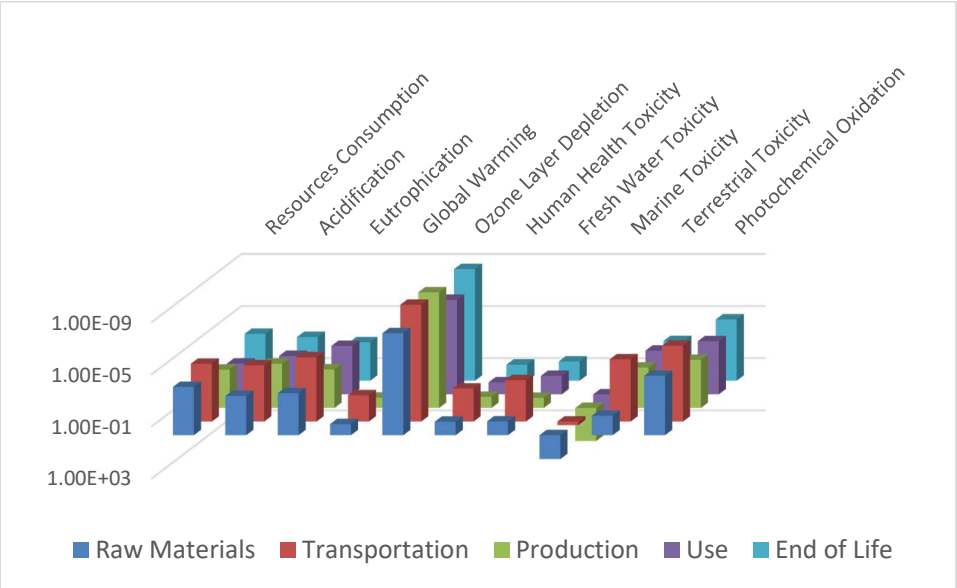

Figure 4.27. Normalization of environmental impact categories in bar soap life cycle.

4.2.1. Resources Consumption

Resource consumption, which is the category of impact expressing the consumption of natural resources (petroleum, iron ore, etc.), is given in Figure 4.28 for the production of 1 handmade bar soap. The highest impacts comes from the use phase, production phase respectively. This is due to the fossil source energy consumed during the production phase. As seen in Figure 4.29, the main sources affecting the resource consumption are natural gas and lignite.

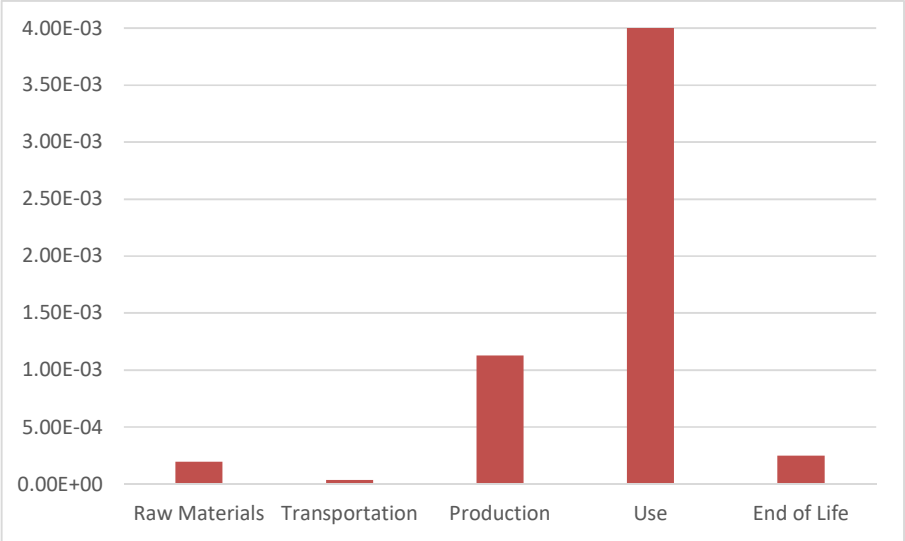

Figure 4.28. Resources consumption impact in bar soap life cycle.

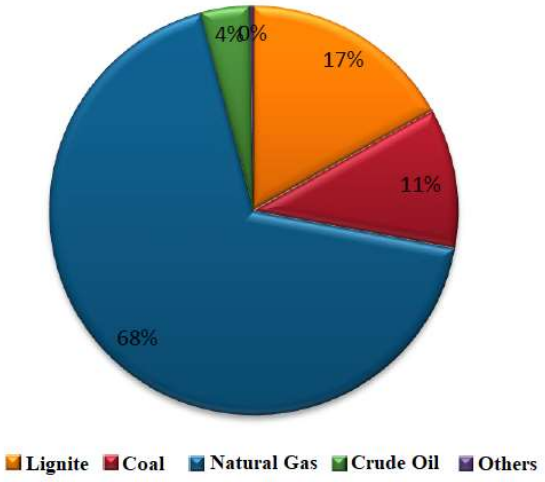

Figure 4.29. Decomposition of substances affecting recources consumption.

4.2.2. Environmental Impact Assessment of Raw Materials

The environmental loads of the raw materials used in the production are compared with each other in Figure 4.30. Sodium chloride has the greatest effect on resource consumption, while prina oil and caustic are prominent in all other effects. Here, prina oil, acidification, eutrophication, global warming, ozone layer thinning, human health toxicity, freshwater ecotoxicity, terrestrial ecotoxicity and photochemical oxidation effect is great, while caustic causes marine ecotoxicity.

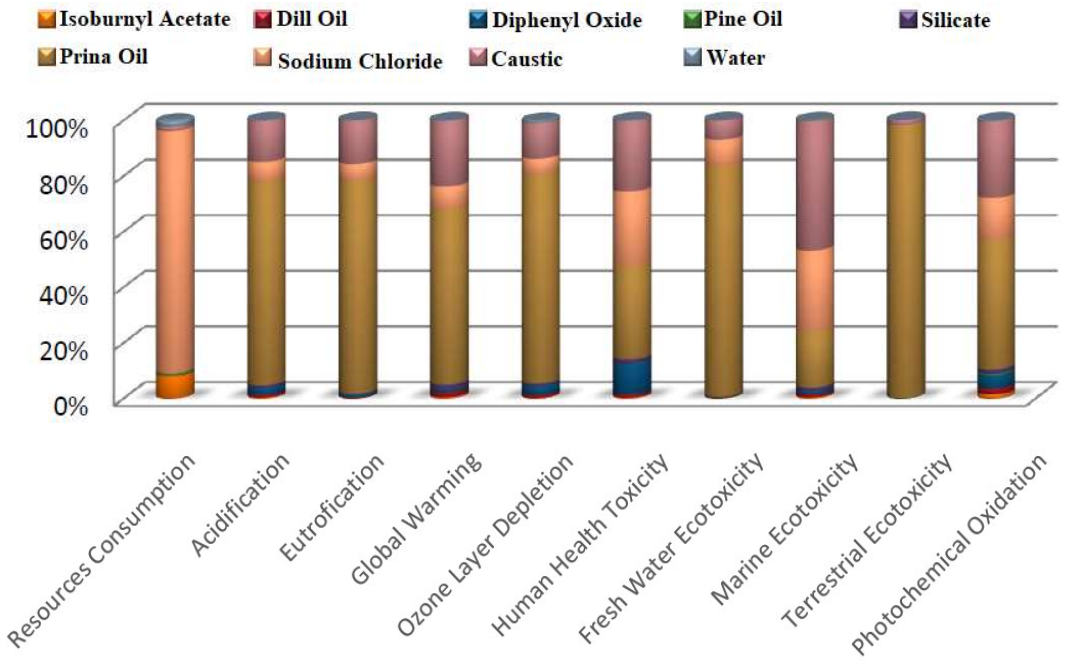

Figure 4.30. Comparison of raw materials according to environmental impact categories.

4.2.3. Global Warming Potential

The global warming potential, in other words, the distribution of the environmental impact of carbon footprint by LCA stages is given in Figure 4.31. According to the results, the consumer use stage is the hot spot. This is caused by the consumer habits, ie the amount of water used.

The second main impact on climate change comes from production. The greatest effect in the production phase is due to the saponification stage and the energy consumed here has a great impact on global warming. The effect on the raw material stage is due to the use of prina oil and caustic.

As a result of these effects, the carbon footprint, which causes global warming, has been found to originate from carbon dioxide (Figure 4.32).

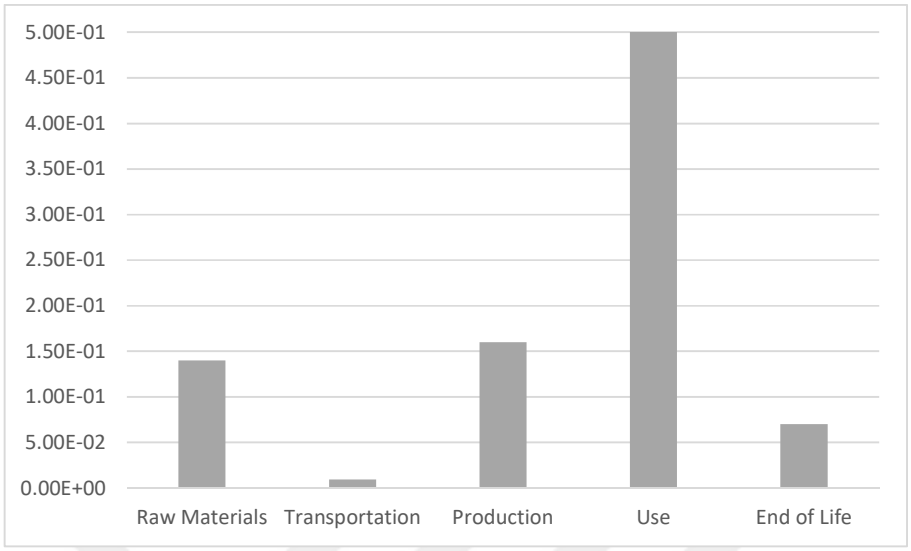

Figure 4.31. Global warming potential in bar soap life cycle.

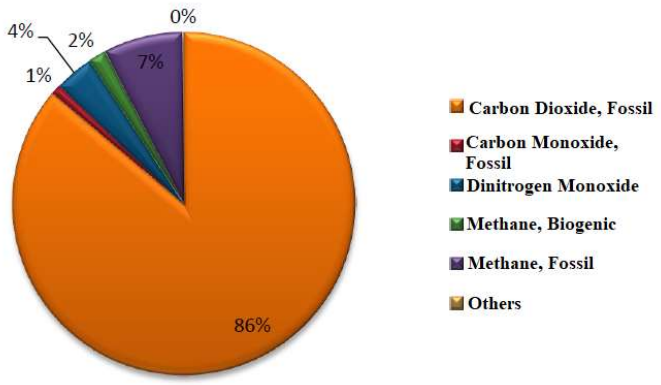

Figure 4.32. Decomposition of substances affecting global warming.

4.2.4. Acidification Potential

When we look at the acidification potential which expresses the toxic effect of acid on soil, surface/ground water, organisms, ecosystems and materials, it is seen that the usage, raw materials acquisition and production phase of 1 handmade bar soap have impacts. The main reason for the effect during the use phase is the emissions from the production of energy used to heat the water used (Figure 4.33). Likewise, the production of raw materials used and the production of energy consumed during the production of sulfur dioxide emissions from the production of the main reason for these effects (Figure 4.34).

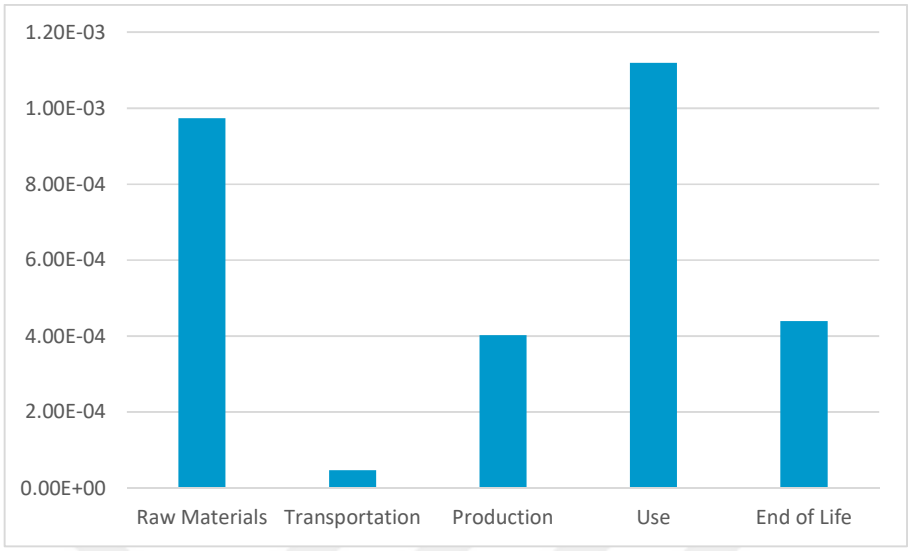

Figure 4.33. Acidification potential in bar soap life cycle.

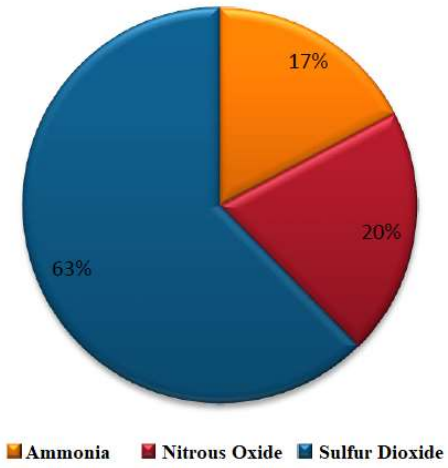

Figure 4.34. Decomposition of substances affecting acidification.

4.2.5. Eutrophication Potential

When eutrophication which is defined as impacts of excessive release of nutrients to air, water and soil is examined, it is seen that the production contributes the most and the raw material follows (Figure 4.35). The effect during the production phase is due to the emissions generated during the production of the energy consumed during the process. The effect on the raw material stage is mainly due to prina oil. The eutrophication are caused mostly by phosphate and nitrate (Figure 4.36).

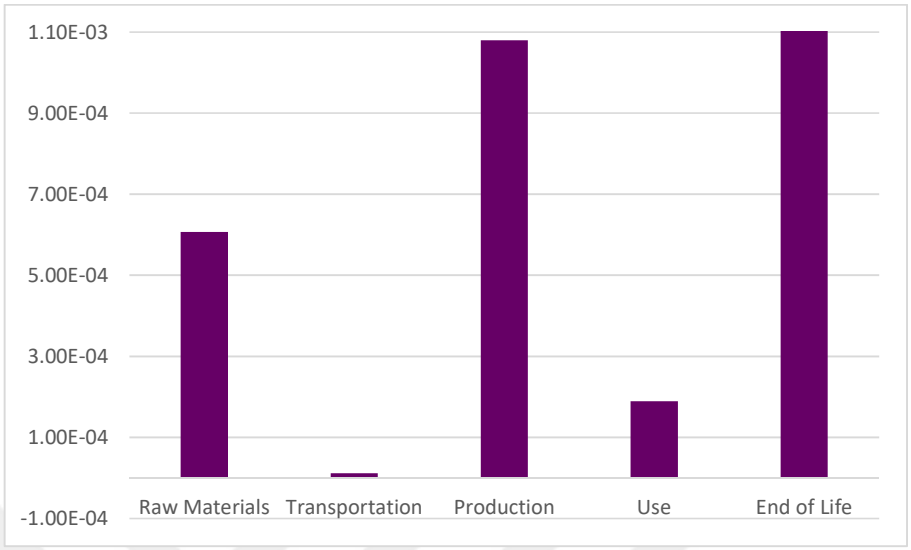

Figure 4.35. Eutrophication potential in bar soap life cycle.

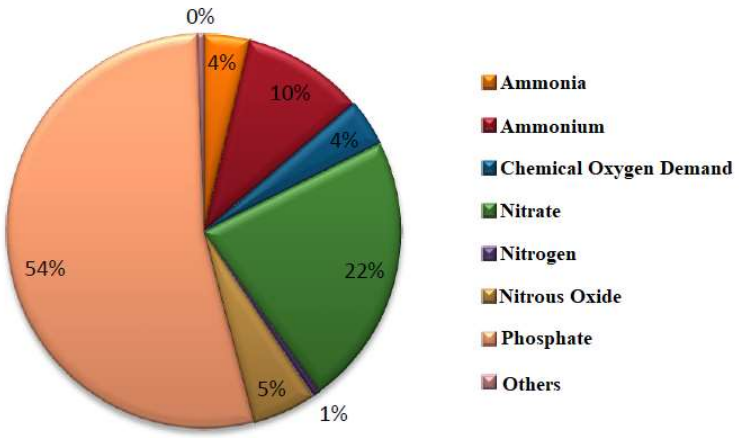

Figure 4.36. Decomposition of substances affecting eutrophication.

4.2.6. Ozone Layer Depletion Potential

This impact, which expresses the decrease in the amount of ozone in the stratosphere and the depletion of the ozone layer due to the effects of human gases, such as CFC, HCFC, chlorine and bromine, is seen to be more effective in the use phase (Figure 4.37). The major reason for this is the emissions during hot water consumption. The impact on the raw material stage is due to the emissions generated during the production of energy used in the production of raw materials. The distribution of gaseous components which are causing this impact are given in Figure 4.38.

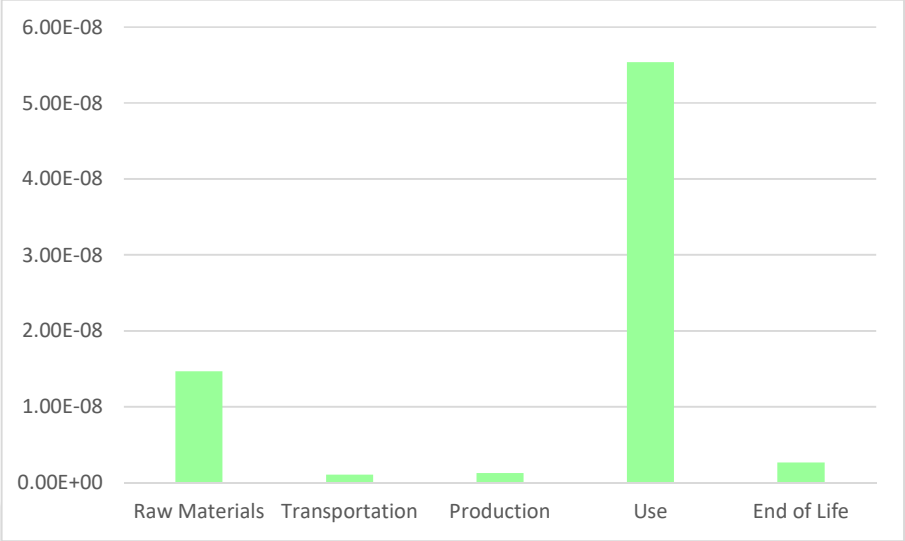

Figure 4.37. Ozone layer depletion potential in bar soap life cycle.

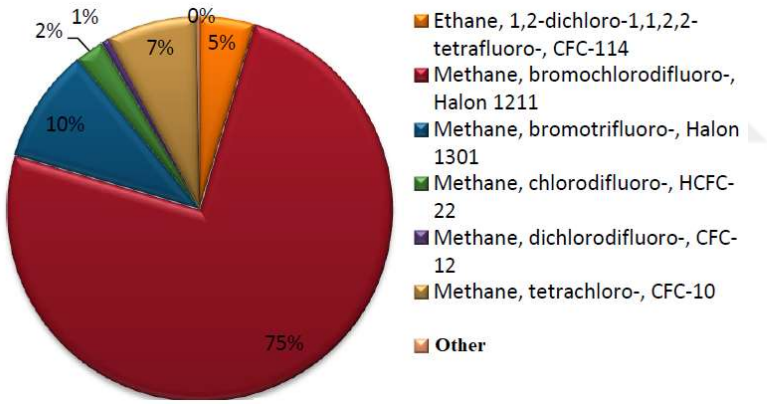

Figure 4.38. Decomposition of substances affecting ozone layer depletion.

4.2.7. Human Health Toxicity Potential

Human health toxicity, which expresses the toxic effect on human health caused by the release of various chemicals to the environment, is due to respectively, from production, use and raw material stages (Figure 4.39). The reason for the effect during the production phase is the emissions generated during the production of the energy consumed. The reason for the impact in the use and raw material stages is the chemical and hazardous metal emissions that occur during the use and raw material production processes. Some of them originate from energy production. The decomposition of the chemicals and metals active here is given in Figure 4.40.

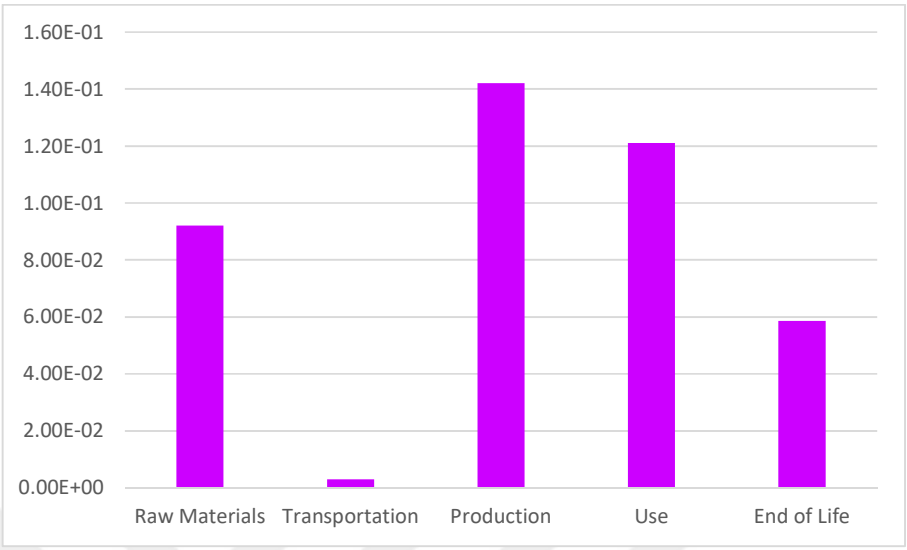

Figure 4.39. Human health toxicity potential in bar soap life cycle.

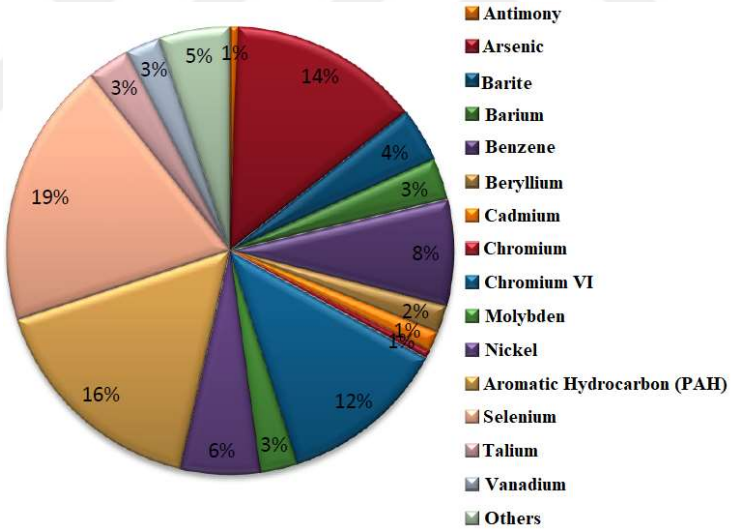

Figure 4.40. Decomposition of substances affecting human health toxicity.

4.2.8. Fresh Water Ecotoxicity Potential

This effect, which expresses the adverse impact to the freshwater ecosystem as a result of the mixture of toxic substance-induced emissions to air, water or soil, is due to the production stage rather than other impact categories (Figure 4.41). These impacts are caused by energy-related emissions, mainly due to emissions generated during the burning of fossil fuels used in

electricity generation. The biggest effect in the raw material stage is due to prina oil (Figure 4.42).

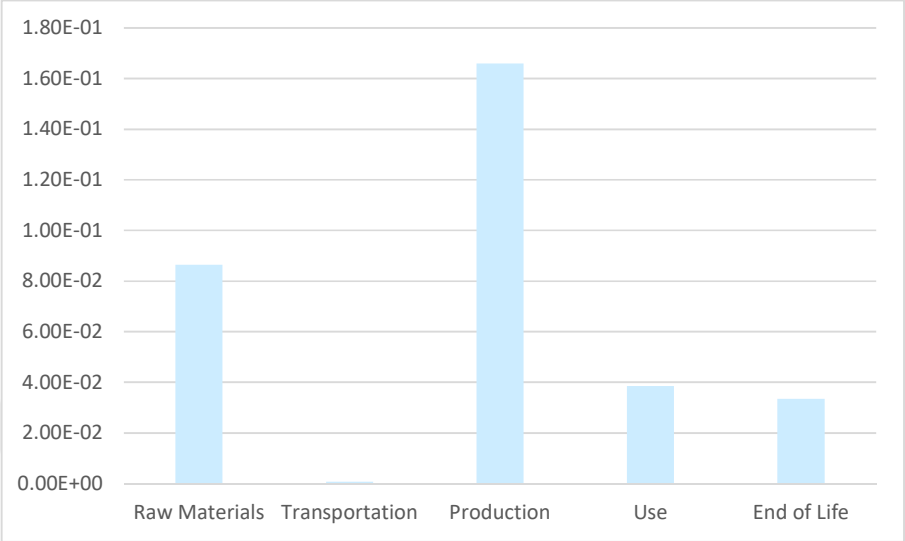

Figure 4.41. Fresh water ecotoxicity potential in bar soap life cycle.

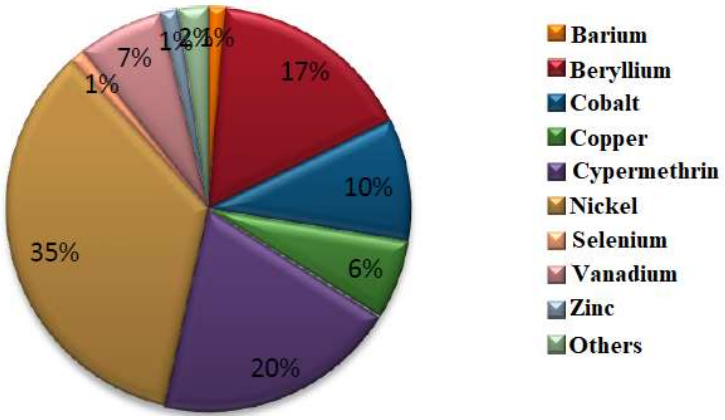

Figure 4.42. Decomposition of substances affecting fresh water ecotoxicity.

4.2.9. Marine Ecotoxicity Potential

This impact category, which expresses the impacts of toxic substances on marine ecosystem, is mostly seen in production, raw material and usage stages. The impact on production is due to the emissions generated during the energy production, the effect on the raw material stage, the emission from the production of raw materials, and the effect on the use phase, the emissions generated during the production of the heating energy (Figure 4.43). The

classification of the causative agents was given in Figure 4.44 and the effect was caused by vanadium and beryllium.

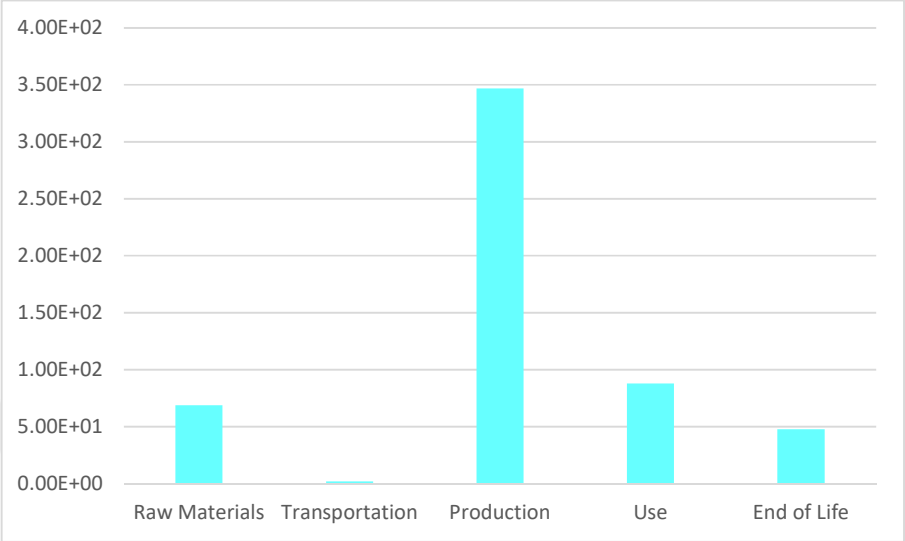

Figure 4.43. Marine ecotoxicity potential in bar soap life cycle.

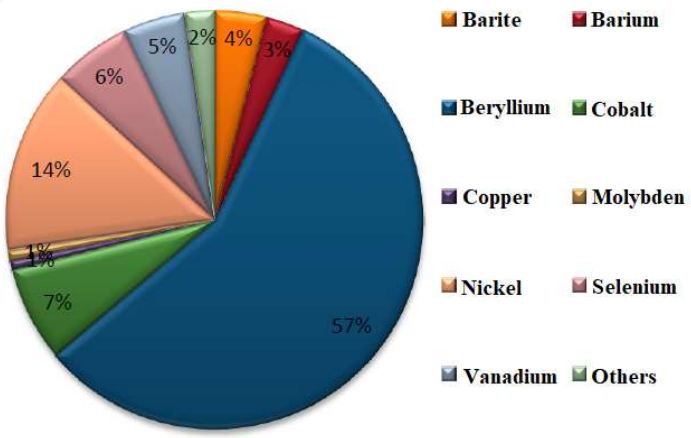

Figure 4.44. Decomposition of substances affecting marine ecotoxicity.

4.2.10. Terrestrial Ecotoxicity Potential

This impact, which expresses the impacts of toxic substances released to the environment on the terrestrial ecosystem, is of raw material origin. The reason for this impact in the raw material acquisiton is due to the emissions from the production of raw materials (Figure 4.45).

The classification of the causative agents was given in Figure 4.46 and most of the effect was from cypermethrin.

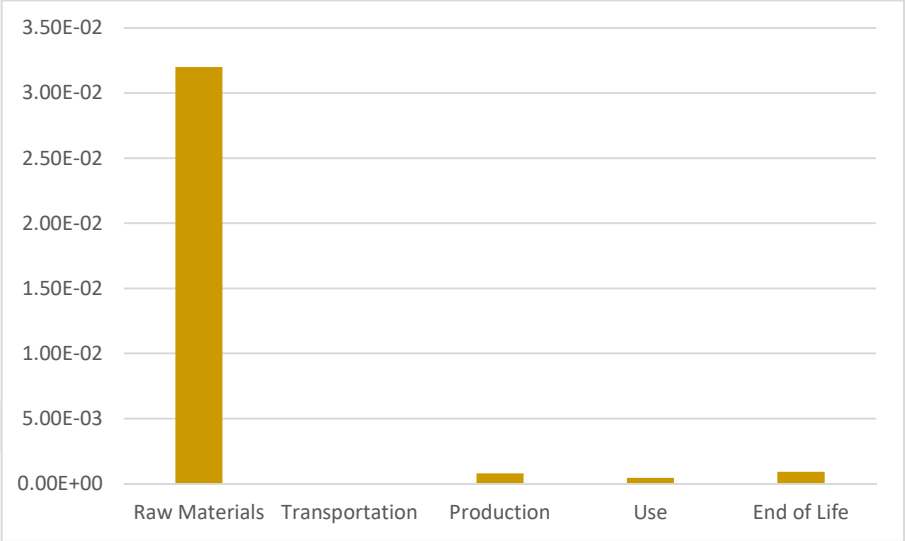

Figure 4.45. Terrestrial ecotoxicity potential in bar soap life cycle.

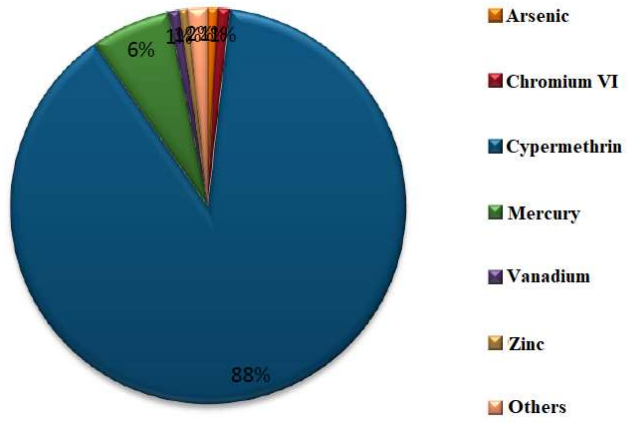

Figure 4.46. Decomposition of substances affecting terrestrial ecotoxicity.

4.2.11. Photochemical Oxidation Potential

The raw material stage is important in this impact category, which defines the formation of reactive substances that damage agricultural products, human health and ecosystems. Emissions during the production of raw materials and during the production phase are the main reason for this (Figure 4.47). The decomposition of the substances that cause these effects due

to emissions during energy production is given in Figure 4.48, and most of the effect has been observed to be carbon monoxide and ethene.

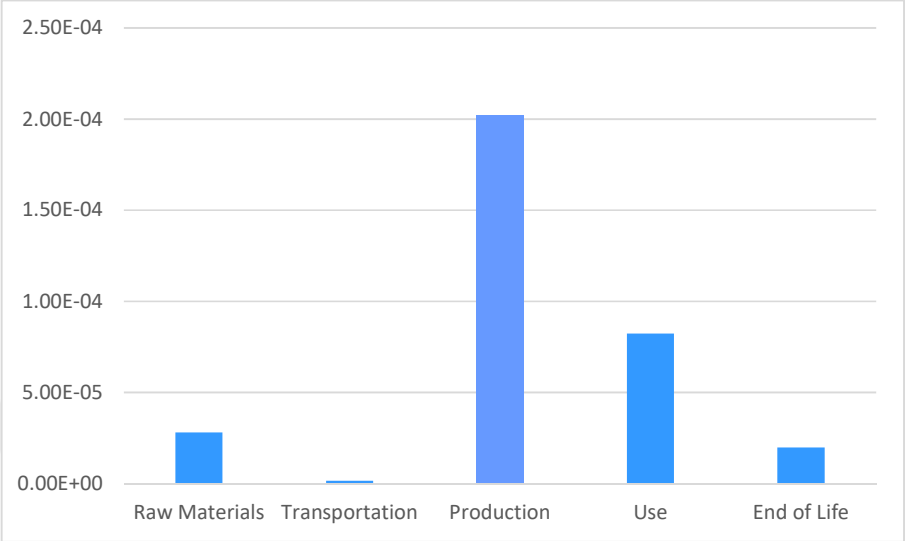

Figure 4.47. Photochemical oxidation potential in bar soap life cycle.

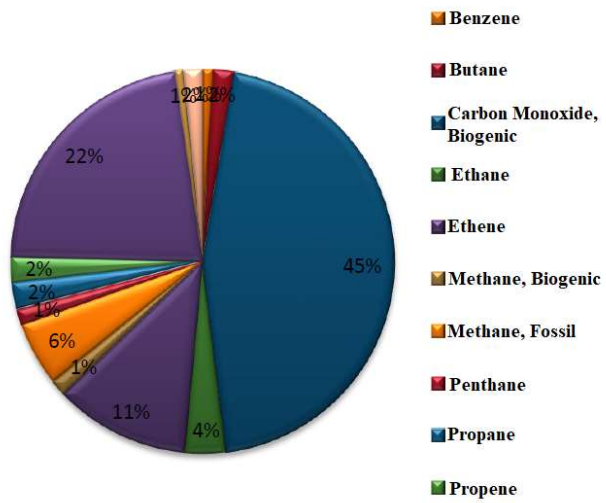

Figure 4.48. Decomposition of substances affecting photochemical oxidation.

4.3. Selected Shampoo Product

Within the scope of this study raw materials acquisition, production, use and disposal phases of selected shampoo product have been analyzed. Functional unit for shampoo product is 400mL (412 g) as one bottle of product.

The highest environmental impacts have been found in consumer use phase within the entire life cycle assessment of shampoo product. It is required from producers to create new policies which rise awareness of consumers. When consumer use phase is not included, raw materials have the biggest contribution in environmental footprint of shampoo production. One of the main components is water which is delivered as tap water by the local municipal utility. Ingredients with a major environmental load are surfactants such as cocoamidopropyl betaine and fatty alkanolamides, and also the controlling viscosity agent and finally sodium benzoate and sodium laureth sulphate. For all substances, global warming, non-renewable energy and land occupation are the impact categories with higher values.

In order to select correct data within the system, raw materials composition of product has been listed and different ways have been followed. Chemicals which are included in EcoInvent database have been used directly. For the ones which are not placed in database; approximations have been done according to chemical structures and production technologies. The chemicals used in selected shampoo production are given in table below with their CAS numbers and roles in formulation.

Table 4.5. The chemicals used in selected shampoo production.

Raw materials	Cas number	Environmental hazards	Role in formulation	The selected data from ecoinvent
Sodium Lauret Sulphate (SLES)	68891-38-3	Acutely toxic to aquatic life. Readily biodegradable. Significant accumulation in organisms is not to be expected.	Anionic surfactant	Sodium sulphate, powder, production mix, at plant
Cocoamidoprophyl Betaine	61789-40-0	Readily biodegradable.	Seconder amphoteric surfactant & foam booster	Fatty alcohol/ production, from coconut oil

Table 4.5. Continued.

Sodium Chloride	7647-14-5	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise. The product itself and its products of degradation are not toxic.	Thickening agent	Sodium chloride, powder/production
Trideceth-2 Carboxamide Mea	107628-04-6		Viscosity adjustment	Vegetable oil methyl ester/ esterification of rape oil
Glycol Distearate	627-83-8	Readily biodegradable.	Softener	Vegetable oil methyl ester/ esterification of rape oil
Cocoamid Mea	68140-00-1		Color adjustment & foaming agent	Monoethanolamine/ ethanolamine production
Sodium Hydroxide	1310-73-2	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.	Buffer	Sodium hydroxide, without water, in 50% solution state/ market for
Ethyl Alcohol	64-17-5		Solvent	Ethanol, without water, in 99,7% solution state, from ethylene/ ethylene hydration
Citric Acid	77-92-9	Readily biodegradable.	Acidity adjustment	Fatty acid/ production, from vegetable oil
Triethanolamine	102-71-6	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise. The product itself and its products of degradation are not toxic.	pH adjustment & Stabilization	Triethanolamine/ ethanolamine production
Hydrolized Silk	96690-41-4		Film forming agent for frazzled hair	Lactic acid / production

Table 4.5. Continued.

Hydrolized Albumin	91079-84-4		Hair protection	Lactic acid / production
Methylchloroisothiazolinone	26172-55-4	Risk phase acc. to Directive 2001/59/EC: R50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.	Protection against bacterial&fungal growth	Biocides, for paper production, unspecified, at plant
Methylisothiazolinone	2682-20-4		Preservative	Biocides, for paper production, unspecified, at plant
CI 19140	1934-21-0	Toxicity to daphnia and other aquatic invertebrates EC50 - Daphnia - 5.706,55 mg/l - 48 h	Coloring agent	Chemical organic/ production
CI 14720	3567-69-9		Coloring agent	Chemical organic/ production
Deionized water	7732-18-5	R36/38:Irritating to eyes&skin	Solvent	Water, deionised, at plant

As a result of the life cycle assessment, it was determined that the highest environmental impact was caused by the user. It is important to ensure the communication of the effect of hot water consumed by the consumer while using the product. The carbon footprint of selected shampoo product was 6.28 kg CO_2eq per functional unit.

In case the consumer's impact is neglected, the raw materials in the recipe come to the fore. Since there was no energy consumption due to hot water, it was observed that the carbon footprint was 0.125 kg CO_2eq per functional unit. A large part of this value comes from the raw material stage.

When the environmental effects of the raw materials in the product content are examined, Sodium Lauret Sulfate (SLES), which is used as a surfactant, has the greatest effect on many effect categories. Kokoamidoplastic Betain, Sodium Chloride, Trideceth-Me 2 Carboxamide Mea, Glycol Distearate and Cocomide Mea are the leading chemicals in the categories of effects, respectively. Reduction in the amount of use of these chemicals in the prescription or equivalent use of a cleaner production is recommended.

It is recommended that the company be in compliance with EU Ecolabel criteria, which is an excellent reference for clean production, and to carry out R & D activities based on these criteria in new product development studies. Providing the communication and / or communication of the outputs of this study to the final consumer as the competitors of the international level, will create new opportunities for branding and awareness raising. More responsive to increasing environment and health. The consumer group expects this approach from international brands and products that are suitable for this approach.

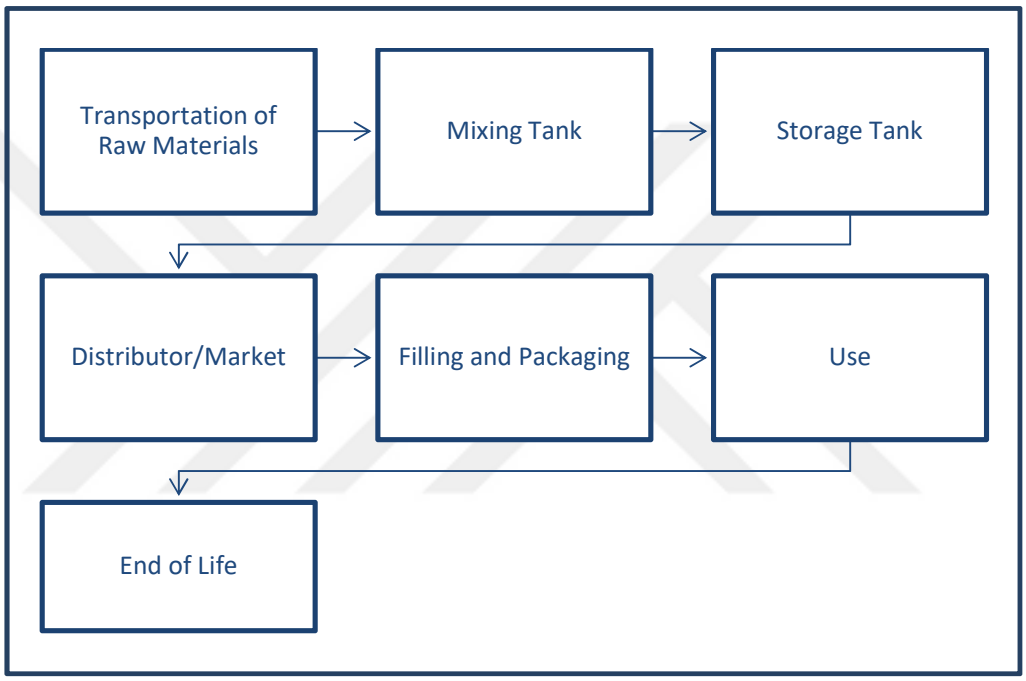

Figure 4.49. Process diagram for shampoo product.

In this study, raw materials and packaging materials used in the raw material stage, raw materials from the producer to the factory and the final product from the factory to the consumer during the transportation stage, energy and water consumed in the factory during the production phase, the product and water used by the consumer during the usage phase and the packaging wastes at the end of the life and treated wastewater after use.

Here in Figure 4.50; each category of environmental impacts is shown as percentage distributions according to the LCA stages. When the results are examined, eutrophication and end-of-life stage in terrestrial ecotoxicity stand out, while the effect of use phase in residual impact categories is observed.

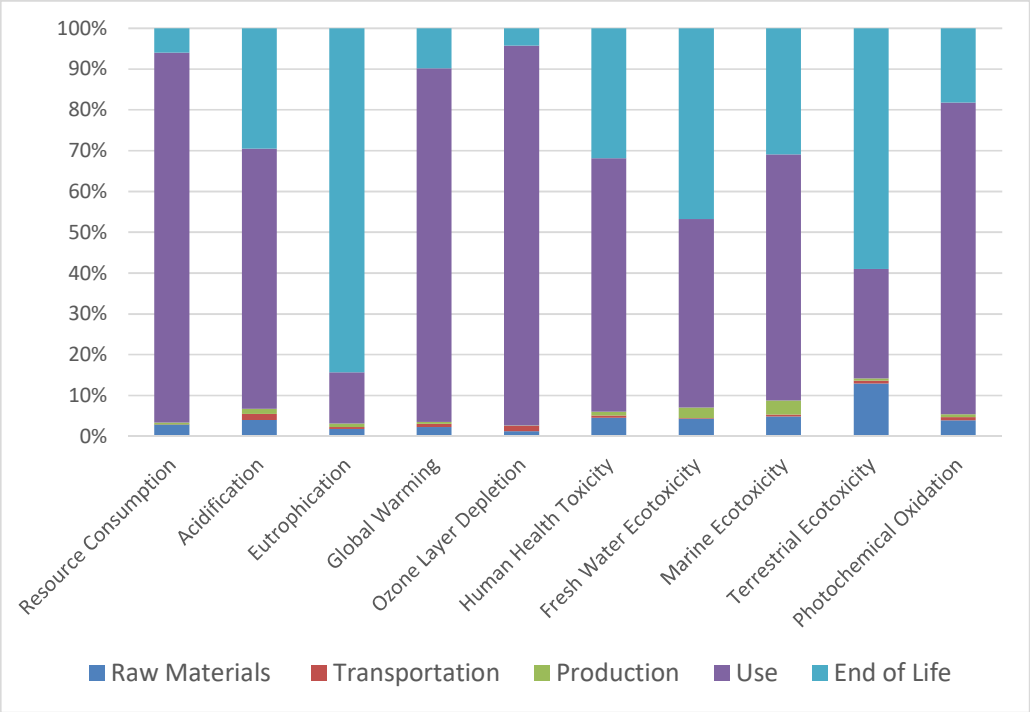

Figure 4.50. Characterization of environmental impact categories in shampoo life cycle.

In order to compare the above mentioned environmental impact categories with each other, the normalization process was carried out (Figure 4.51). The normalization process is done by reference to the environmental effects of a human being on the world average. Within the results, resource consumption, marine and freshwater ecotoxicity appear as three are three major impact categories and the highest environmental pollution load comes from production, use and raw materials acquisition phase.

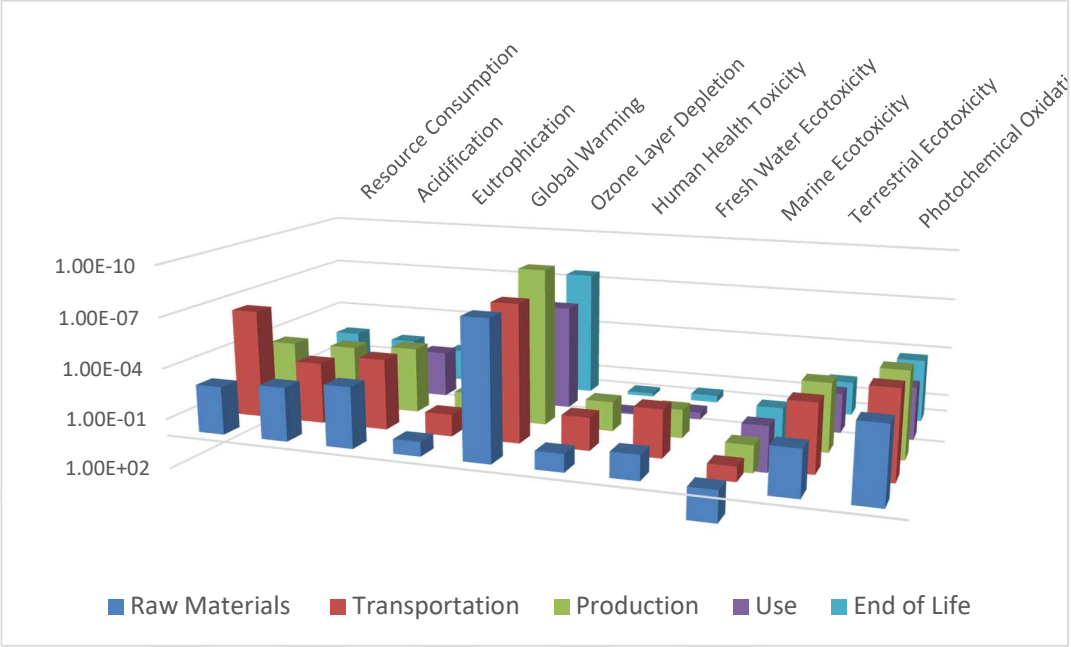

Figure 4.51. Normalization of environmental impact categories in shampoo life cycle.

4.3.1. Resources Consumption

Resource consumption, which is the category of impact expressing the consumption of natural resources (petroleum, iron ore, etc.), is given in Figure 4.52 for the production of 1 bottle of shampoo. The highest impacts comes from the use phase resulting from energy need of hot water consumption in shower. Figure 4.53 shows the decomposition of the sources that affect the resource consumption. As it is seen, the use of natural gas for hot water use is the major impact.

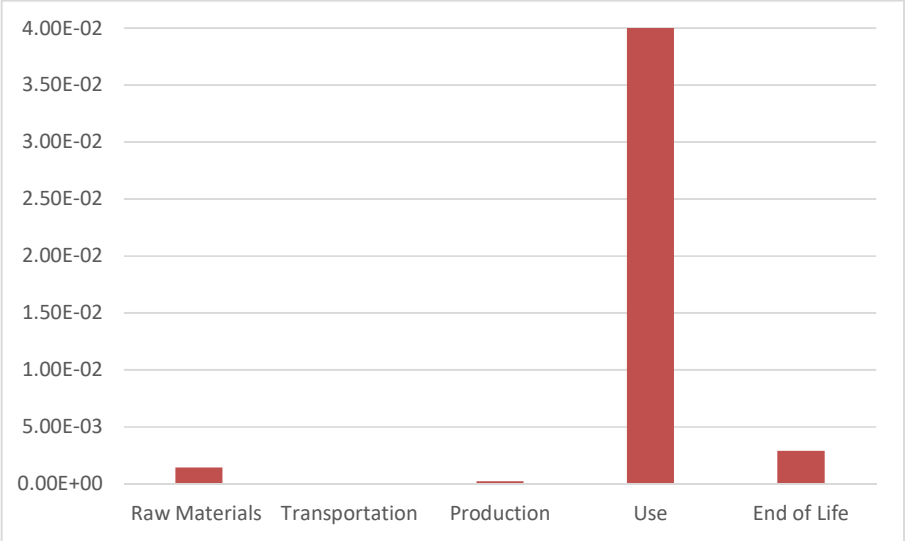

Figure 4.52. Resources consumption impact in shampoo life cycle.

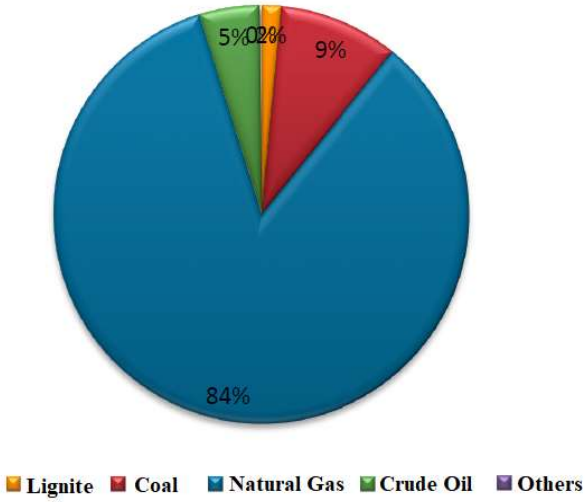

Figure 4.53. Decomposition of substances affecting resources consumption.

4.3.2. Environmental Impact Assessment of Raw Materials

The environmental loads of the raw materials used in the production excluding water are compared with each other in Figure 4.54. Sodium Lauret Sulfate (SLES) appears to have a great impact on acidification, eutrophication, global warming, ozone depletion, marine ecotoxicity and photochemical oxidation. Sodium chloride and cocoamidopropyl betaine on the resources consumption are derived from Trideceth- 2 Carboxamide Mea and Glycol Distearate in

terrestrial ecotoxicity, and human health ecotoxicity Cocomide Mea. Raw materials have similar effects on the remaining environmental impact categories.

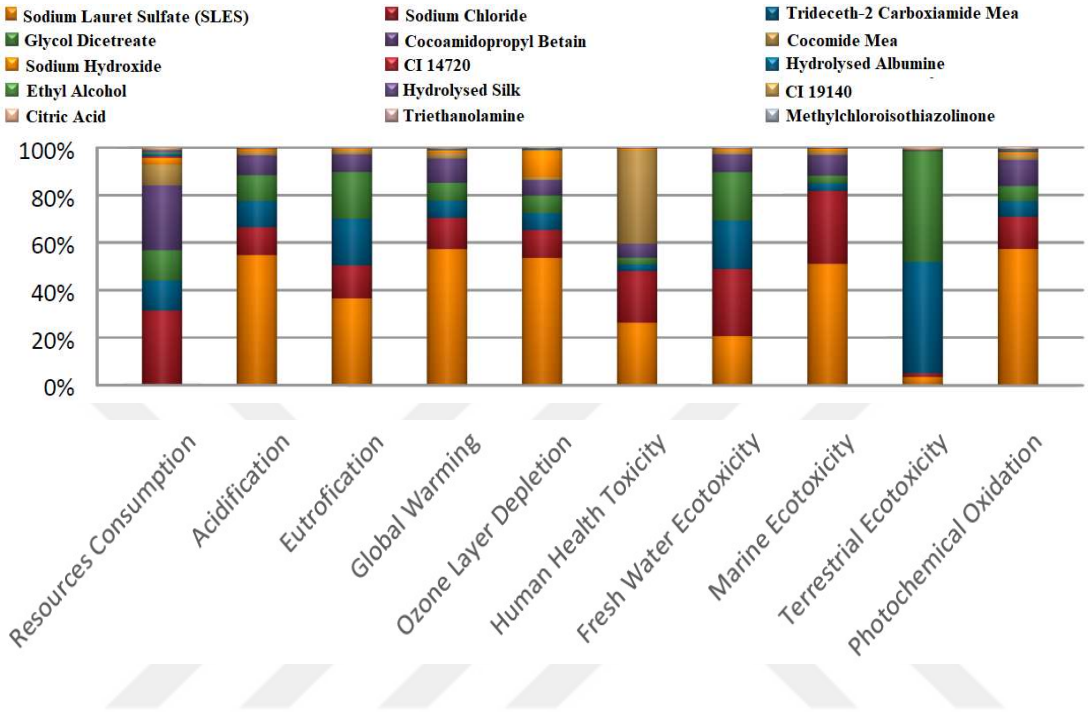

Figure 4.54. Comparison of raw materials according to environmental impact categories.

4.3.3. Global Warming Potential

The global warming, in other words, the distribution of the environmental impact of carbon footprint by LCA stages is given in Figure 4.55. According to the results, the consumer use stage is the hot spot. This is caused by the consumer habits, ie the amount of hot water used.

Carbon dioxide gas is one of the leading causes of global warming (Figure 4.56).

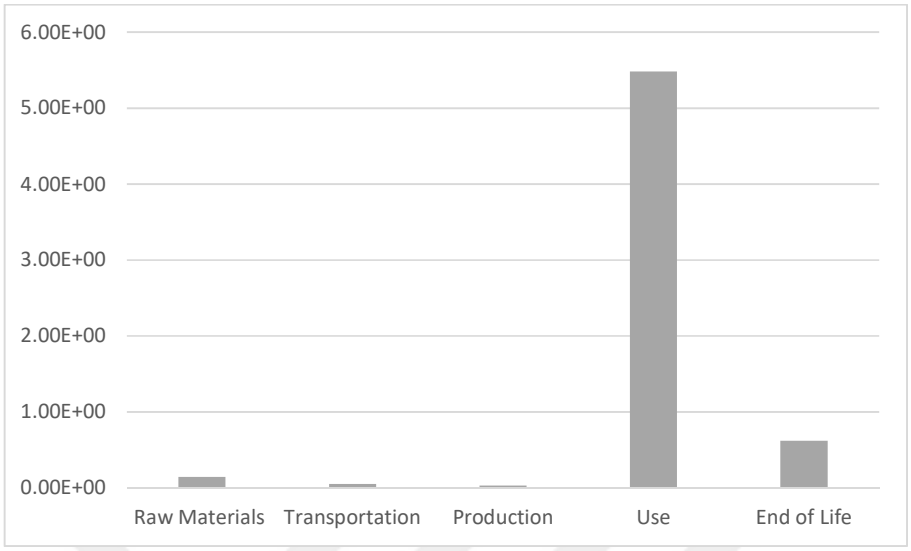

Figure 4.55. Global warming potential in shampoo life cycle.

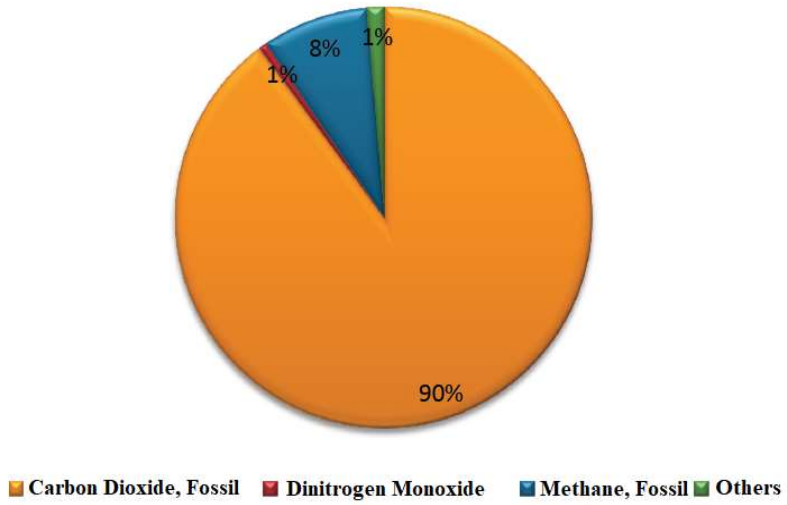

Figure 4.56. Decomposition of substances affecting global warming.

4.3.4. Acidification Potential

When we look at the acidification potential which expresses the toxic effect of acid on soil, surface/ground water, organisms, ecosystems and materials, it is seen that the use phase of 1 bottle of shampoo have major impacts (Figure 4.57). The main reason for the effect during the use phase is the emissions from the production of energy used to heat the water used.

The end-of-life impact is due to the resulting wastewater treatment, and the details of the substances that cause it are given in Figure 4.58.

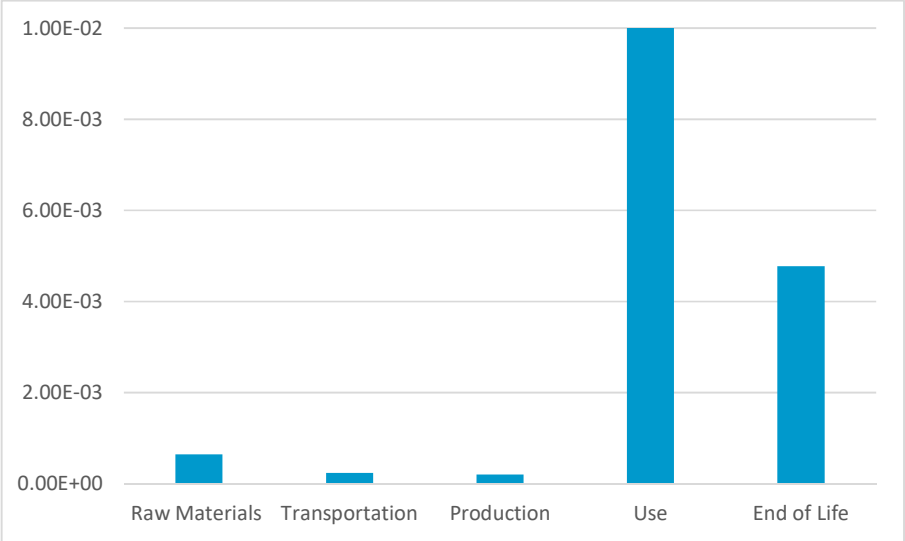

Figure 4.57. Acidification potential in shampoo life cycle.

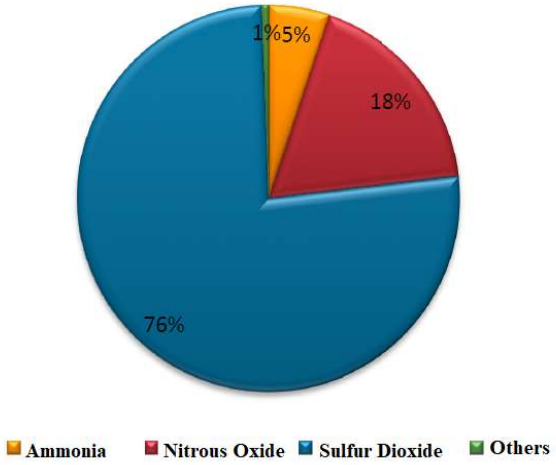

Figure 4.58. Decomposition of substances affecting acidification.

4.3.5. Eutrophication Potential

When eutrophication which is defined as impacts of excessive release of nutrients to air, water and soil is examined, it is seen that the end of life phase contributes the most and the raw material follows (Figure 4.59). The effect during the production phase is due to the wastewater generated during the consumption of shampoo product.

The reason for this is that after the treatment of the wastewater generated after use, it accelerates eutrophication and increases aquatic growth in lakes by discharging such substances

as nitrogen and phosphorus. The effects of eutrophication are caused by phosphate, nitrate and ammonium (Figure 4.60).

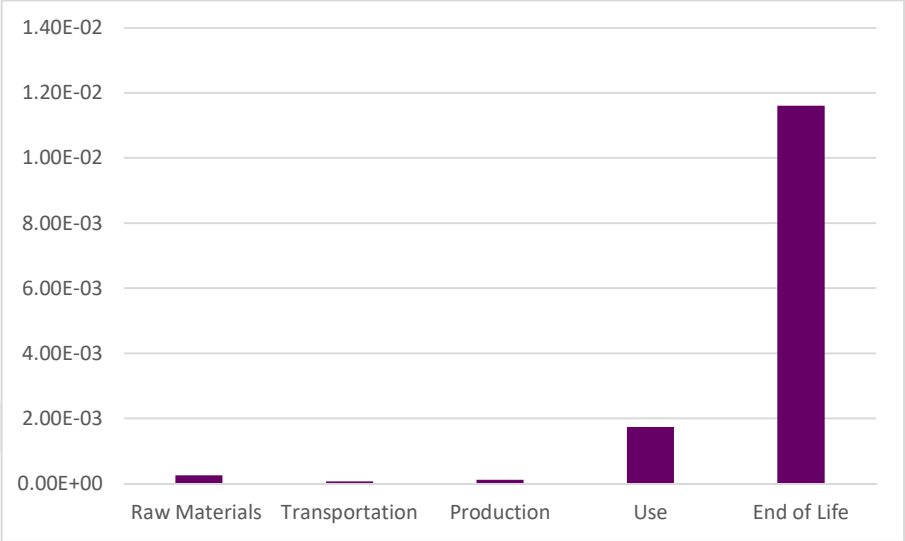

Figure 4.59. Eutrophication potential in shampoo life cycle.

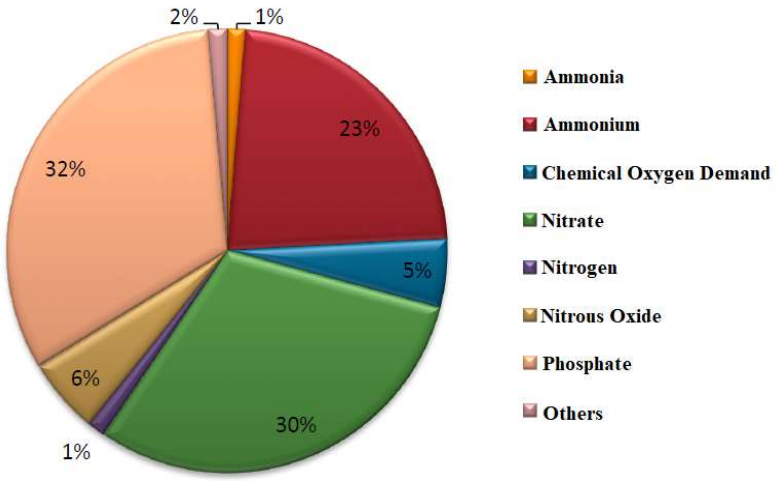

Figure 4.60. Decomposition of substances affecting eutrophication.

4.3.6. Ozone Layer Depletion Potential

This impact, which expresses the decrease in the amount of ozone in the stratosphere and the depletion of the ozone layer due to the effects of human gases, such as CFC, HCFC, chlorine and bromine, is seen to be more effective in the use phase (Figure 4.61). The major reason for

this is the emissions during hot water consumption. The distribution of the gases that cause this effect category is shown in Figure 4.62.

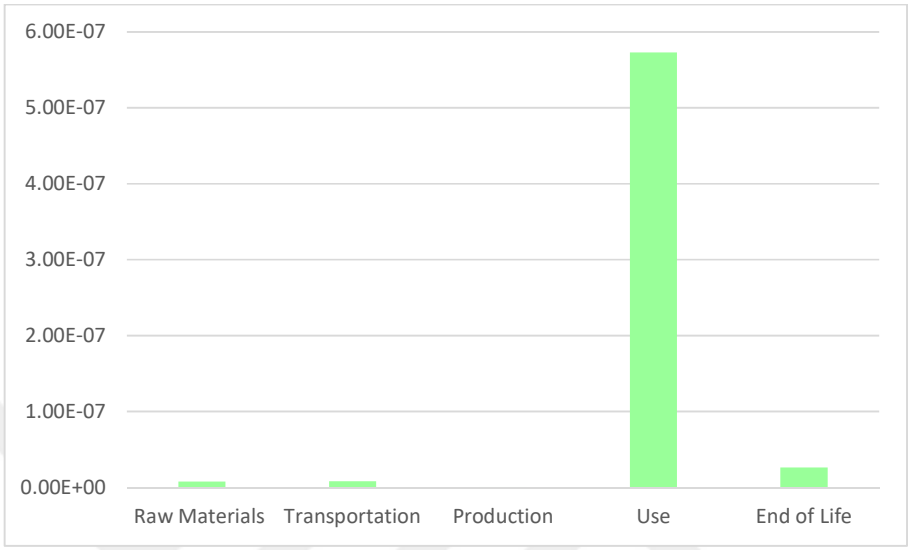

Figure 4.61. Ozone layer depletion potential in shampoo life cycle.

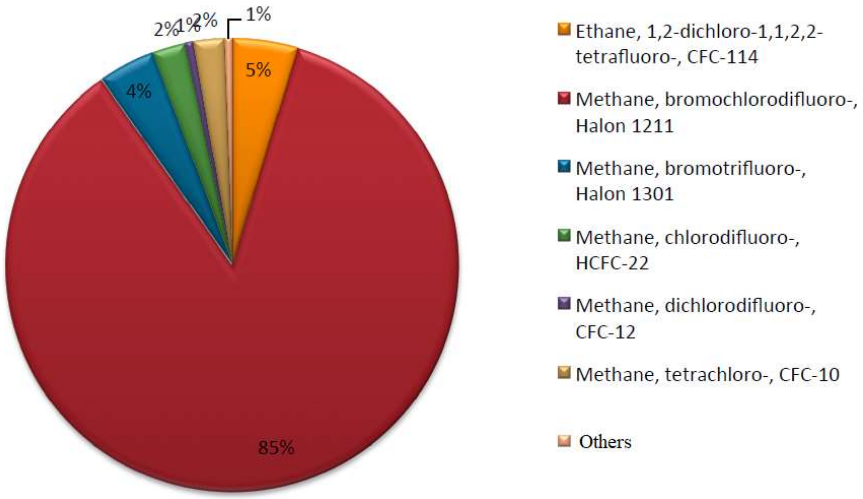

Figure 4.62. Decomposition of substances affecting ozone layer depletion.

4.3.7. Human Health Toxicity Potential

Human health toxicity, which expresses the toxic effect on human health caused by the release of various chemicals to the environment, is due to respectively, from use and end of life stages (Figure 4.63). The reason for the impact in the use phase is the chemical and heavy metal emissions that occur due to energy consumption. Some of them originate from energy

production. The end-of-life effect is due to heavy metal originating from chromium IV as a result of domestic wastewater treatment. The decomposition of the active chemicals and metals is given in Figure 4.64.

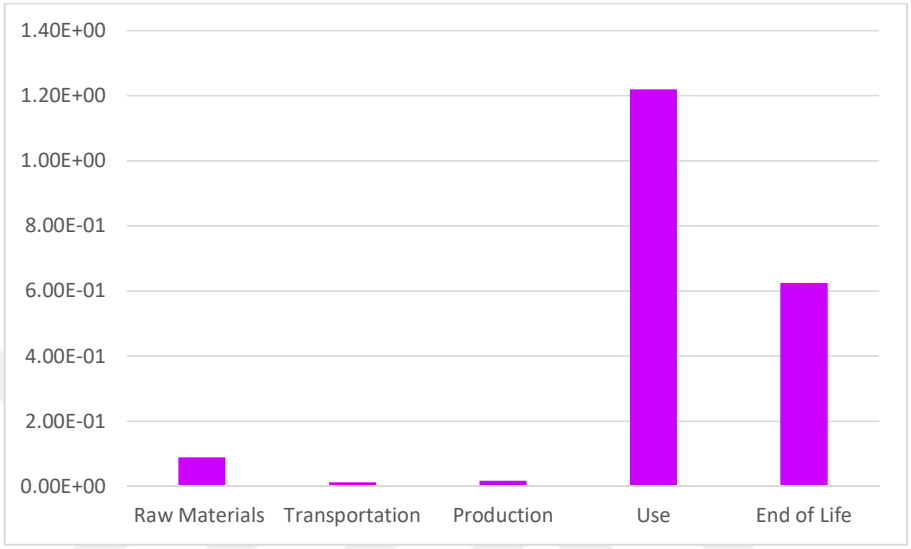

Figure 4.63. Human health toxicity potential in shampoo life cycle.

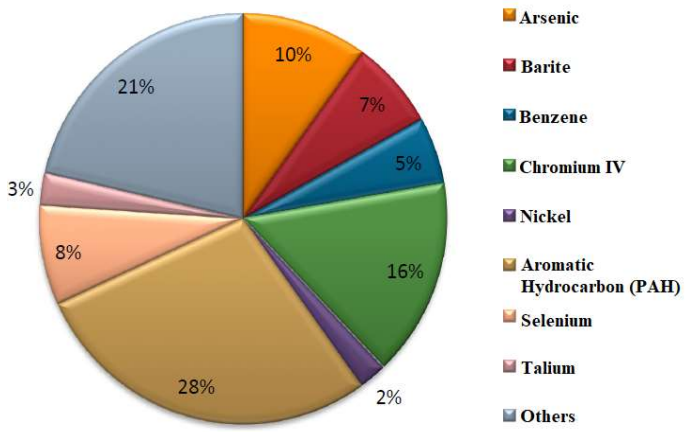

Figure 4.64. Decomposition of substances affecting human health toxicity.

4.3.8. Fresh Water Ecotoxicity Potential

This effect, which expresses the adverse impact to the freshwater ecosystem as a result of the mixture of toxic substance-induced emissions to air, water or soil, is due to the use stage rather than other impact categories (Figure 4.65). These impacts are caused by energy-related emissions, mainly due to emissions generated during the burning of fossil fuels used in

electricity generation. The effect of the end-of-life phase is due to the necessary infrastructure for the treatment of wastewater and the toxic effect caused by the release of treated water into the environment. A detailed representation of the elements that cause freshwater ecotoxicity is given in Figure 4.66.

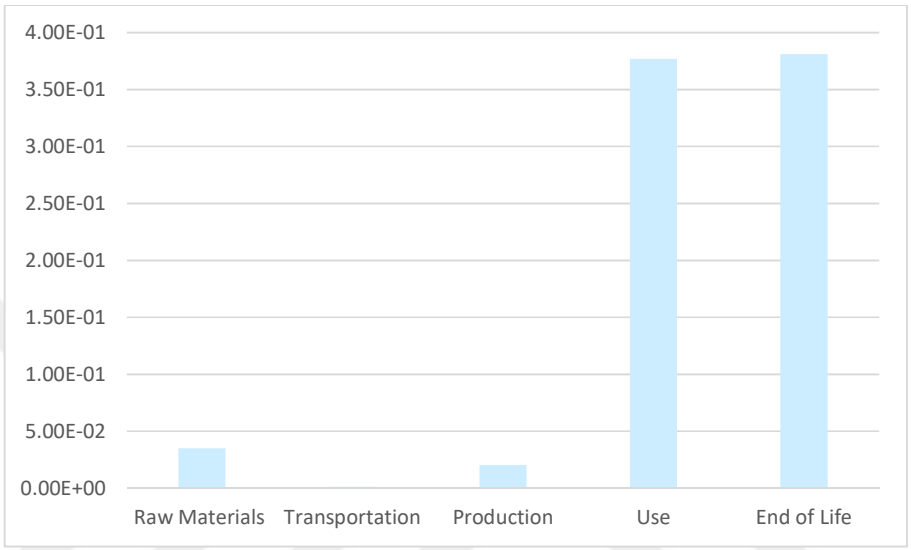

Figure 4.65. Fresh water ecotoxicity potential in shampoo life cycle.

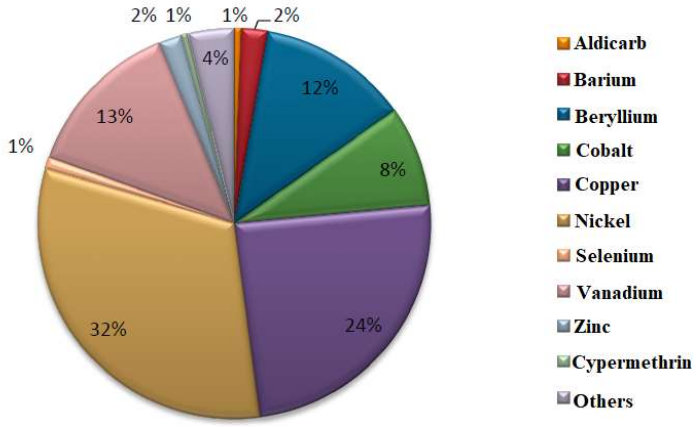

Figure 4.66. Decomposition of substances affecting fresh water ecotoxicity.

4.3.9. Marine Ecotoxicity Potential

This impact category, which expresses the impacts of toxic substances on marine ecosystem, is mostly seen in use and enf of life stages. The effect at the end of life stage is due to the necessary infrastructure for the treatment of wastewater as well as the toxic effect caused

by the release of treated water to the nature (Figure 4.67). The classification of the causative agents was given in Figure 4.68 and the effect was mostly caused by beryllium.

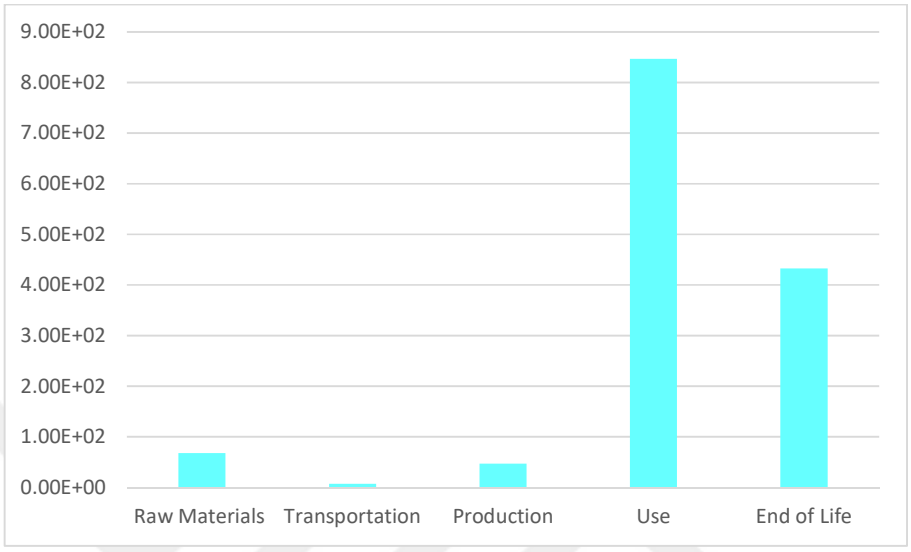

Figure 4.67. Marine ecotoxicity potential in shampoo life cycle.

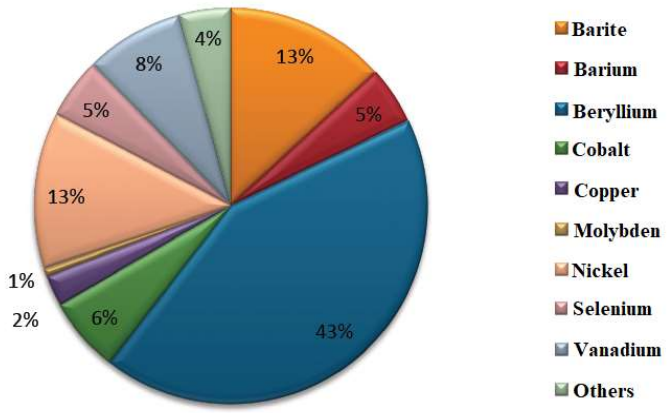

Figure 4.68. Decomposition of substances affecting marine ecotoxicity.

4.3.10. Terrestrial Ecotoxicity Potential

This impact, which expresses the impacts of toxic substances released to the environment on the terrestrial ecosystem, is of raw material origin (Figure 4.69). The reason for this impact in the enf of life stage is due to the wastewater treatment infrastructure and the emissions of treated water to the nature as mentioned earlier. The effect during the use phase is due to the

effects of meeting the fossil fuel requirement for hot water. The classification of the causative agents was given in Figure 4.70 and most of the effect was due to mercury.

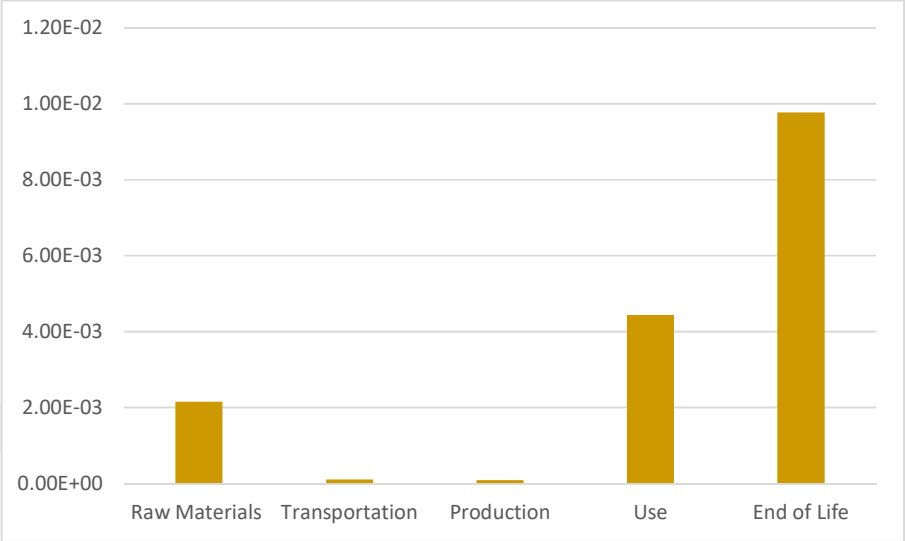

Figure 4.69. Terrestrial ecotoxicity potential in shampoo life cycle.

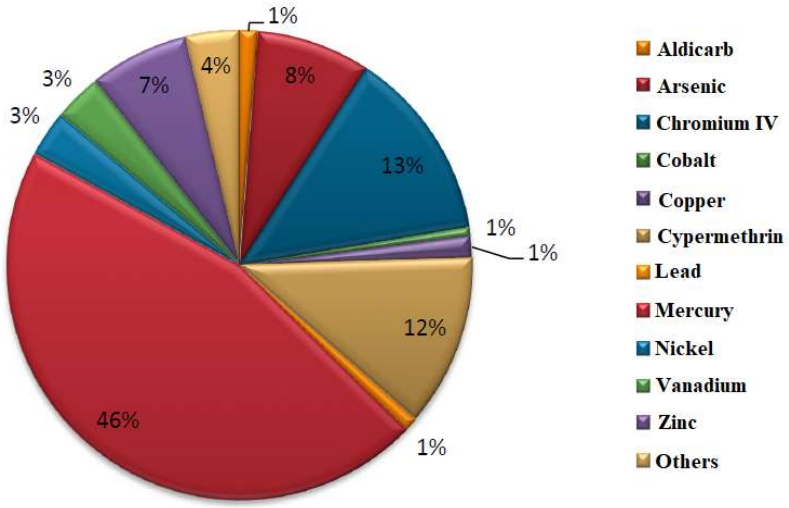

Figure 4.70. Decomposition of substances affecting terrestrial ecotoxicity.

4.3.11. Photochemical Oxidation Potential

The use stage is important in this impact category, which defines the formation of reactive substances that damage agricultural products, human health and ecosystems (Figure 4.71). The decomposition of the substances causing this effect is shown in Figure 4.72 and most of the effect is from sulfur dioxide. This is related to emissions from the use of fossil fuel as energy.

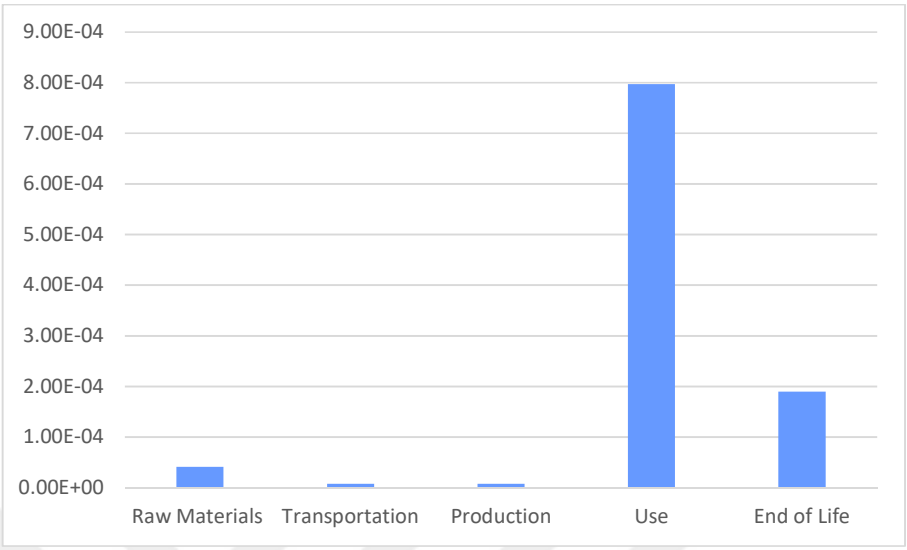

Figure 4.71. Photochemical oxidation potential in shampoo life cycle.

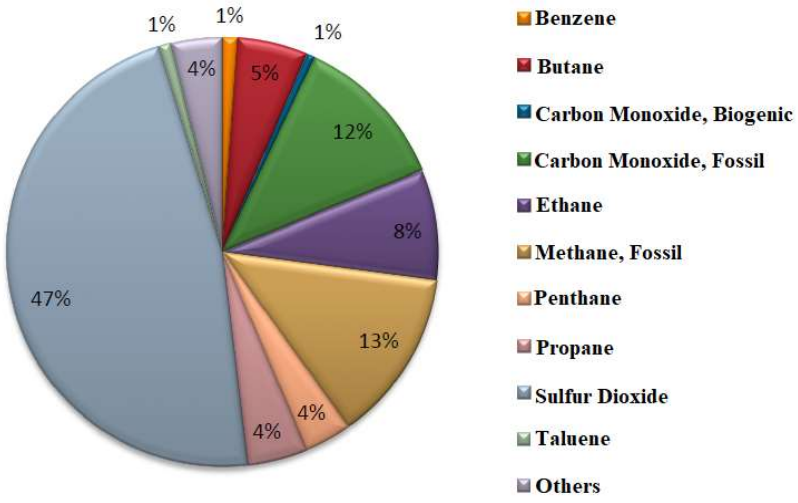

Figure 4.72. Decomposition of substances affecting photochemical oxidation.

4.4. Selected Shower Gel Product

Within the scope of this study raw materials acquisition, production, use and disposal phases of selected shower gel product have been analyzed. Functional unit for shower gel product is 250mL as one bottle of product.

The highest environmental impacts have been found in consumer use phase within the entire life cycle assessment of shower gel product. When consumer use phase is not included, raw materials have the biggest contribution in environmental footprint of shampoo production. Cocoamidopropil Betain, Methylisothiazolinone, Sodium Lauret Sulphate and perfumes are major contributors to environmental foot print of shower gel production. Additionally Triethanolamine and Acrylic Copolymer are also effective.

In order to select correct data within the system, raw materials composition of product has been listed and different ways have been followed. Chemicals which are included in EcoInvent database have been used directly. For the ones which are not placed in database; approximations have been done according to chemical structures and production technologies. The chemicals used in selected shampoo production are given in table below with their CAS numbers and roles in formulation.

Table 4.6. The chemicals used in selected shower gel production.

Raw Materials	CAS number	Environmental hazards	Role in formulation	The selected data from ecoinvent
Sodium Lauret Sulphate (SLES)	68891-38-3	Acutely toxic to aquatic life. Readily biodegradable. Significant accumulation in organisms is not to be expected.	Anionic surfactant	Sodium sulphate, powder, production mix, at plant
Cocoamidoprophyl Betaine	61789-40-0	Readily biodegradable.	Seconder amphoteric surfactant & foam booster	Fatty alcohol/ production, from coconut oil
Sodium Chloride	7647-14-5	The product itself and its products of degradation are not toxic.	Thickening agent	Sodium chloride, powder/production
Benzophenone (Methyl Ethyl Ketone)	4065-45-6	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.	UV absorber	Methyl Ethyl Ketone production

Table 4.6. Continued.

Carbopol Aqua (Acrylates Copolymer)	25133-97-5		Suspender	Acrylic Acid at plant
Butylparaben	94-26-8	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.	Preservative	Benzoic-compound production
Sodium Hydroxide	1310-73-2		Buffer	Sodium hydroxide, without water, in 50% solution state/ market for
Ethylparaben	120-47-8		Preservative	Benzoic-compound production
Propilparaben	94-13-3		Preservative	Benzoic-compound production
Isobuthylparaben	4247-02-3	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.	Preservative	Benzoic-compound production
Phenoxyethanol	122-99-6		Preservative	Diphenylether compound production
Propylene Glycol	57-55-6		Antifreeze	Propylene glycol liquid production
Polyquaternium	68610-92-4		Cationic Conditioner	Carboxymethyl Cellulose production
Methylparaben	99-76-3	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.	Preservative	Benzoic-compound production
Glycerin	56-81-5		Moisturizer	Glycerin from vegetable oil at esterification plant
Triethanolamine	102-71-6	Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise. The product itself and its products of degradation are not toxic.	pH adjustment & Stabilization	Triethanolamine/ ethanolamine production
Methylchloroisothiazolinone	26172-55-4	Risk phase acc. To Directive 2001/59/EC: R50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.	Protection against bacterial&fungal growth	Biocides, for paper production, unspecified, at plant

Table 4.6. Continued.

CI 19140	1934-21-0	Toxicity to daphnia and other aquatic invertebrates EC50 – Daphnia – 5.706,55 mg/l – 48 h	Coloring agent	Chemical organic/ production
CI 42090	3844-45-9		Coloring agent	Chemical organic/ production
CI 17200	3567-66-6		Coloring agent	Chemical organic/ production
Deionized water	7732-18-5	R36/38:Irritating to eyes&skin	Solvent	Water, deionised, at plant

It has been determined that the major impact of shower gel on the whole life cycle evaluation is caused by the consumer. It is recommended that this information be communicated to the final consumer. In this case, the carbon footprint is calculated as 3.31 kg CO_2eq per functional unit. When consumer's effect is neglected, the raw materials acquisition phase come to the fore. Considering the environmental impacts of raw materials in the content of the product, cocoamidopropyl betaine, Methylisothiazolinone, Sodium Lauret Sulphate and perfume are the leading chemicals in this sense. In particular, resource consumption is a significant impact category.

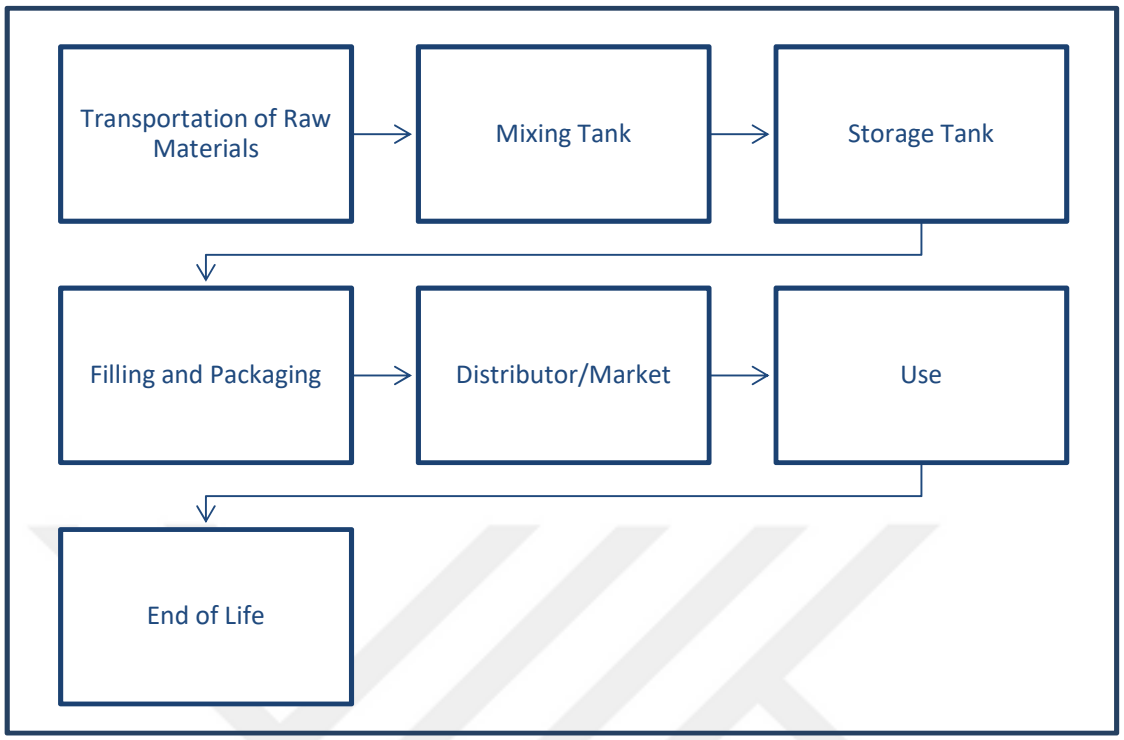

Figure 4.73. Process diagram for shower gel product.

In this study, raw materials and packaging materials used in the raw material stage, raw materials from the producer to the factory and the final product from the factory to the consumer during the transportation stage, energy and water consumed in the factory during the production phase, the product and water used by the consumer during the usage phase and the packaging wastes at the end of the life and treated wastewater after use.

Here in Figure 4.74; each category of environmental impacts is shown as percentage distributions according to the LCA stages. When the results are examined, eutrophication and end-of-life stage in terrestrial ecotoxicity stand out, while the effect of use phase in residual impact categories is observed.

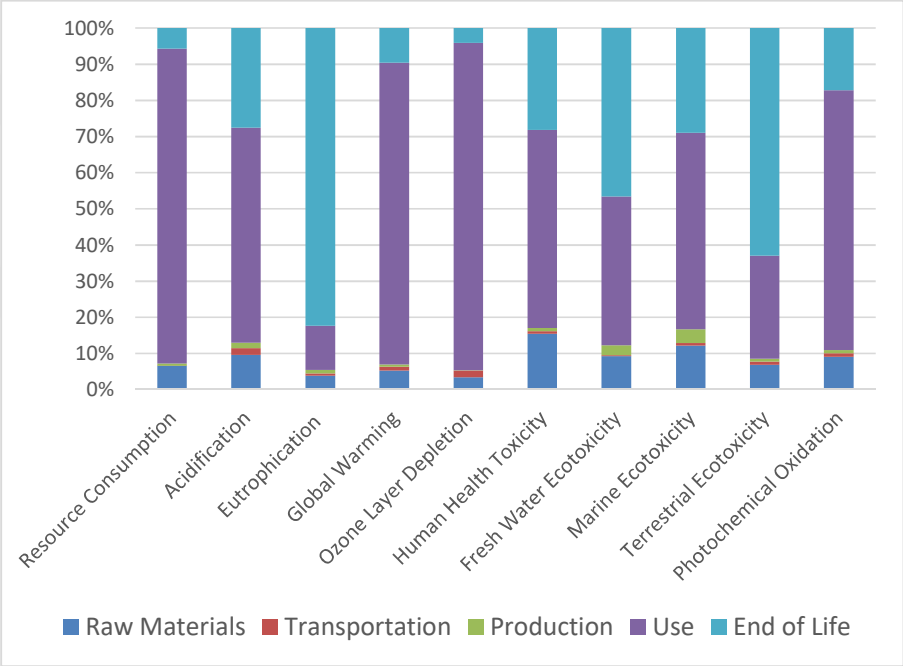

Figure 4.74. Characterization of environmental impact categories in shower gel life cycle.

In order to compare the above mentioned environmental impact categories with each other, the normalization process was carried out (Figure 4.75). The normalization process is done by reference to the environmental effects of a human being on the world average. Within the results, resource consumption, marine and freshwater ecotoxicity appear as three are three major impact categories and the highest environmental pollution load comes from use phase.

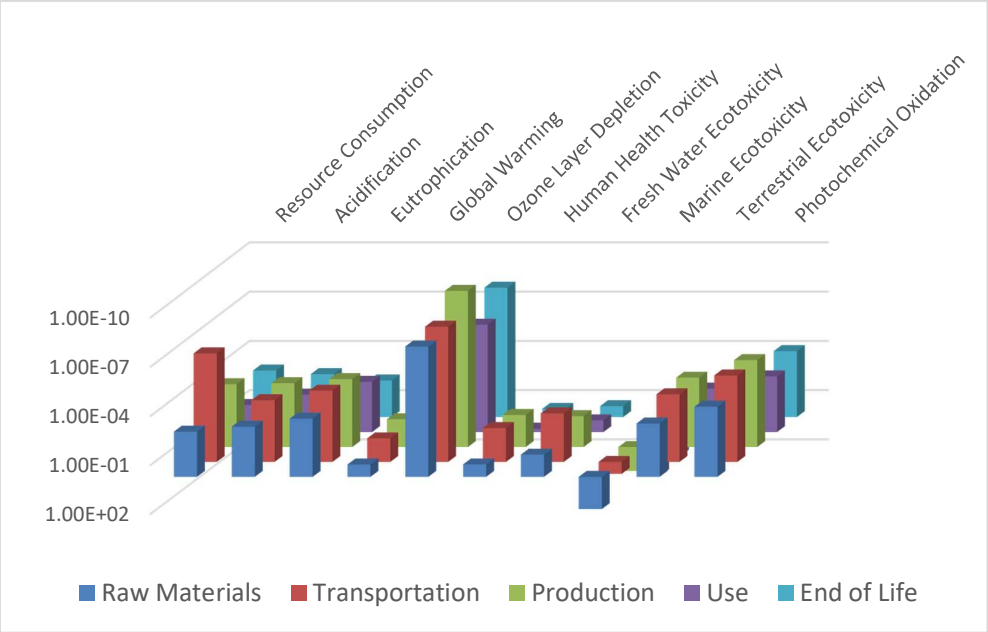

Figure 4.75. Normalization of environmental impact categories in shower gel life cycle.

4.4.1. Resources Consumption

Resource consumption, which is the category of impact expressing the consumption of natural resources (petroleum, iron ore, etc.) for the production of 1 bottle of shower gel is given in Figure 4.76. The highest impacts comes from the use phase resulting from energy need of hot water consumption in shower.

The reason for the impact on the raw material stage is the consumption of the raw materials used during the production and the biggest effect comes from acrylate copolymers. Figure 4.77 shows the decomposition of the sources that affect the resource consumption. Natural gas, which is the fossil fuel required for hot water, have primer impact.

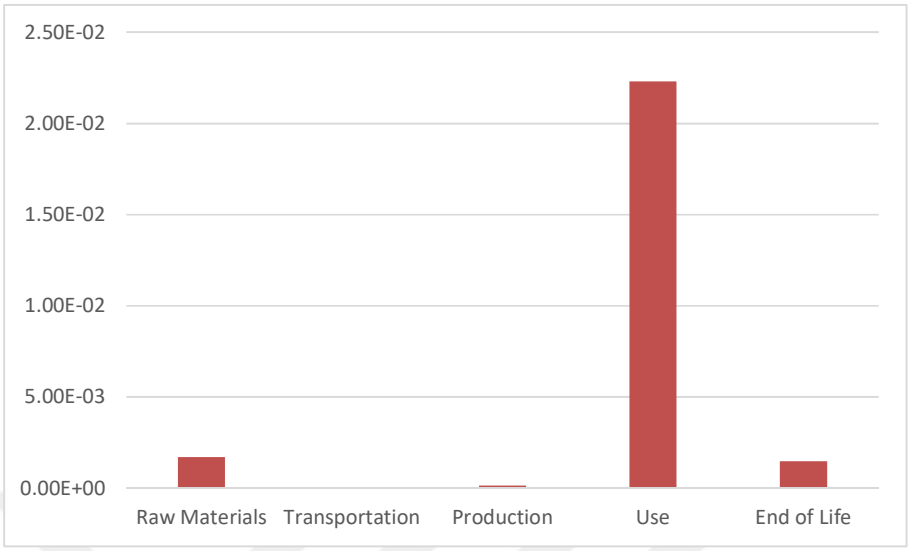

Figure 4.76. Resources consumption impact in shower gel life cycle.

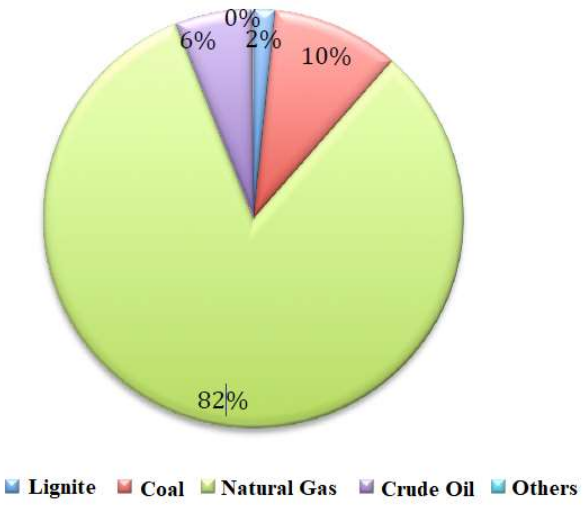

Figure 4.77. Decomposition of substances affecting resources consumption.

4.4.2. Environmental Impact Assessment of Raw Materials

The environmental loads of the raw materials used in the production are compared with each other in Figure 4.78. While prescription, cocoamidopropyl betaine, Methylisothiazolinone, Sodium Lauret Sulfate and perfume are the most important agents, Triethanolamine and Acrylic Copolymer chemicals emerge as raw materials with a significant environmental burden. Leading raw materials in resource consumption are cocoamidopropyl betaine, acrylic copolymer and perfume. Sodium Lauret Sulphate is the predominant of all the effect categories except resource consumption.

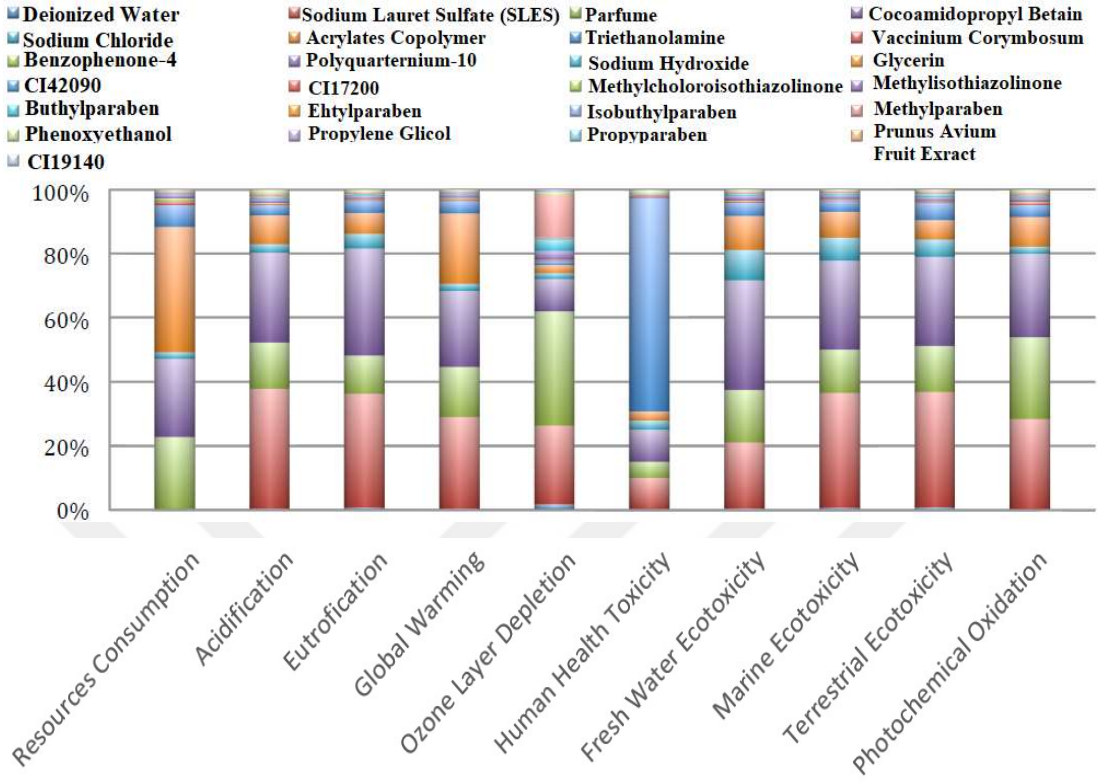

Figure 4.78. Comparison of raw materials according to environmental impact categories.

4.4.3. Global Warming Potential

The global warming, in other words, the distribution of the environmental impact of carbon footprint by LCA stages is given in Figure 4.79. According to the results, the consumer use stage is the hot spot. This is caused by the consumer habits, ie the amount of hot water used.

For example, lowering the shower water temperature by 1°C in the case of a shower at 37 ° C instead of 38° C, the reduction of carbon footprint is about 4%. The carbon dioxide gas produced by the combustion of natural gas plays a dominant role here (Figure 4.80).

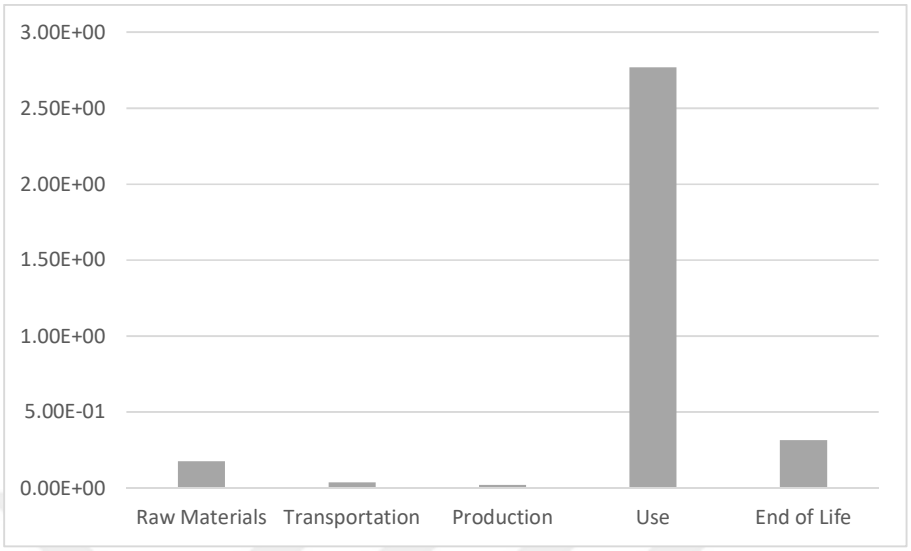

Figure 4.79. Global warming potential in shower gel life cycle.

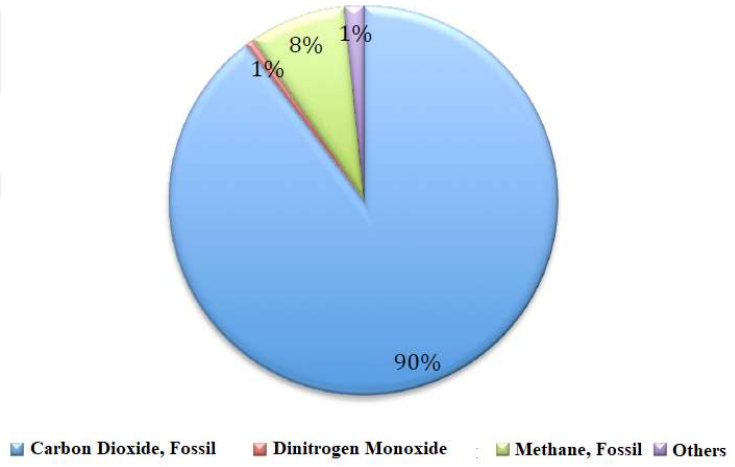

Figure 4.80. Decomposition of substances affecting global warming.

4.4.4. Acidification Potential

When we look at the acidification potential which expresses the toxic effect of acid on soil, surface/ground water, organisms, ecosystems and materials, it is seen that the use phase of 1 bottle of shower gel have major impacts (Figure 4.81). The main reason for the effect during the use phase is the emissions from the production of energy used to heat the water used. The details of the substances that cause this are given in Figure 4.82 and the emissions of sulfur dioxide from the burning of natural gas used for heating the consumed water are the main cause. The end-of-life effect is due to the energy spent for the treatment of waste water after the use of shower gel.

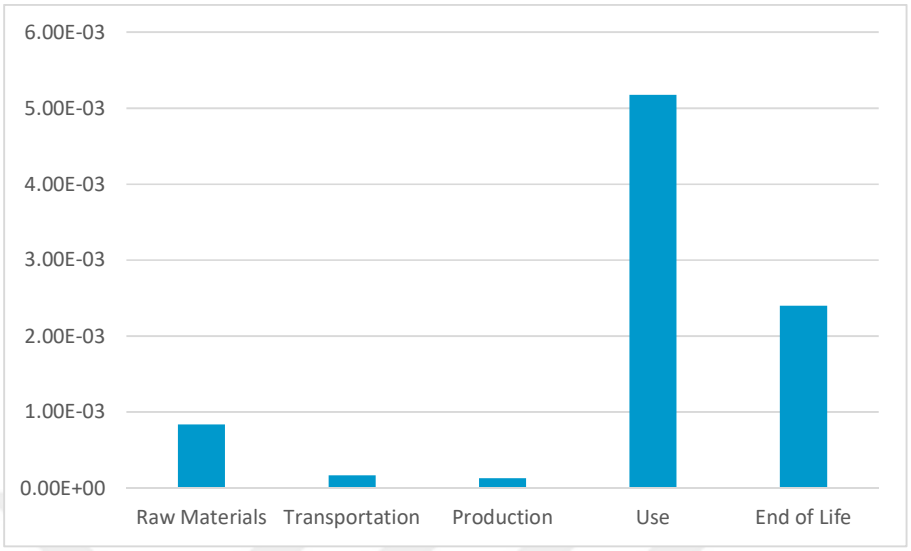

Figure 4.81. Acidification potential in shower gel life cycle.

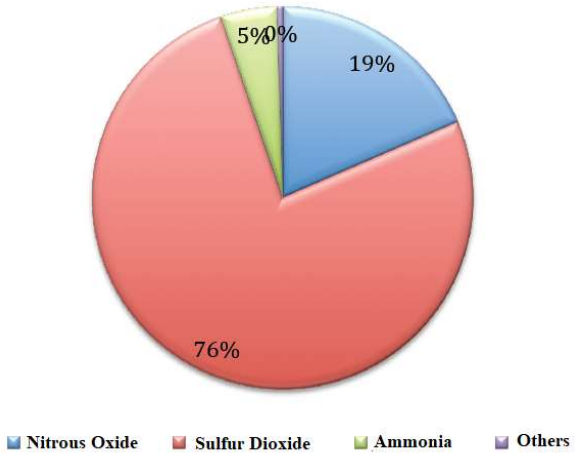

Figure 4.82. Decomposition of substances affecting acidification.

4.4.5. Eutrophication Potential

When eutrophication which is defined as impacts of excessive release of nutrients to air, water and soil is examined, it is seen that the end of life phase contributes the most and the raw material follows (Figure 4.83). The effect during the use phase is due to the wastewater generated during the consumption of shower gel product, increase in phosphate and nitrate after wastewater treatment. (Figure 4.84).

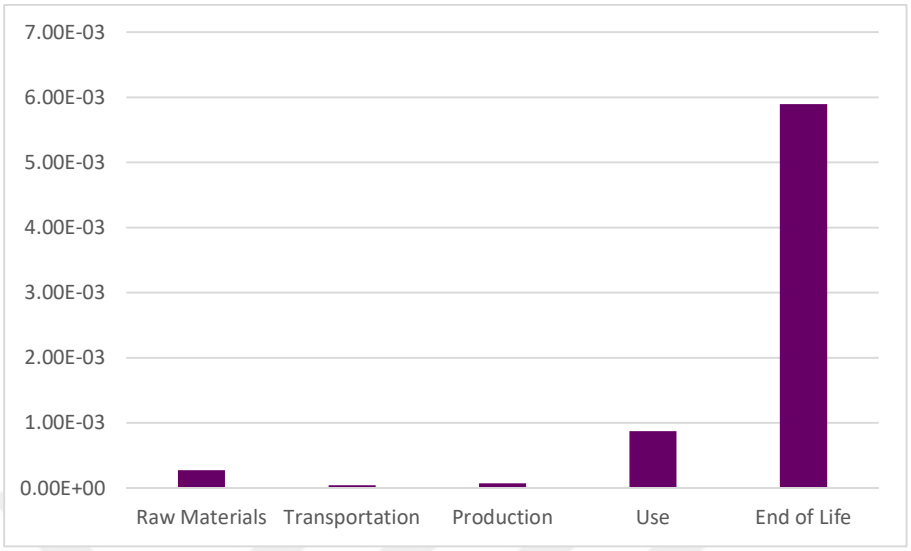

Figure 4.83. Eutrophication potential in shower gel life cycle.

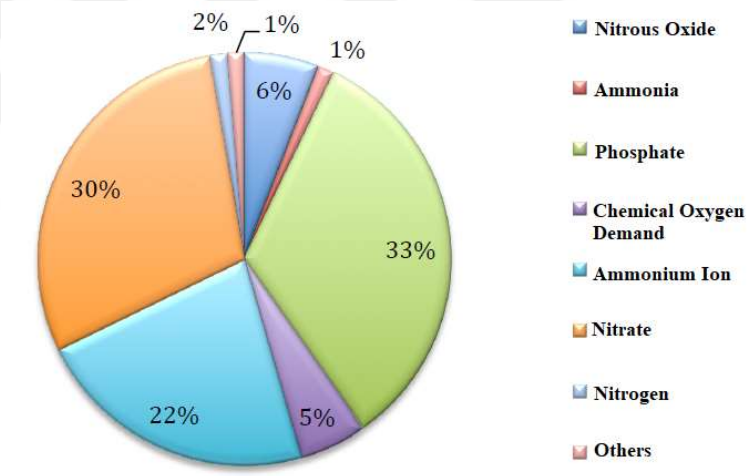

Figure 4.84. Decomposition of substances affecting eutrophication.

4.4.6. Ozone Layer Depletion Potential

This impact, which expresses the decrease in the amount of ozone in the stratosphere and the depletion of the ozone layer due to the effects of human gases, such as CFC, HCFC, chlorine and bromine, is seen to be more effective in the use phase. The major reason for this is the emissions during hot water consumption (Figure 4.85).

The distribution of the gases causing this effect category is shown in Figure 4.86. Bromochlorodifluoromethane, known under the trade name Halon 1211, stands out. This gas is actually banned in many countries, but its use is free in some countries when it is recycled.

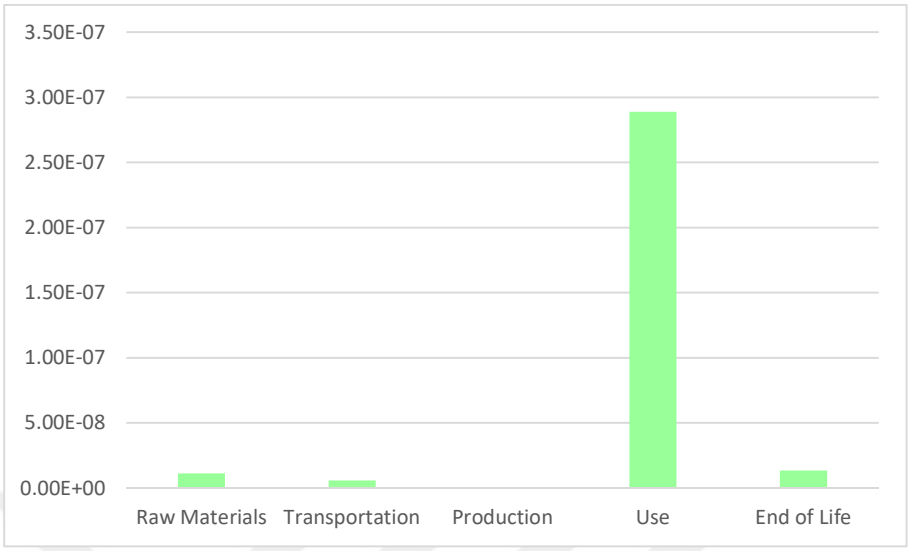

Figure 4.85. Ozone layer depletion potential in shower gel life cycle.

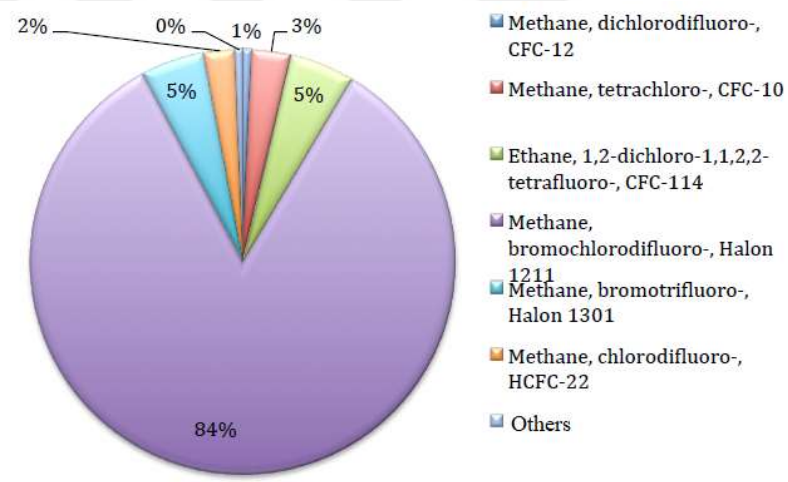

Figure 4.86. Decomposition of substances affecting ozone layer depletion.

4.4.7. Human Health Toxicity Potential

Human health toxicity, which expresses the toxic effect on human health caused by the release of various chemicals to the environment, is due to respectively, from use and end of life stages. The reason for the impact in the use phase is the chemical and heavy metal emissions that occur due to energy consumption (Figure 4.87). Some of them originate from energy production. Because, in the production of energy, aromatic hydrocarbons emerge as emissions and waste. The decomposition of other active chemicals is given in Figure 4.88.

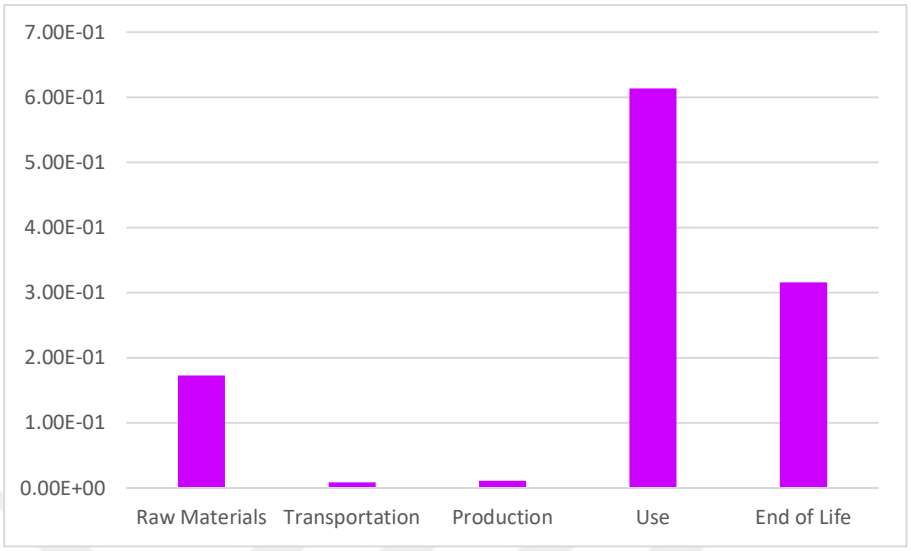

Figure 4.87. Human health toxicity potential in shower gel life cycle.

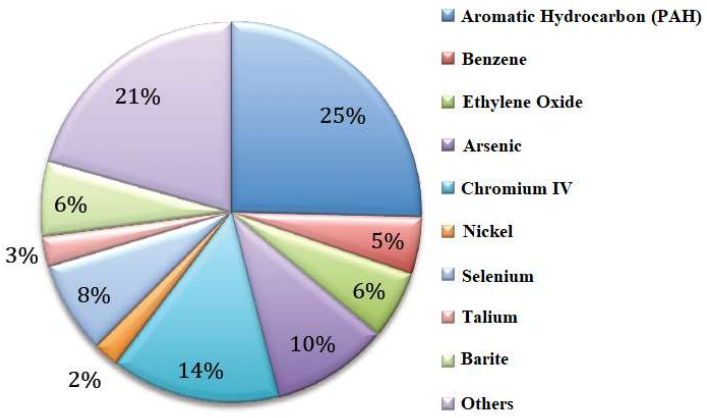

Figure 4.88. Decomposition of substances affecting human health toxicity.

4.4.8. Fresh Water Ecotoxicity Potential

This effect, which expresses the adverse impact to the freshwater ecosystem as a result of the mixture of toxic substance-induced emissions to air, water or soil, is due to the use stage rather than other impact categories (Figure 4.89).

The heavy metals that cause this impact are usually caused by the dissolution of soil and rocks into the water system, as well as the activities of human beings such as mining and metal production. Another factor is the loss of metals through the flue gases as a result of the use of coal in electricity generation. The most known of these metals are arsenic, cadmium, chromium, copper, nickel, lead

and mercury. A detailed representation of the elements that cause freshwater ecotoxicity is given in Figure 4.90.

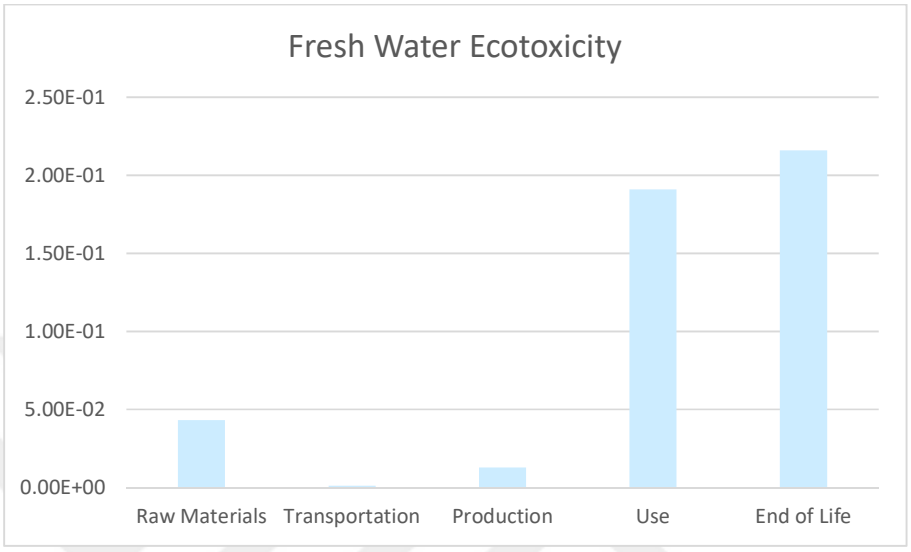

Figure 4.89. Fresh water ecotoxicity potential in shower gel life cycle.

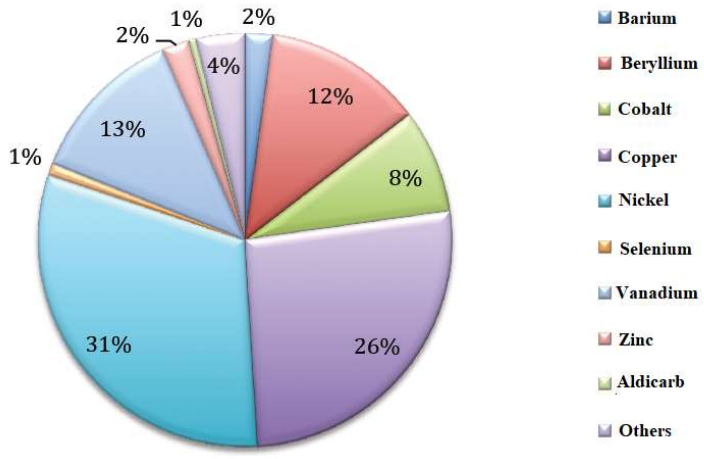

Figure 4.90. Decomposition of substances affecting freash water ecotoxicity.

4.4.9. Marine Ecotoxicity Potential

This impact category, which expresses the impacts of toxic substances on marine ecosystem, is mostly seen in use and enf of life stages (Figure 4.91). The classification of the causative agents was given in Figure 4.92 and the effect was mostly caused by beryllium. The main reason for the release of beryllium to the environment is due to the burning of fossil fuels.

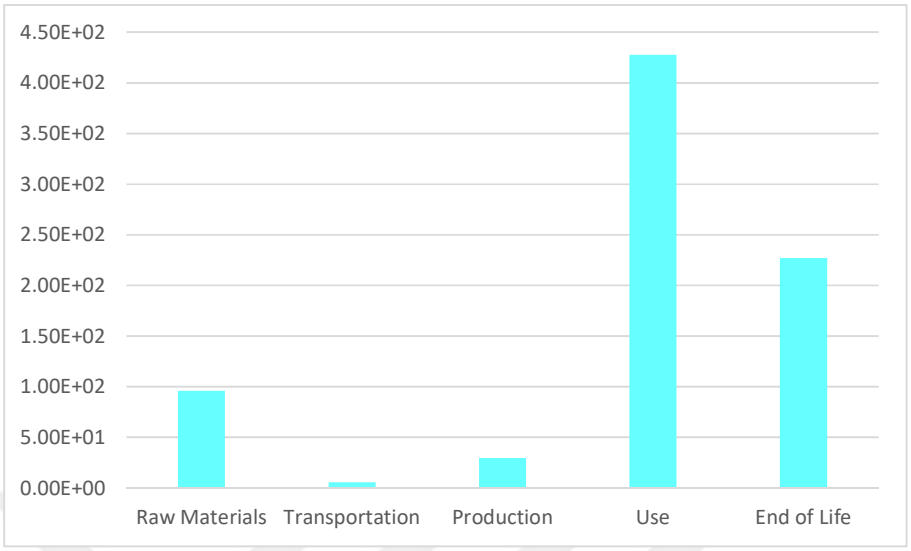

Figure 4.91. Marine ecotoxicity potential in shower gel life cycle.

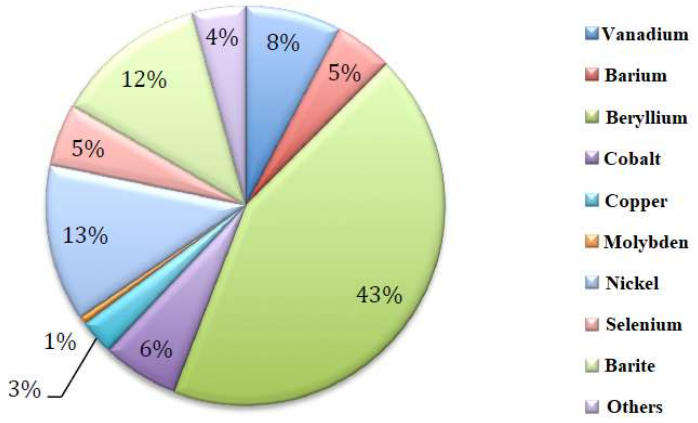

Figure 4.92. Decomposition of substances affecting marine ecotoxicity.

4.4.10. Terrestrial Ecotoxicity Potential

This effect, which expresses the effects of toxic substances released to the environment on the terrestrial ecosystem, is end-of-life (Figure 4.93). This is due to the treatment of wastewater, the classification of the substances that cause it is given in Figure 4.94 and a large part of the effect has been found to be mercury-based.

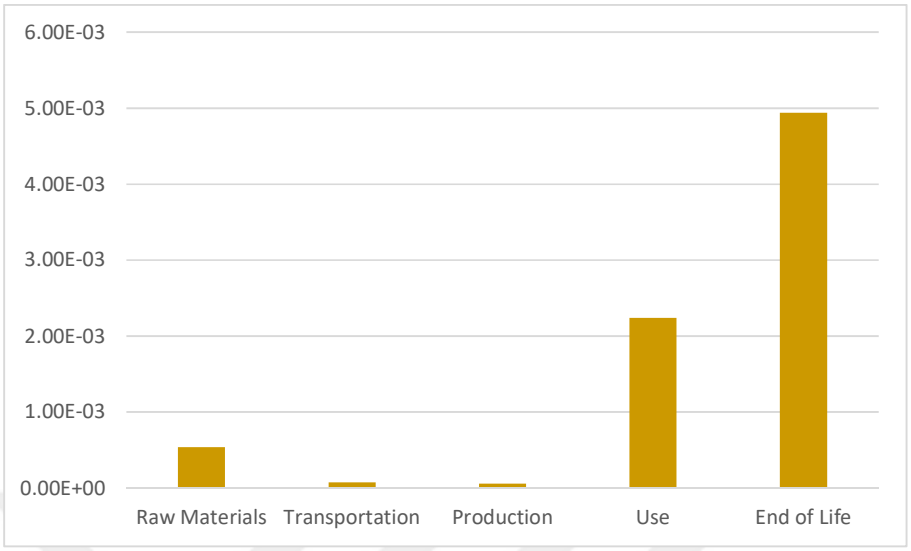

Figure 4.93. Terrestrial ecotoxicity potential in shower gel life cycle.

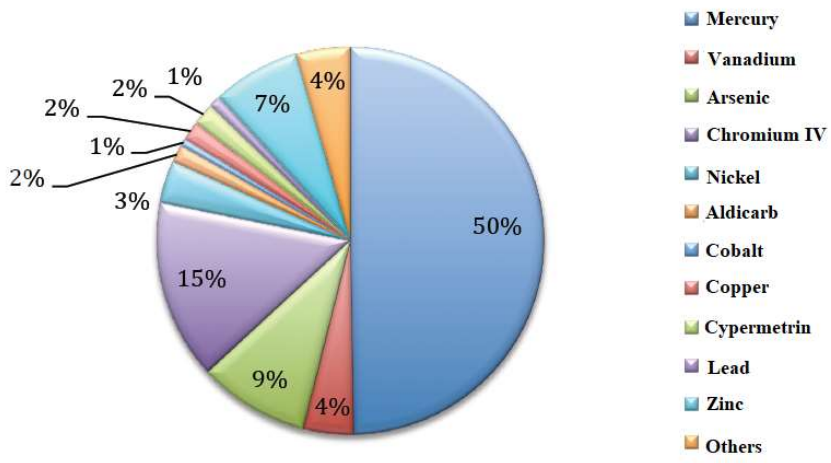

Figure 4.94. Decomposition of substances affecting terrestrial ecotoxicity.

4.4.11. Photochemical Oxidation Potential

The use stage is important in this impact category, which defines the formation of reactive substances that damage agricultural products, human health and ecosystems (Figure 4.95).

The decomposition of the substances causing this effect is shown in Figure 4.96 and most of the effect is from sulfur dioxide. As in other impact categories, the use of natural gas, the fossil fuel, is the main reason.

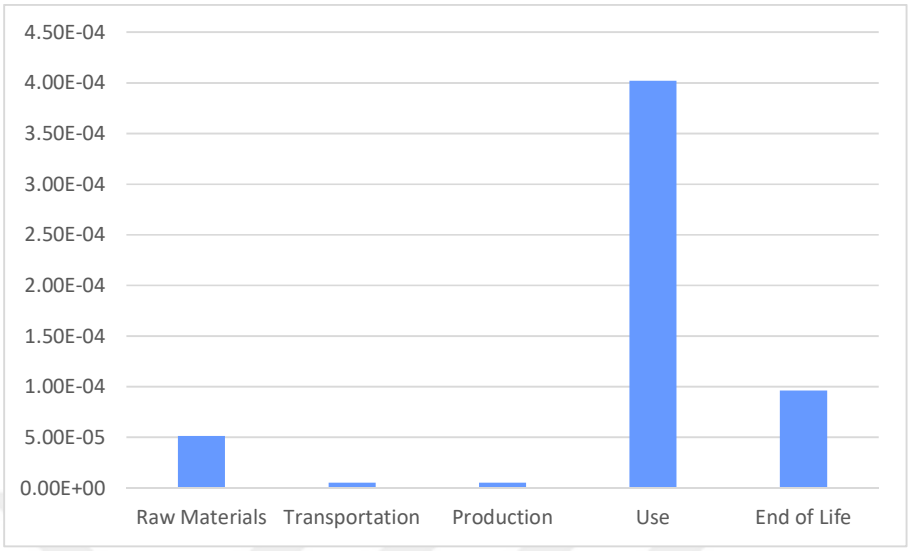

Figure 4.95. Photochemical oxidation potential in shower gel life cycle.

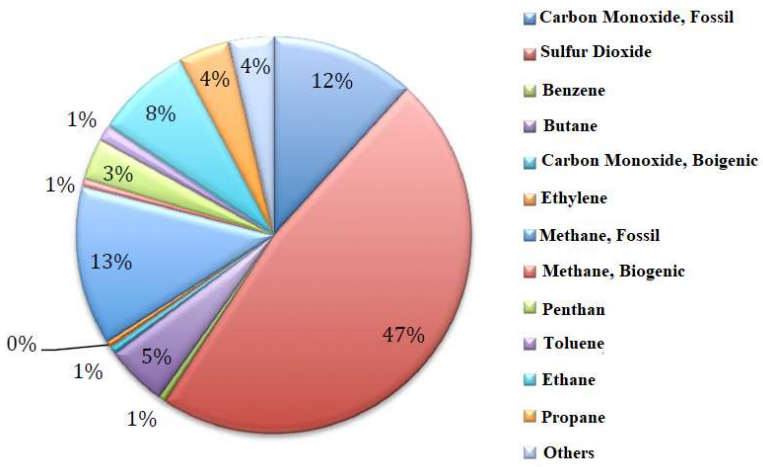

Figure 4.96. Decomposition of substances affecting photochemical oxidation.

5. RESULTS AND DISCUSSION

The combined assessment of all selected products has been performed by using GaBi 6.0 Software program outputs for Life Cycle Assessments of Selected Personal Care Products. Some assumptions and use scenarios have been used both in individual and combined assessments of all selected products.

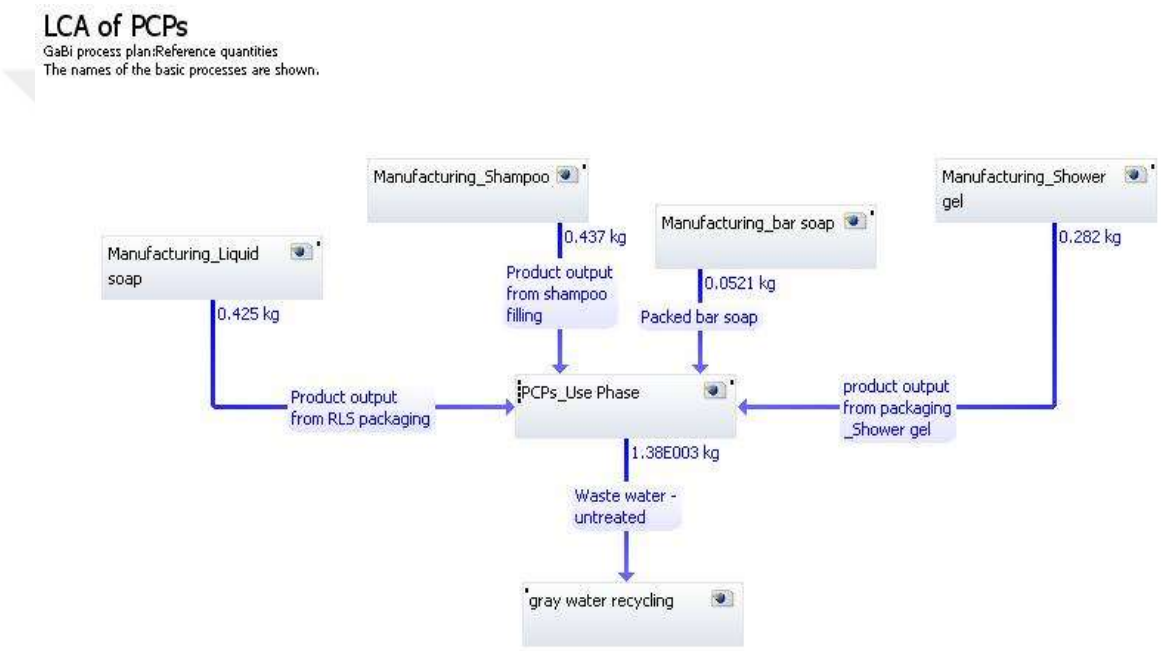

Figure 5.1. Gabi 6.0 Software Screenshot for LCA of PCPs.

Functional units of selected products have been taken same as it has been used in Life Cycle Assessments. Bogazici University's full capacity dormitory population and some survey results which has been performed among students are used in order to make assumptions of consumer use habits. The product amounts based on consumer behavior approaches are given in Table 5.2.

Table 5.1. The assumptions based on industrial data and consumer behavior.

Functional unit	Liquid soap product	Shampoo product	Shower gel product	Bar soap product
Weight	400 mL – 425 g	400 mL – 412 g	250 mL – 257 g	200 g
Dosage	4 mL / use	10.5 g / use	12.9 g / use	2 g / use

Table 5.1. Continued.

Number of use	100 use / 400 mL product	39 use / 400 mL product	20 use / 250 mL product	100 use / 200 g product
Water Temperature	38	38	38	38
High Season, People	2699	4089	3721	1390
Assumptions	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days	Hair wash every 2 days, 6 months = 90 days	Shower every 2 days, 6 months = 90 days	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days
High Season, Product Amount	34004	9660	16810	17517
Low Season, People	676	1024	932	348
Assumptions	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days	Hair wash every day, 6 months = 180 days	Shower every day, 6 months = 180 days	Hand wash every 2 hours, 14 hours awake, 6 months = 180 days
Low Season, Product Amount	8516	4839	8418	4385
Literature Assumptions	Not a specific number for hand washing	Hair wash in a week is recommendable	Body wash every day is recommendable	Not a specific number for hand washing

Table 5.2. The product amounts based on consumer behavior approaches.

Dormitory	**High season population**	**Liquid soap amount**	**Bar soap amount**	**Shampoo amount**	**Shower gel amount**
1. Erkek Yurdu	216	1796	925	510	888
1. Kız Yurdu	205	1705	878	484	843
1. Kuzey Yurdu	468	3892	2005	1106	1924
2. Kuzey Yurdu	450	3742	1928	1063	1850
3. Kuzey Yurdu	562	4674	2408	1328	2310
4. Kuzey Yurdu	367	3052	1572	867	1509
1. Kilyos Yurdu	440	3659	1885	1040	1809
3. Kilyos Yurdu Ek Bina	83	690	356	196	341
3. Kilyos Yurdu	558	4640	2390	1318	2294
Kandilli Yurdu	256	2129	1097	605	1052
Superdorm	484	4025	2073	1143	1990
TOTAL	4089	34004	17517	9660	16810

Table 5.2. Continued.

Dormitory	Low season population	Liquid soap amount	Bar soap amount	Shampoo amount	Shower gel amount
1. Erkek Yurdu	54	449	231	255	444
1. Kız Yurdu	51	424	218	241	419
1. Kuzey Yurdu	117	973	501	553	962
2. Kuzey Yurdu	113	940	484	534	929
3. Kuzey Yurdu	141	1173	604	666	1159
4. Kuzey Yurdu	92	765	394	435	756
1. Kilyos Yurdu	110	915	471	520	904
3. Kilyos Yurdu Ek Bina	21	175	90	99	173
3. Kilyos Yurdu	140	1164	600	662	1151
Kandilli Yurdu	64	532	274	302	526
Superdorm	121	1006	518	572	995
TOTAL	1024	8516	4385	4839	8418

With respect to before mentioned assumptions and individual LCA studies of products; the selected environmental impact categories in high season have shown graphically in Figure 5.2. It is seen that the combined assessment's hot spot is use phase of PCP's in dormitories.

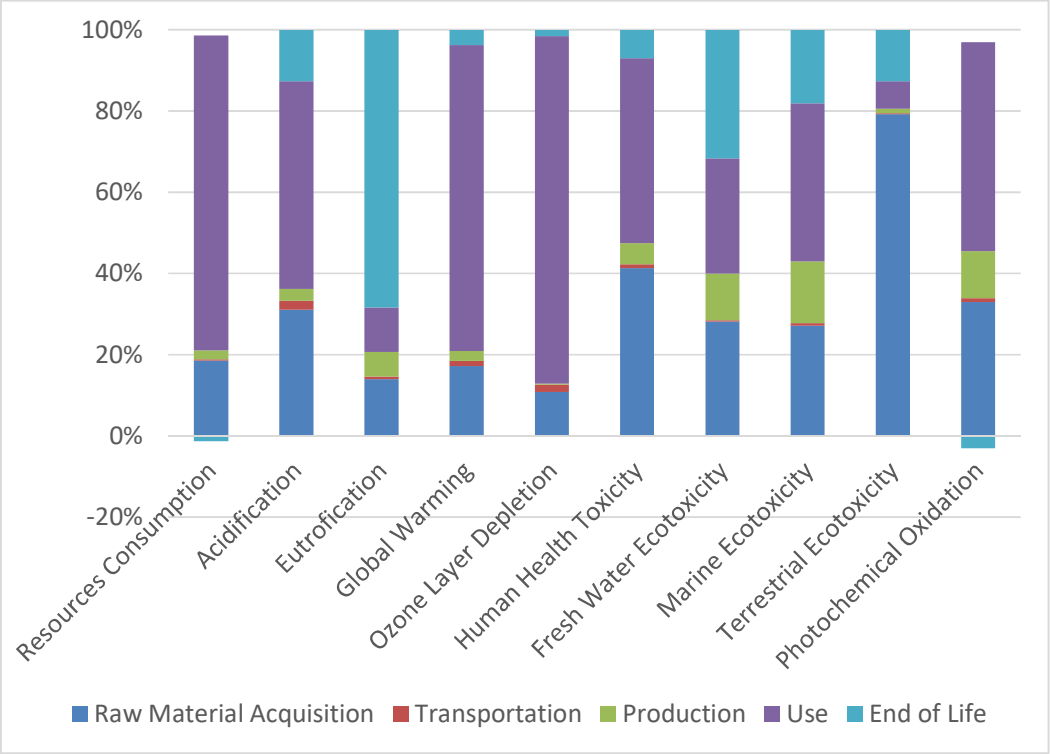

Figure 5.2. The selected environmental impact categories in high season.

Here in Figure 5.3; combined environmental impacts is graphically shown according to the seasonal changes. Although production stage of selected product groups has contribution to environmental footprints, considerable impacts are caused in consumer use phase. Environmental impacts have been evaluated by considering results of product inventories. Especially marine ecotoxicity potential of using personal care products is remarkable. The reason for this; packaging materials and hot water usage in shower.

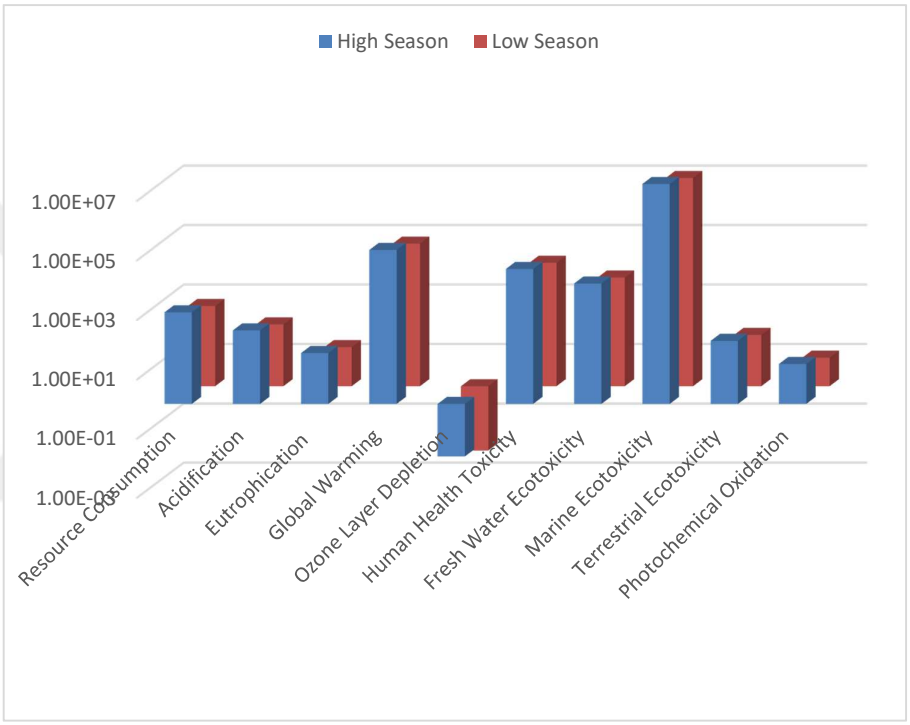

Figure 5.3. Consumer use phase of personal care products.

In order to compare the above mentioned environmental impact categories with each other, the normalization process was carried out (Figure 5.4). The characterization of environmental impact categories is done by reference to the environmental impacts of a human being on the world average. Results showed that using shampoo and shower gel have more adverse impacts on environment than liquid and bar soap products.

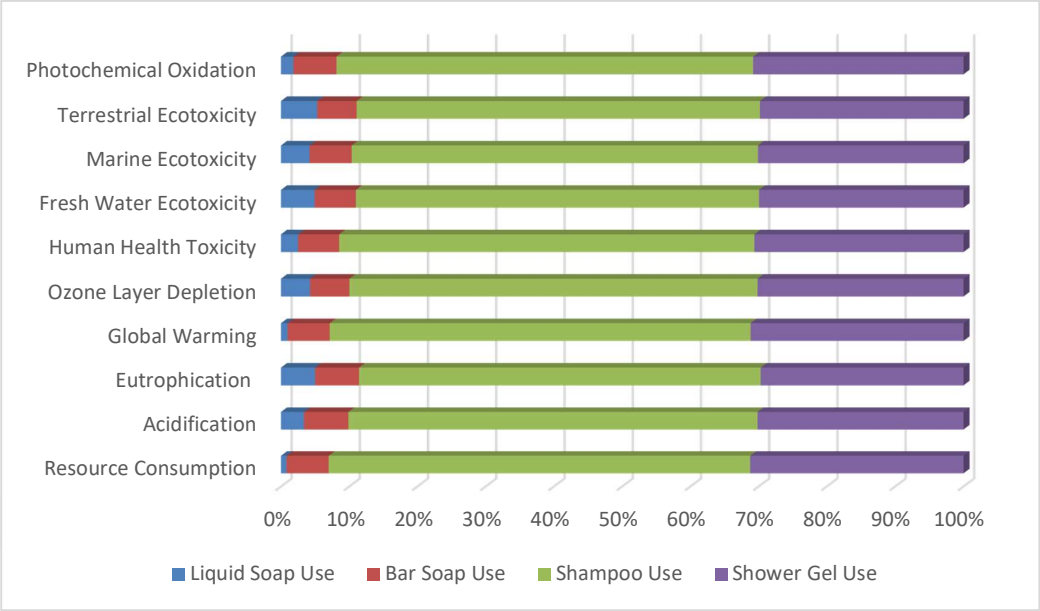

Figure 5.4. Characterization of environmental impact categories in consumer use phase of personal care products.

'Environmental footprint of university residents' has been evaluated considering seasonal PCPs' consumption with comparison of different products and scenarios. Ten dormitories in Bogazici University's Campus (1. Erkek Yurdu, 1. Kız Yurdu (Zeynep-Ayşe Birkan Kız Yurdu, 1. Kuzey Yurdu, 2. Kuzey Yurdu, 3. Kuzey Yurdu, 4. Kuzey Yurdu, 1. Kilyos Yurdu, 3. Kilyos Yurdu Ek Bina, 3. Kilyos Yurdu, Kandilli Yurdu, Superdorm) have been evaluated with 4089 residents.

Installation of gray water recovery systems for all dormitories benefits the university's water consumption rates and wastewater loads, at the same time it affects the product's environmental footprint in use phase. In dormitory buildings, personal choices influence water consumption and wastewater characterization. The dormitories provide an excellent venue for controlled study of the selected products use and also for campus sustainability.

The combined environmental impacts have been calculated as percentages according to the seasonal changes. 29% of significant impacts occurs during spring and summer times while 71% of overall impacts occur during fall and winter times. The results of this assumptions show that during high season there are significant impacts on water consumption rates and wastewater loads but also during low season the average of water and products consumption are higher per resident. This impact can not be underestimated.

Water footprint is one of the main indicators that measure the amount of water needed for the production and consumption of personal care products. Although production of food and beverages have supposed to consume more water than the production of PCPs, the use phases of PCPs have relatively high water footprint because of the water needs during shower and hand wash. Total water footprint generated from personal care products use in one year in Bogazici University's ten dormitories has been calculated as 1312 m^3 (0.32 m^3/capita.year). From a representative point of view, it takes 2720 litres of water to make a cotton t-shirt and that value is also how much a person needs to drink within almost 3 years.

Table 5.3. Water Footprint of PCPs.

PCPs	High season, pcs	Water footprint, m^3	Water footprint, m^3
Liquid Soap	34004	0.00089	30.26356
Bar Soap	17517	0.00962	168.51354
Shampoo	9660	0.0406	392.196
Shower Gel	16810	0.0188	316.028
Total Water Footprint, m^3 / season			907.0011
	Low Season, pcs	Water Footprint, m^3	Water Footprint, m^3
Liquid Soap	8516	0.00089	7.57924
Bar Soap	4385	0.00962	42.1837
Shampoo	4839	0.0406	196.4634
Shower Gel	8418	0.0188	158.2584
Total Water Footprint, m^3 / season			404.48474

6. CONCLUSION

PCPs have been analyzed for sustainability indicators considering the production technologies and strategies. Moreover, the defined future targets on the selection of raw materials, production, and service concept have been considered within the context of the European Union Ecolabel scheme.

The target of the study reflected future goals of Turkish PCPs' production technologies and use policies. Special emphasize has been given for consumption patterns at the dormitory concept. Within this framework, pollution prevention technologies through chemical savings/substitutions and resource conservation aspects have been observed in the defined selected product group including improvement scenarios for LCA interpretation. Mass and energy balances for the production processes and consumption of the products provided the basic information for detailed sustainability assessment of identified product categories. The results have been interpreted for selected normalized environmental impacts. The significant impact of chemicals for the manufacturing stage has been assessed.

Parallel with the increase in living standards, the market demand in personal care products is increasing both in Turkey and in the World. The relevant production sector in Turkey has performed well in terms of quality, production capacity and variety.

Soap, Detergents and Other Washing Officinal production capacity has reached to an export potential of 782.9 million dollars for 2017 with a 2.7% increase from 2016 (Istanbul Chemicals and Chemical Products Exporters' Association 2017 Working Report). Due to the international market requirements, Turkey with its high export capacity gives importance to the European Union Ecolabel and directives on the environment (Turkish Ministry of Economy, 2016). In October 2018; a new regulation "Environmental Label Regulation" came into force by the Ministry of Environment and Urbanization aiming to promote products or services that have reduced environmental impacts throughout the life cycle in line with sustainable environmental targets, to create a voluntary-based environmental label system to ensure the flow of information that is accurate and scientific to consumers, and to regulate the administrative and technical issues and principles and procedures regarding the implementation of the system (Turkish Ministry of Environment and Urbanization, 2018).

Personal Care Products as bar soap, liquid soap, shower gel and shampoo have been assessed in terms of their resources consumption and ecotoxicity potentials. Environmental impacts are higher in their use phase; when water and energy consumption is considered. Producers are now responsible in not only production steps, but also use and disposal phases. Consumer habits are very important, though, to the ultimate consumer of resource consumption during use to ensure communication and awareness are expected from companies. In this sense, the European Sustainable Production and Consumption Directive, the product is not the only manufacturer in the sustainability of the solution of the consumer at the same time emphasizing that it is a part is a good example. Some chemicals used in formulation of products have limited and some have forbidden by The European Union EcoLabel due to their adverse effects on environment and human health. The product compositions have indicated in this study; odorizing agents like perfumes, milkway etc. and methylchloroisothiazoline, methylisothiazoline chemicals which cause an increase in Critical Dilution Volume (CDVtox) of products. CDVtox shows minimum toxicity limits on aquatic environment. Methylisothiazolinone chemicals used as preservatives in these products in the R50 and H331 phase and expected to forbid in formulations. Lowering the minimum levels specified in the recipes of chemicals or equivalent work has suggested initiating.

When the whole life cycle is considered, the hot water consumed by the end-user is seen as a hot spot. Considering that the water is 38ºC, the carbon footprint for one bottle of shower gel is 3.31 kg CO_2 eq. In order to compare shower gel product in terms of carbon footprint, EU Ecolabel studies were discussed in the literature. In this study, since the consumption of hot water is taken, the evaluation is made through this scenario and the comparison is made for the production of one bottle of product. One kg shower gel carbon footprint 2,92 kg CO_2 eq. and for EU Ecolabeled liquid soap this value is 4.27 kg CO_2 eq. When compared with similar products like shampoo and shower gel footprint was found to be comparable. (Figure 6.1)

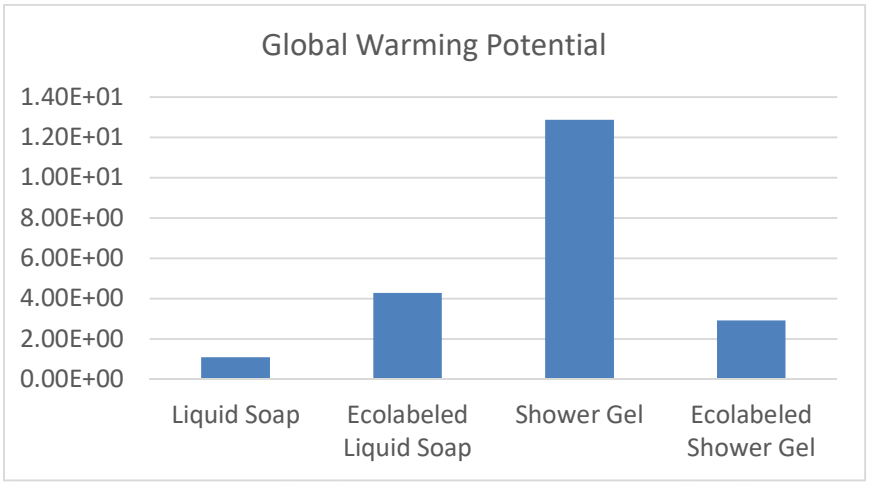

Figure 6.1. Comparison of ecolabeled vs selected products.

After use phase, the chemicals involved in formulations are expected to be soluble in biological media of wastewater treatment system. Assessments made for personal care products that meet these conditions, but generally of flavoring essences have been found to be troublesome chemicals. Chemicals like Geraniol, Limonene, Isoeugenol, Hydroxycitronellal have allergic effects on skin and toxic effects on the environment, these chemicals are expected to forbid according to the EU EcoLabel. Companies which interiorize the cleaner production approach, taking the ISO 14024 standard is defined in the EU Ecolabel is possible to create awareness.

Gray water reflects household activities and its consumption aspects depend on life style. When wastewater discharge of dormitory has been considered; gray water contributes 40-50% of organic load in terms of BOD, 25% of total suspended solids and more than 75% of total phosphorus. In conclusion of LCA case study and consumer information; water savings and pollution load reduction of selected PCPs have been interpreted. A Membrane Bioreactor (MBR) has been selected and installed for gray water recycle; since it is the mostly used system. Chemical load to treatment facility has been gathered from consumer use stage and manufacturing stage. With gray water recovery system; water consumption, which is an important indicator regarding to literature information, significantly decreased (Zhang et al., 2012).

In Bogazici University's 4th North Dormitory there is an already installed gray water recovery system which works with full capacity 1m^3/hr, 16 m^3/day. Regarding to information taken from university rectorate, the cost of 1 m^3 of water is 4.45 TL and it is relatively expensive than natural gas (1 m^3 natural gas = 1TL) and electricity (1kW = 0.30TL) costs. When operating costs is considered, daily operating cost is calculated as 21.09 TL. Daily water consumption for 252 residents

in dormitory is 28.3 m^3 which equals 126 TL/day. Daily recycled water derives a profit as 63.8 TL. From these calculations, the payback period of gray water recovery system has been found as 3.5 years.

The treatment and reuse of greywater will bring the selected ten dormitories closer to achieving sustainability goals of closing the water loop. The greywater collected daily can be reused in place of valuable potable water for subsurface irrigation of outdoor landscaping, toilet flushing, and laundry machines. Most importantly, the greywater treatment system will provide an opportunity for research investigating the water quality, health, and environmental impacts of various treatment technologies. This research will hopefully contribute to the widespread implementation of greywater recycling systems in other campuses and buildings worldwide.

In addition to 4th North Dormitory gray water system, in South Campus, 1st Male Dormitory (Hamlin Hall; which is only one LEDD Gold Certified Green Building in university) has a gray water recovery system too. In Figure 6.2; the marine ecotoxicity potentials of existing systems are compared with conventional systems. When the comparison is made for all ten dormitories in university the marine ecotoxicity potential reduced by 13% with gray water recovery systems (Figure 6.3).

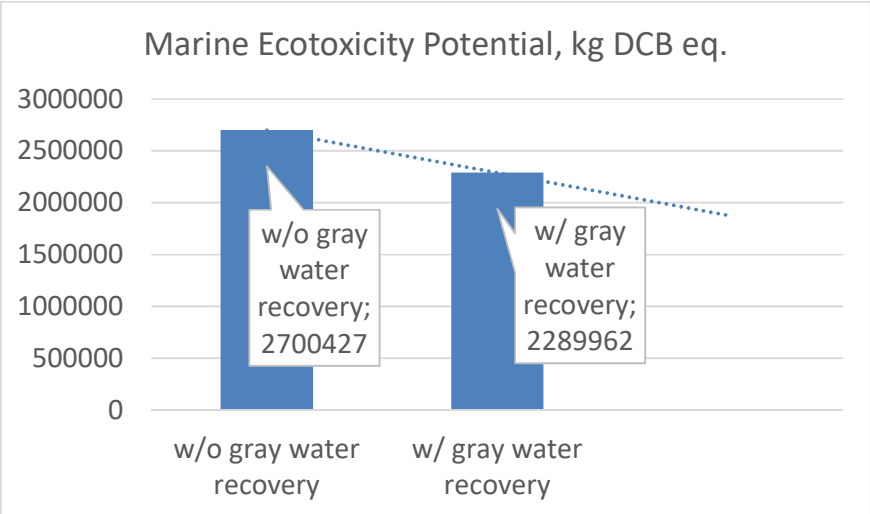

Figure 6.2. Comparison of marine ecotoxicity potential in dormitories which have gray water recovery system.

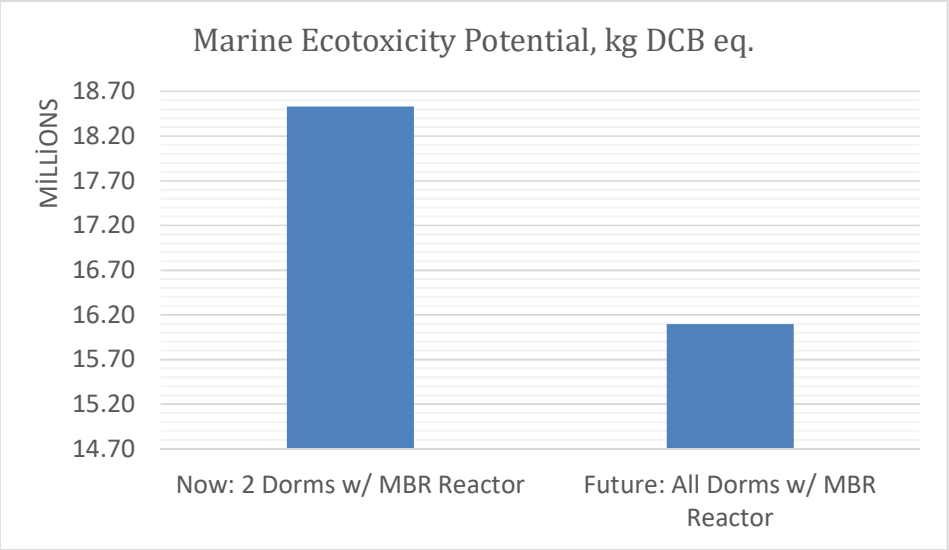

Figure 6.3. Comparison of marine ecotoxicity potential in future dormitories.

The Association for the Advancement of Sustainability in Higher Education (AASHE)'s Sustainability Tracking Assessment & Rating System (STARS) help institutions set and meet sustainability goals and promote information sharing about practices and performance among the campus sustainability community. For water and wastewater credits of STARS checklist; dormitories should be focused on with their relatively high water consumption. PCPs are discharged in both treated wastewater and municipal solid waste stream. By taking into account recycling technologies and wastewater concept in STARS checklist; university's wastewater stream has to be standardized. For the purposes of the credits, utilized water includes related technology for closed-loop systems with the purpose of gray water recovery (STARS, 2018).

The STARS has two Turkish member universities; Marmara University and Ozyegin University. However their data are not available online and their 2018 ranking according to sustainable campus approach is not applicable. Bogazici University's green campus program and investments which serving campus sustainability make collecting operational credits of STARS easier. The only need is monitoring devices and full participation of administrative staff and students. This study is a branch of planning and designing water conservation systems. When it is followed by monitoring and improving; the systems are supposed to be completed.

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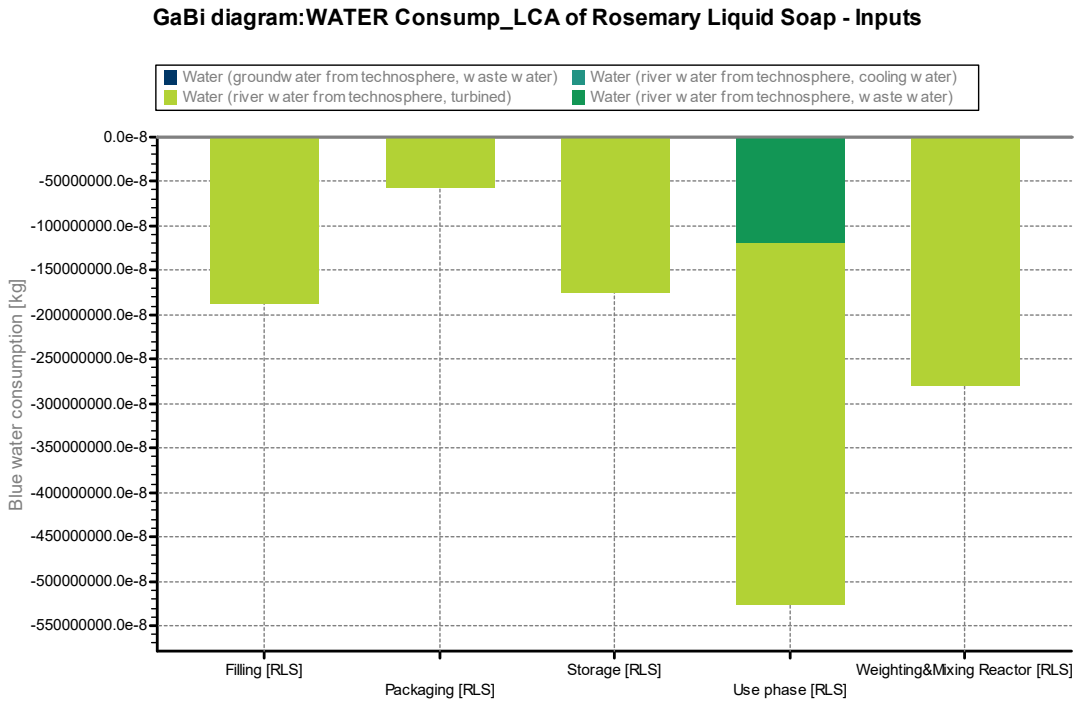
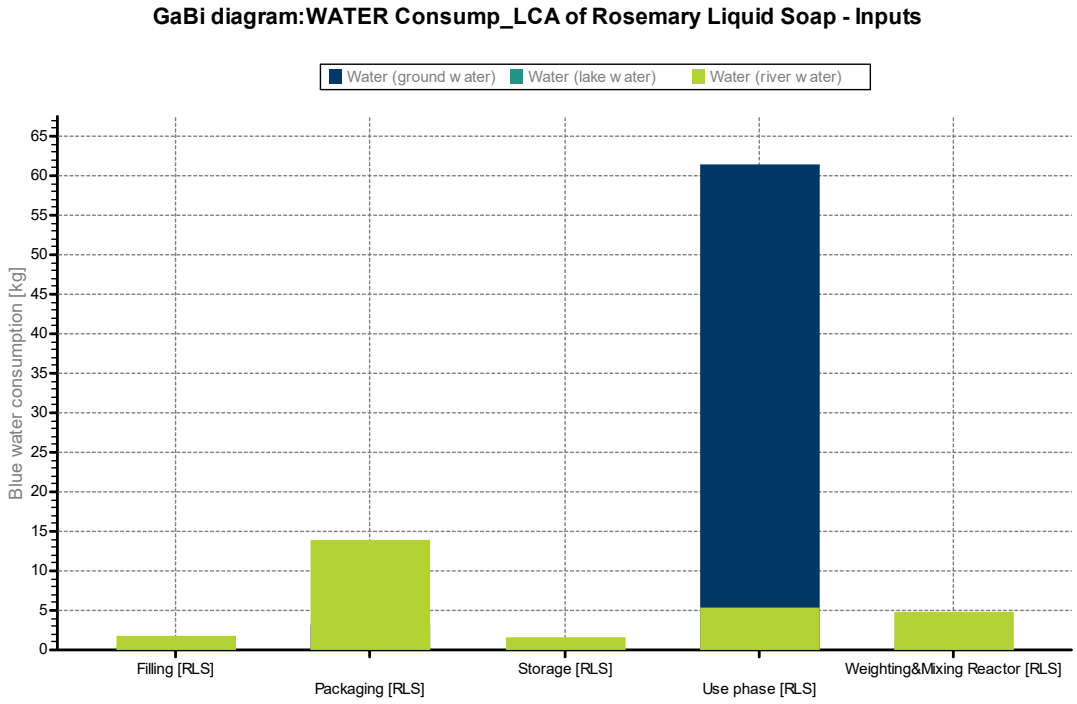
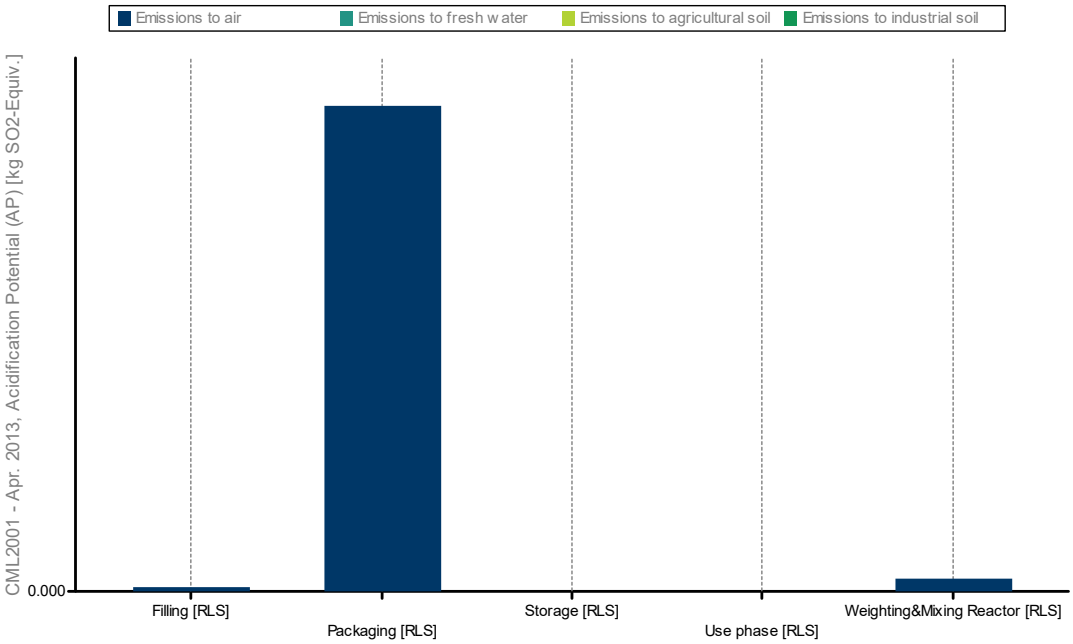
APPENDIX A: GaBi SCREENSHOTS OF THE STUDY





GaBi diagram:Acidification potential LCA of Rosemary Liquid Soap - Inputs



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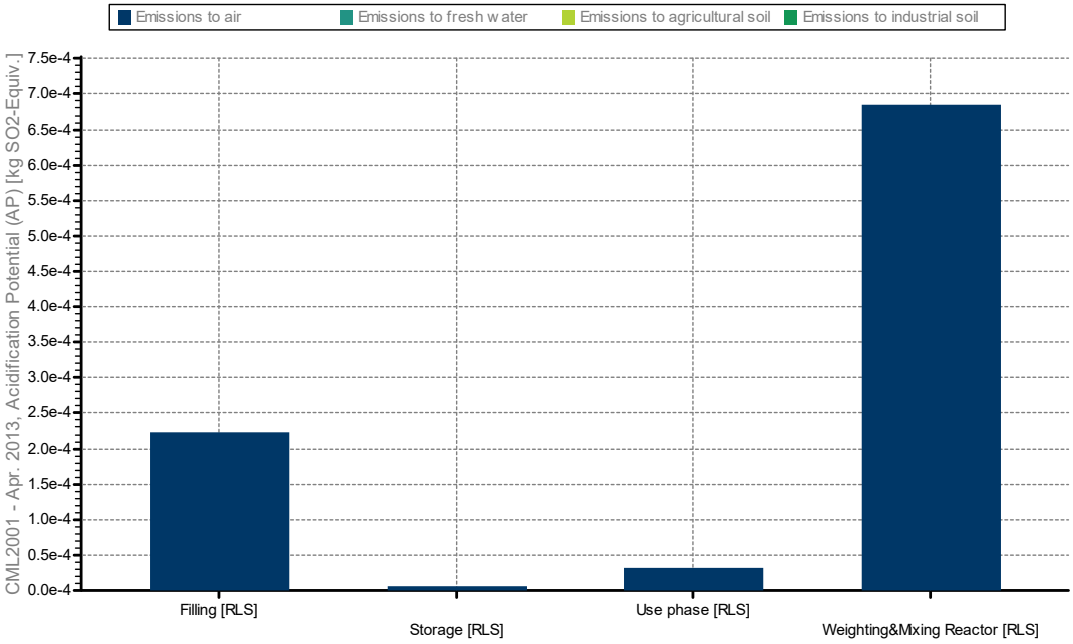

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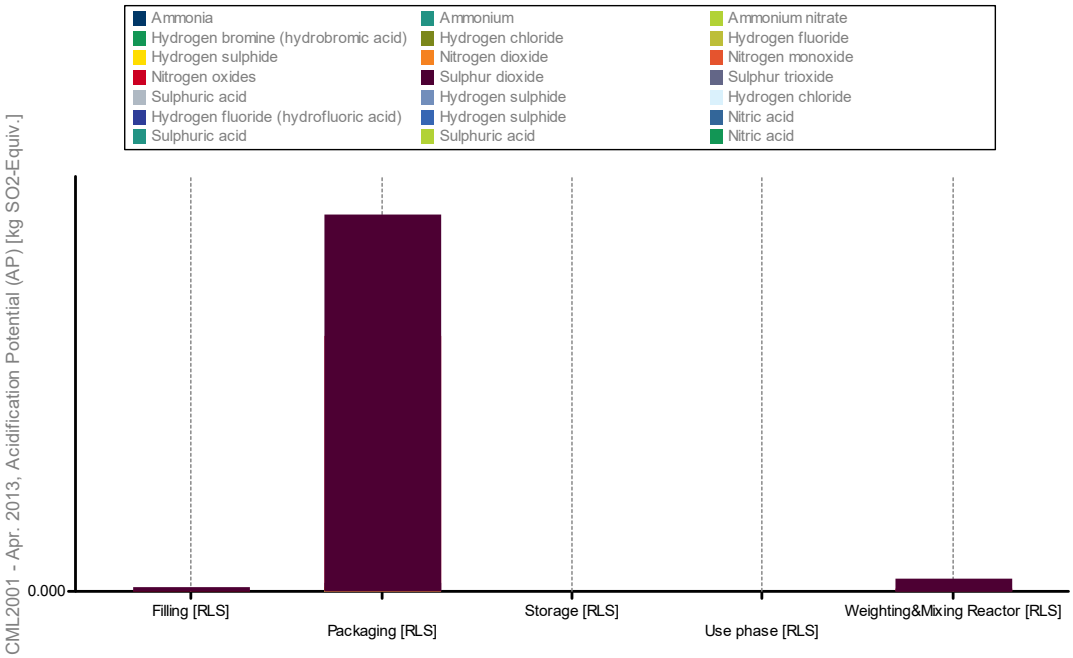

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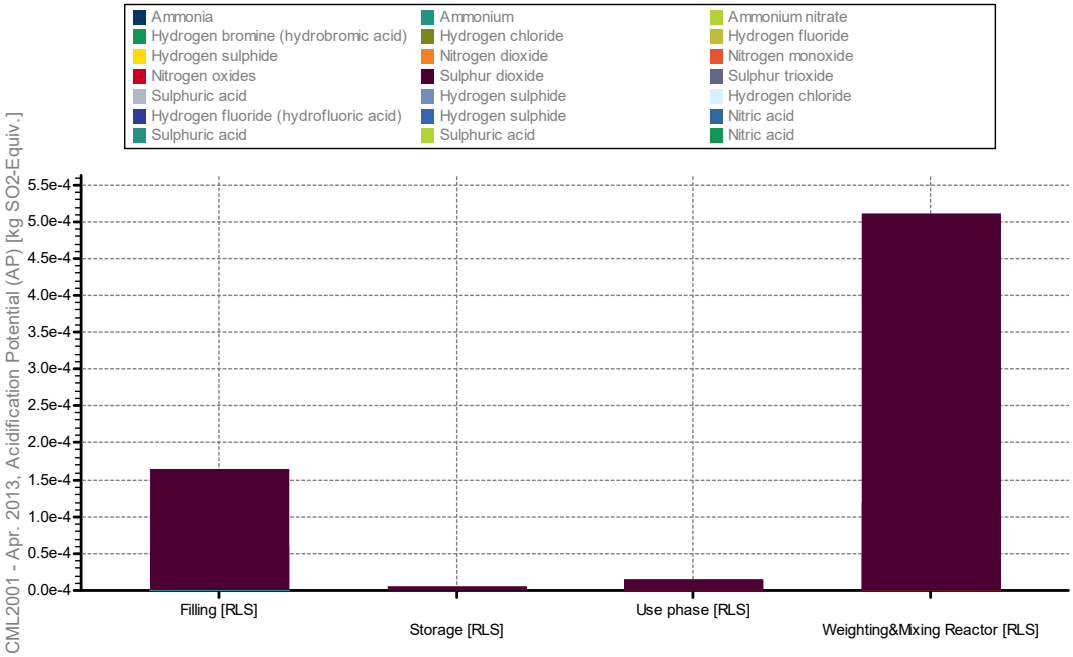
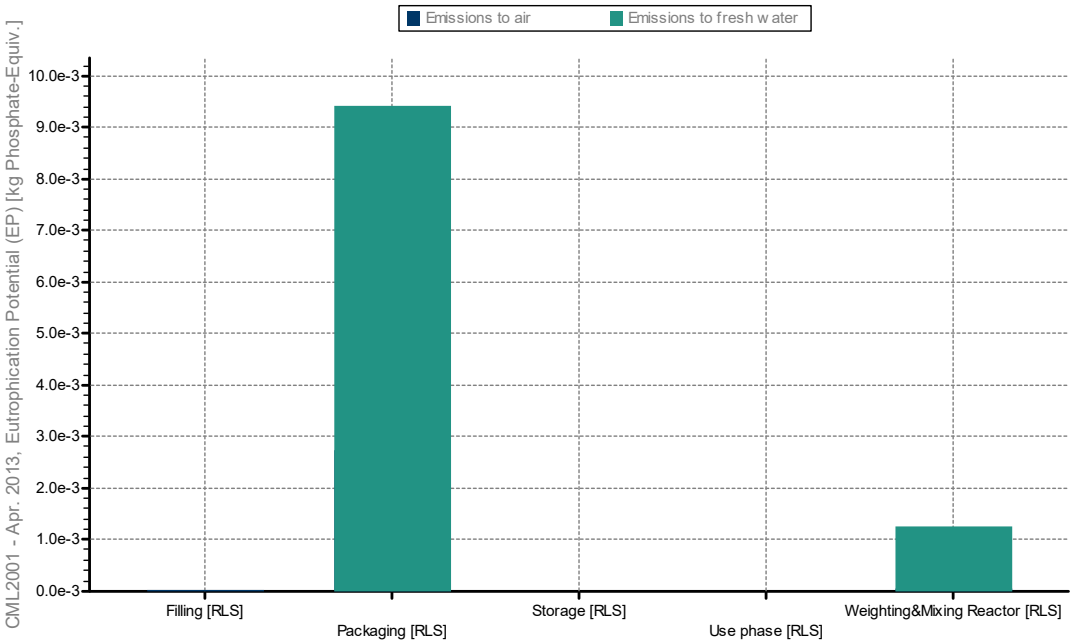
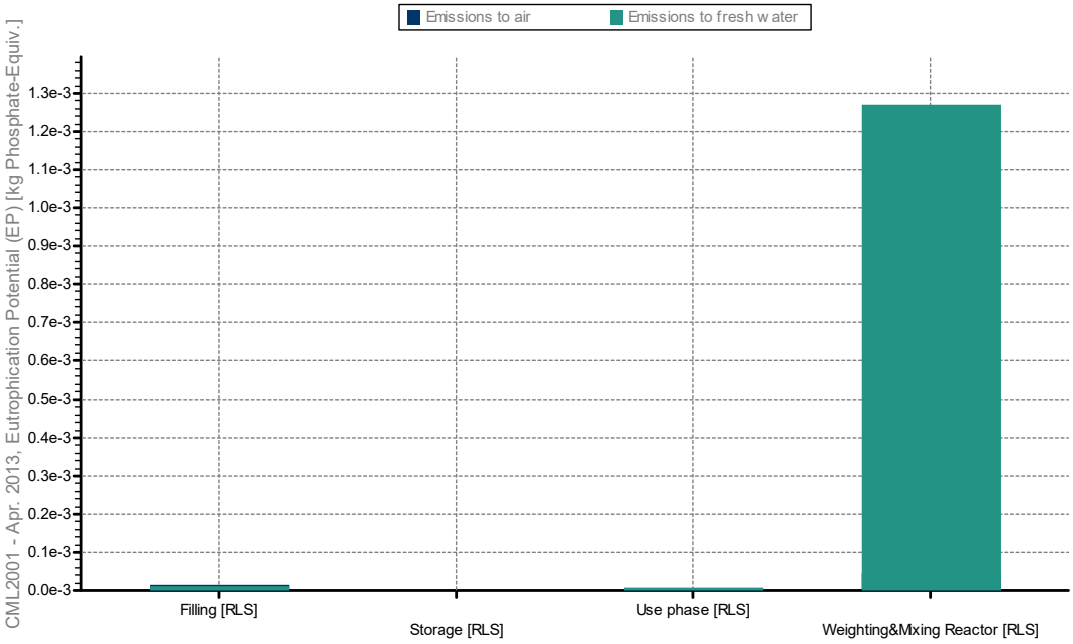


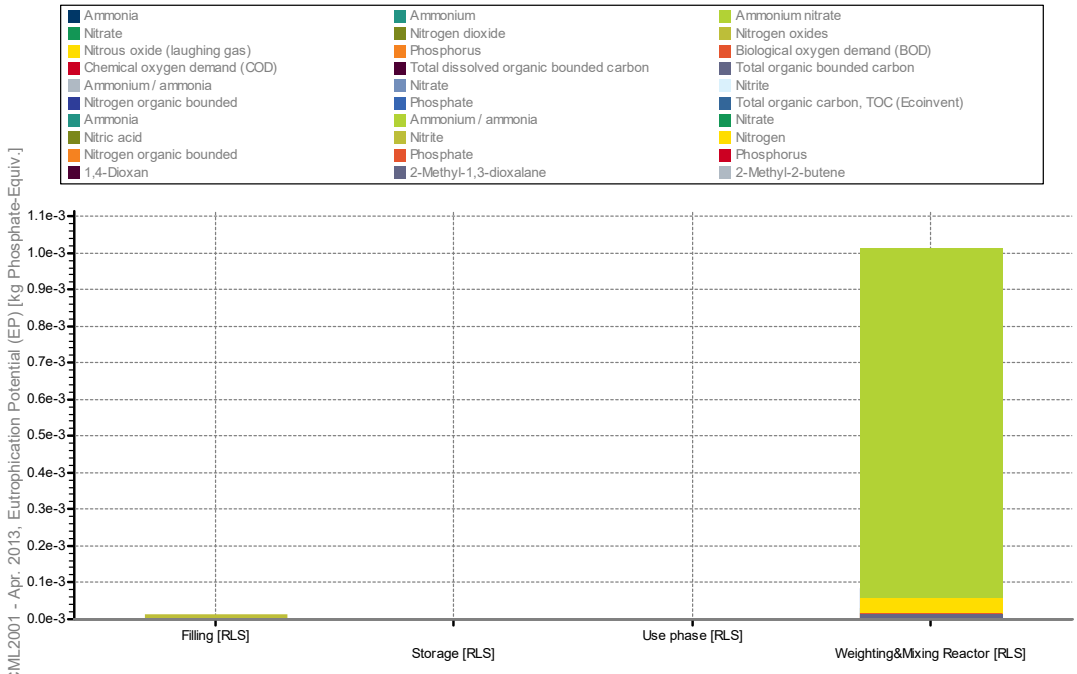
GaBi diagram: Eutrophication pot_LCA of Rosemary Liquid Soap - Inputs



GaBi diagram: Eutrophication pot_LCA of Rosemary Liquid Soap - Inputs



GaBi diagram:Eutrophication pot_LCA of Rosemary Liquid Soap - Inputs



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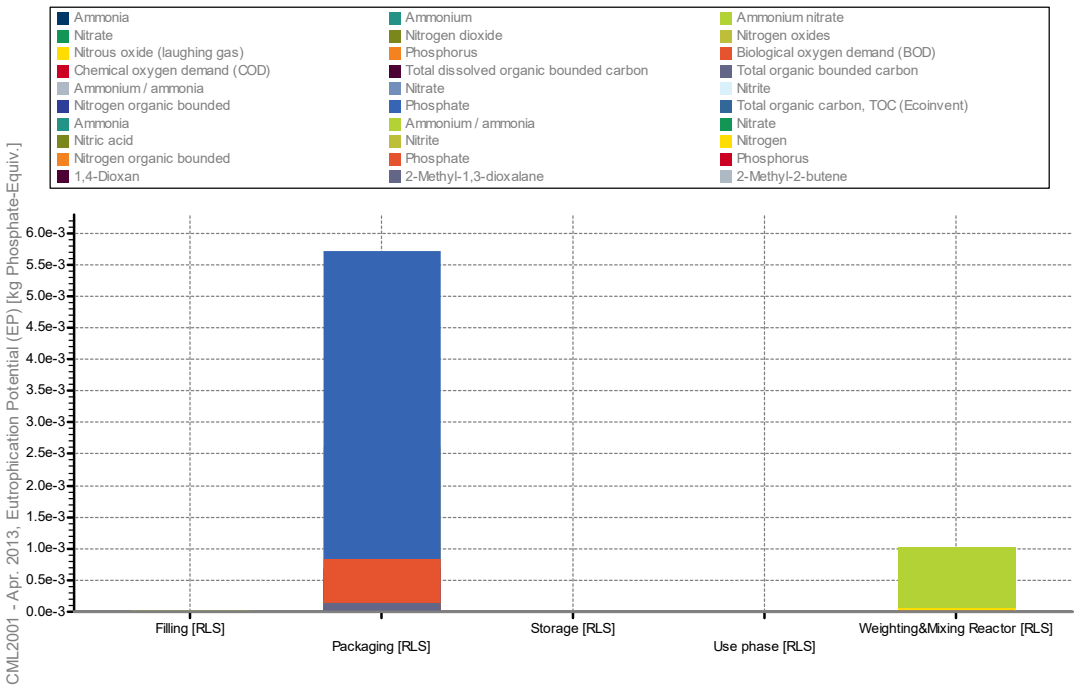

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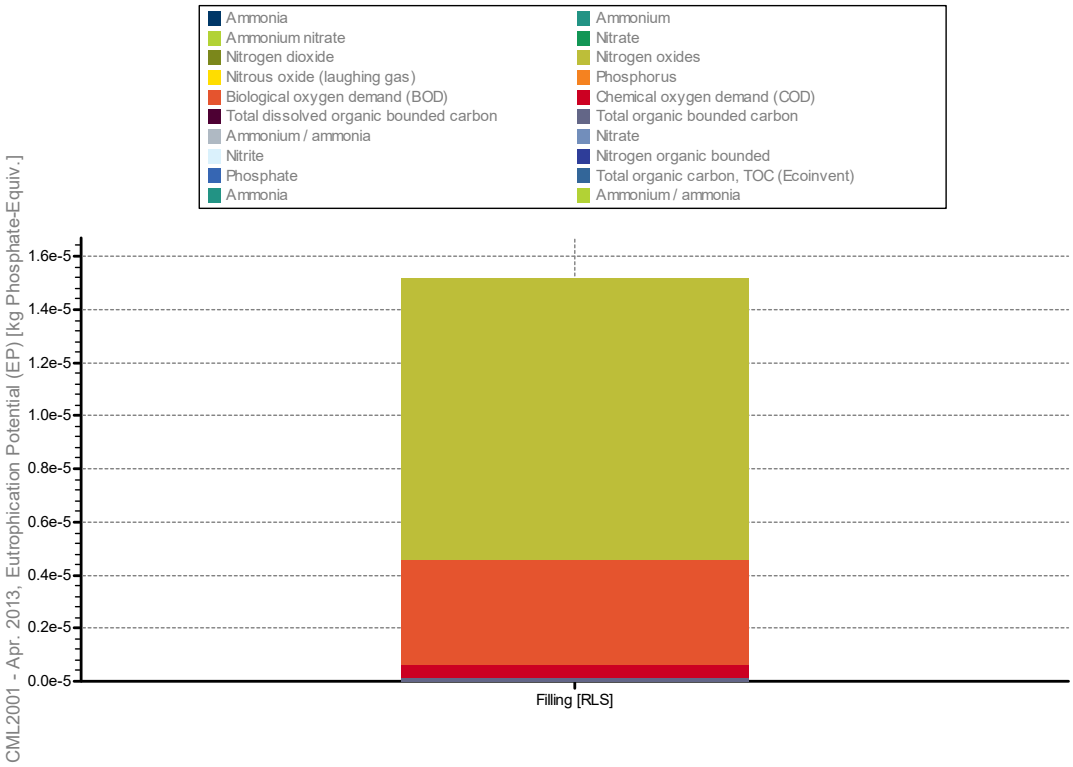
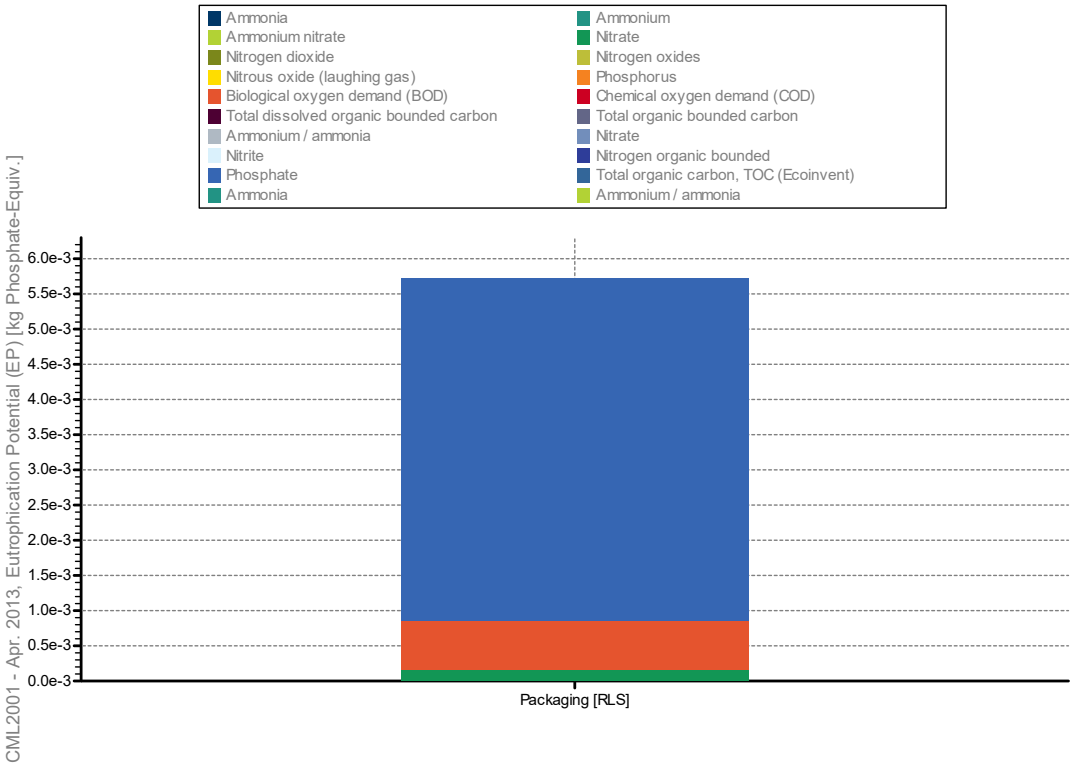
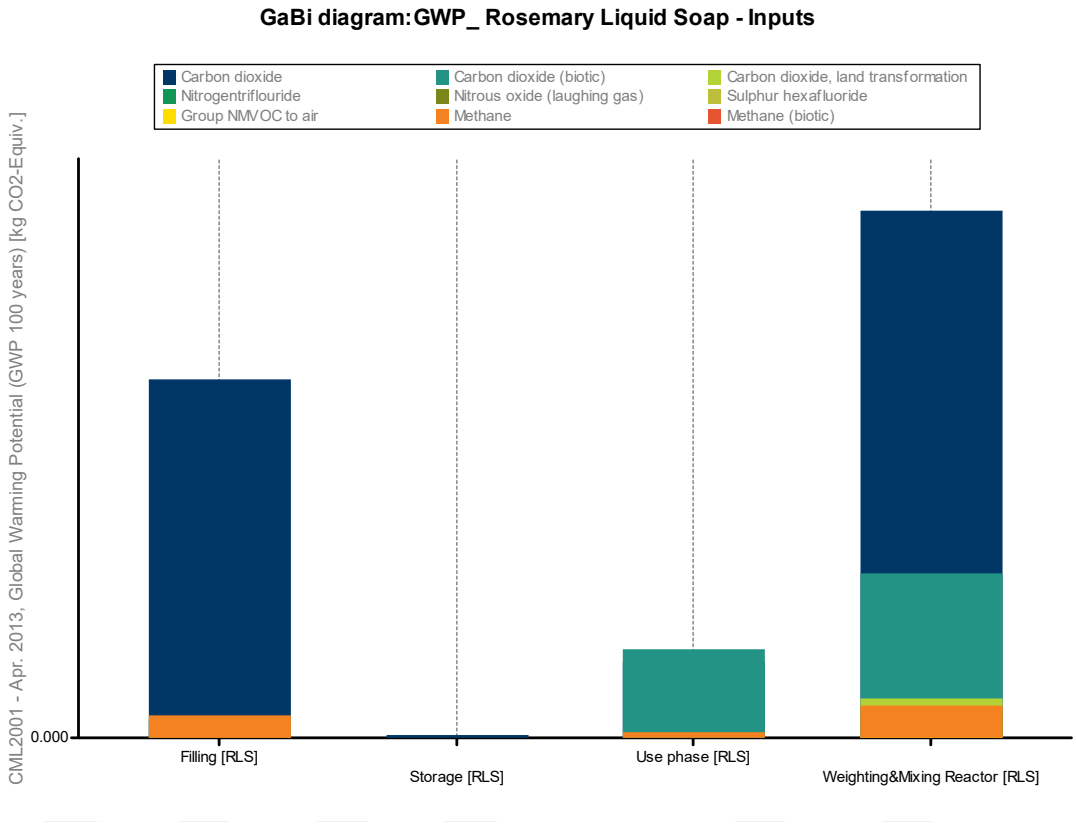
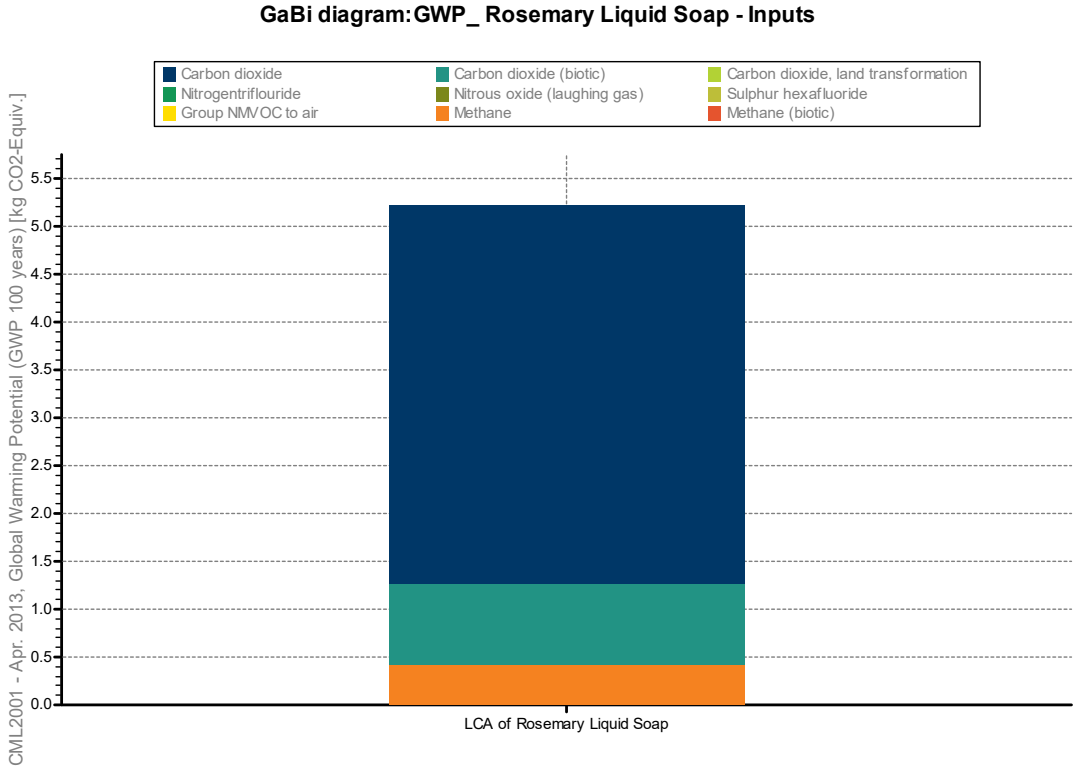


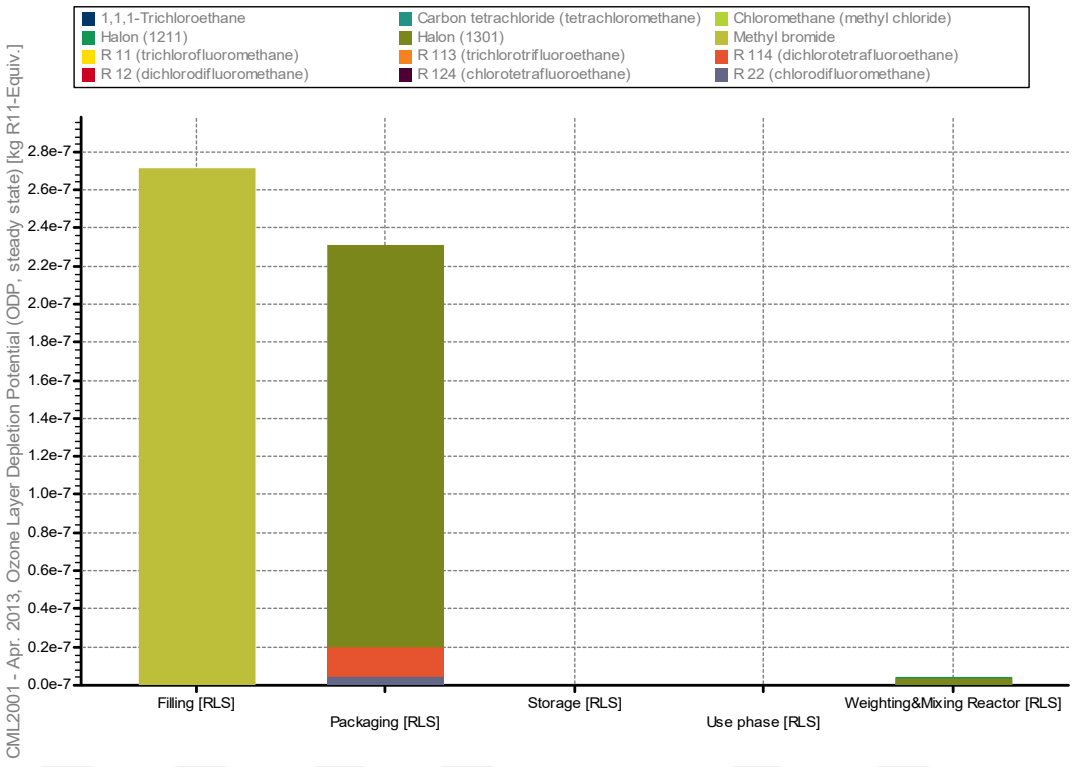
GaBi diagram: Eutrophication pot_LCA of Rosemary Liquid Soap - Inputs



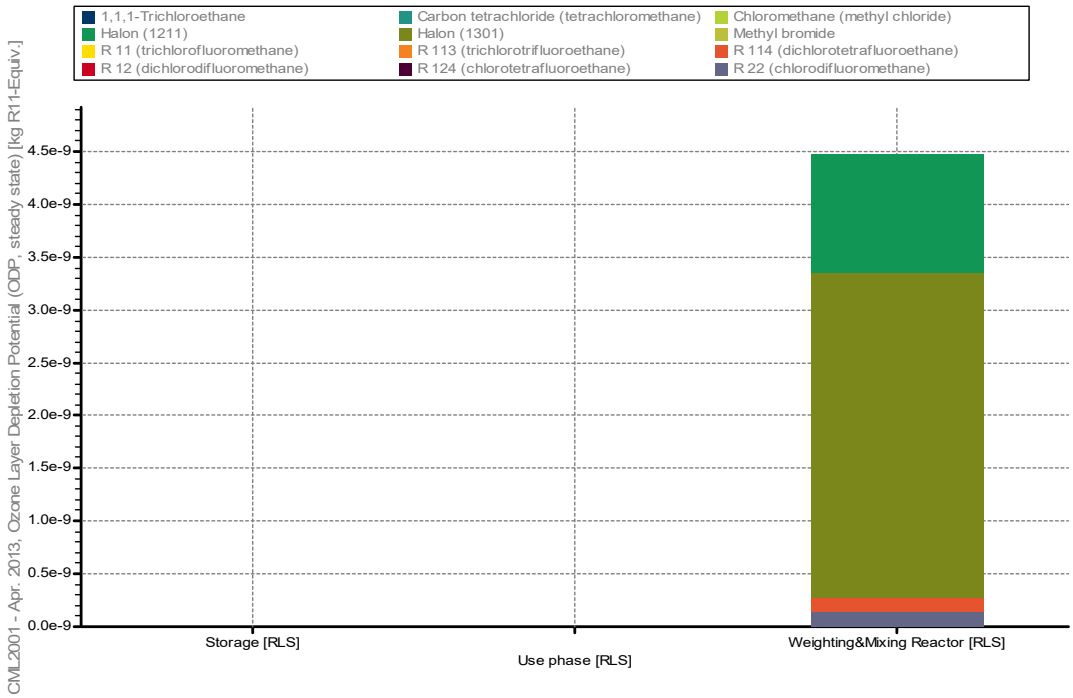

GaBi diagram:GWP_ Rosemary Liquid Soap - Inputs
Carbon dioxide
Carbon dioxide (biotic)
Carbon dioxide, land transformation
Nitrogentriflouride
Nitrous oxide (laughing gas)
Sulphur hexafluoride
Group NMVOC to air
Methane
Methane (biotic)
CML2001 - Apr. 2013, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]
0.000
Filling [RLS]
Storage [RLS]
Use phase [RLS]
Weighting&Mixing Reactor [RLS]

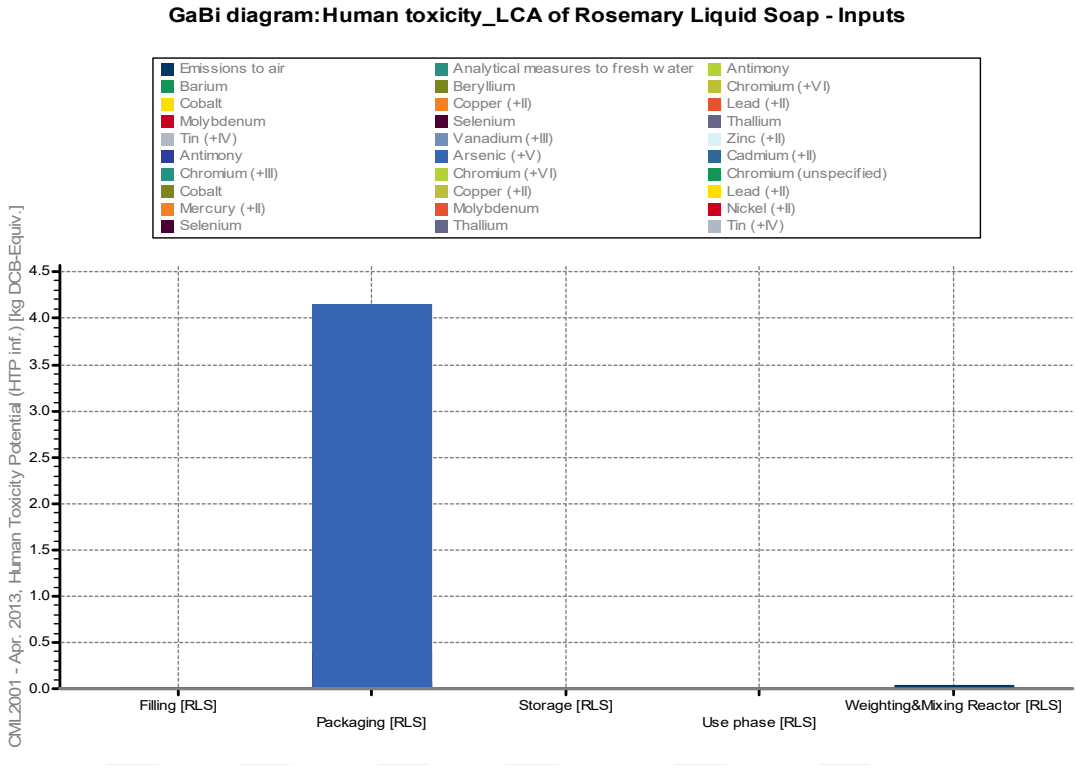

GaBi diagram:GWP_ Rosemary Liquid Soap - Inputs
Carbon dioxide
Carbon dioxide (biotic)
Carbon dioxide, land transformation
Nitrogentriflouride
Nitrous oxide (laughing gas)
Sulphur hexafluoride
Group NMVOC to air
Methane
Methane (biotic)
CML2001 - Apr. 2013, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
LCA of Rosemary Liquid Soap

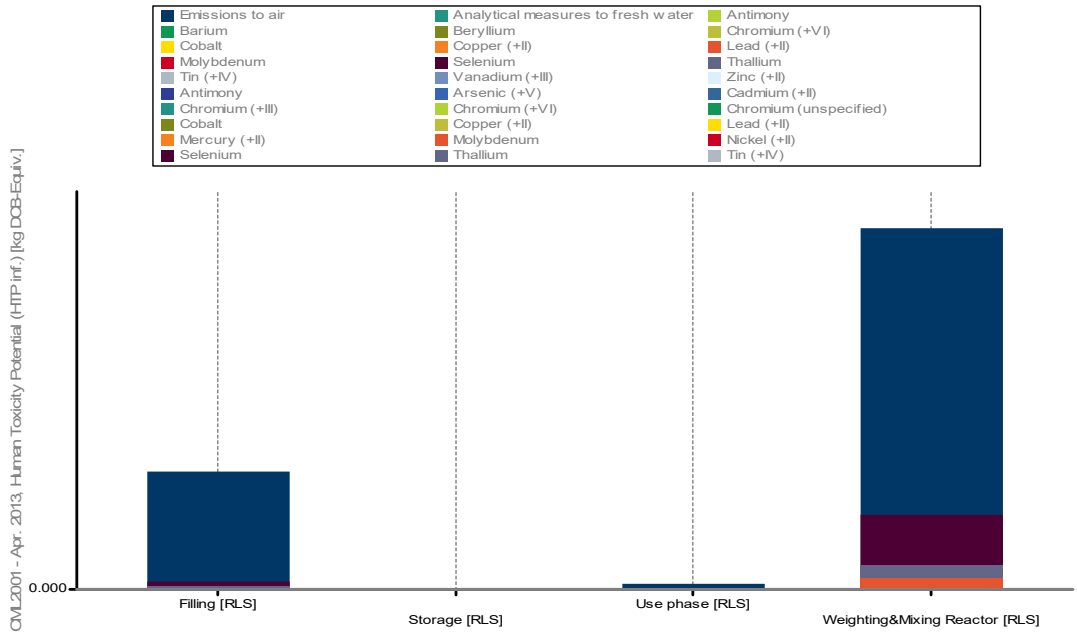
GaBi diagram:Ozone layer dep_ Rosemary Liquid Soap - Inputs



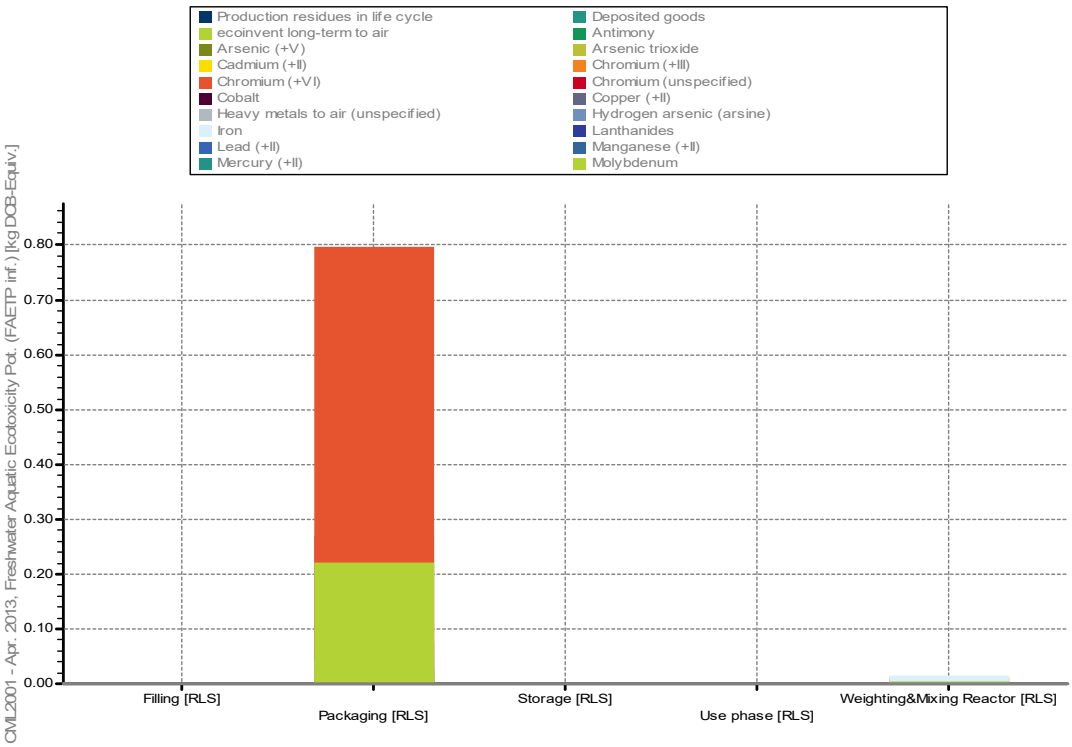
GaBi diagram:Ozone layer dep_ Rosemary Liquid Soap - Inputs



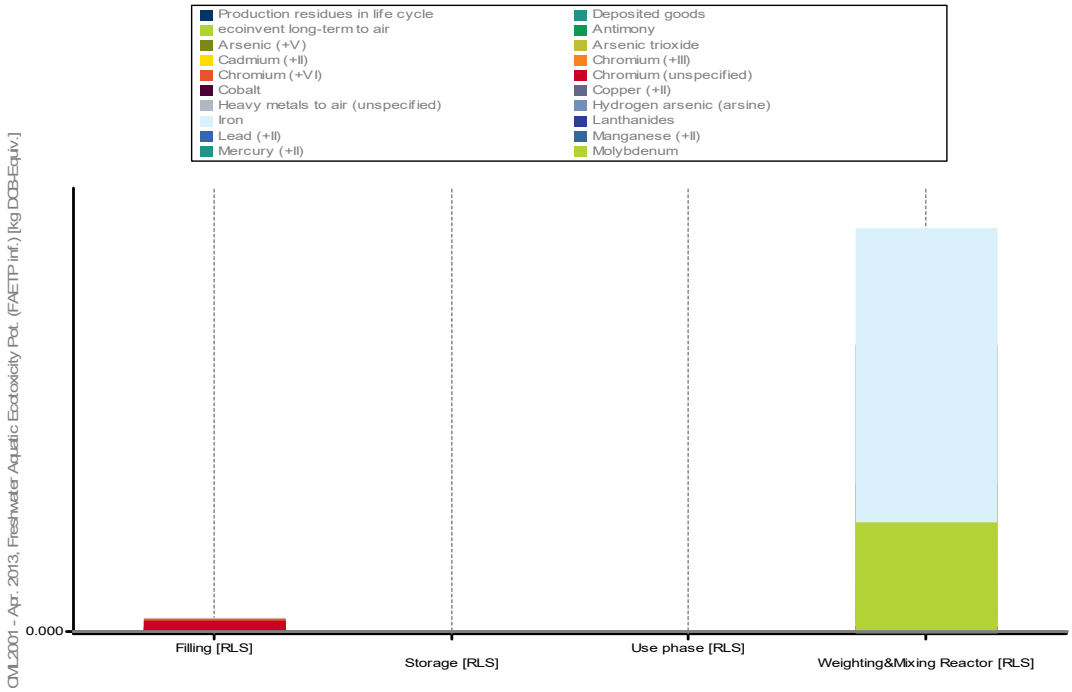

GaBi diagram: Human toxicity_LCA of Rosemary Liquid Soap - Inputs
Emissions to air
Barium
Cobalt
Molybdenum
Tin (+IV)
Antimony
Chromium (+III)
Cobalt
Mercury (+II)
Selenium
Analytical measures to fresh water
Beryllium
Copper (+II)
Selenium
Vanadium (+III)
Arsenic (+V)
Chromium (+VI)
Copper (+II)
Molybdenum
Thallium
Antimony
Chromium (+VI)
Lead (+II)
Thallium
Zinc (+II)
Cadmium (+II)
Chromium (unspecified)
Lead (+II)
Nickel (+II)
Tin (+IV)
CML2001 - Apr. 2013, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Filling [RLS]
Packaging [RLS]
Storage [RLS]
Use phase [RLS]
Weighting&Mixing Reactor [RLS]


GaBi diagram: Human toxicity_LCA of Rosemary Liquid Soap - Inputs
Emissions to air
Barium
Cobalt
Molybdenum
Tin (+IV)
Antimony
Chromium (+III)
Cobalt
Mercury (+II)
Selenium
Analytical measures to fresh water
Beryllium
Copper (+II)
Selenium
Vanadium (+III)
Arsenic (+V)
Chromium (+VI)
Copper (+II)
Molybdenum
Thallium
Antimony
Chromium (+VI)
Lead (+II)
Thallium
Zinc (+II)
Cadmium (+II)
Chromium (unspecified)
Lead (+II)
Nickel (+II)
Tin (+IV)
CML2001 - Apr. 2013, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
0.000
Filling [RLS]
Storage [RLS]
Use phase [RLS]
Weighting&Mixing Reactor [RLS]

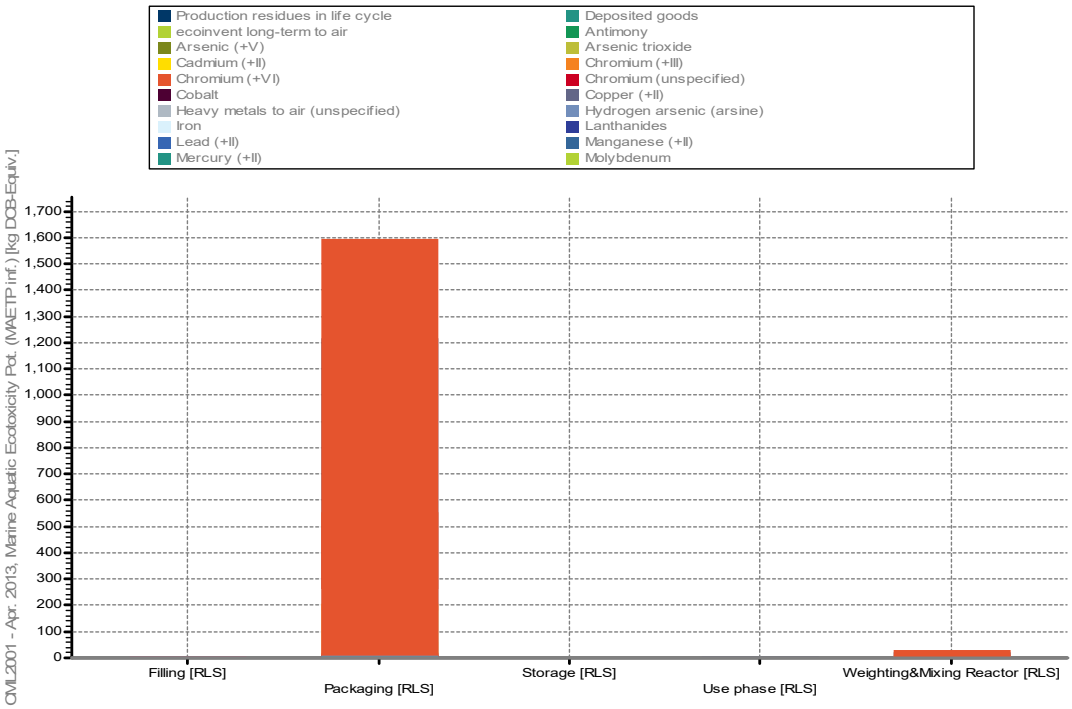
GaBi diagram: freshwater aquatic ecotox_LCA of Rosemary Liquid Soap - Inputs



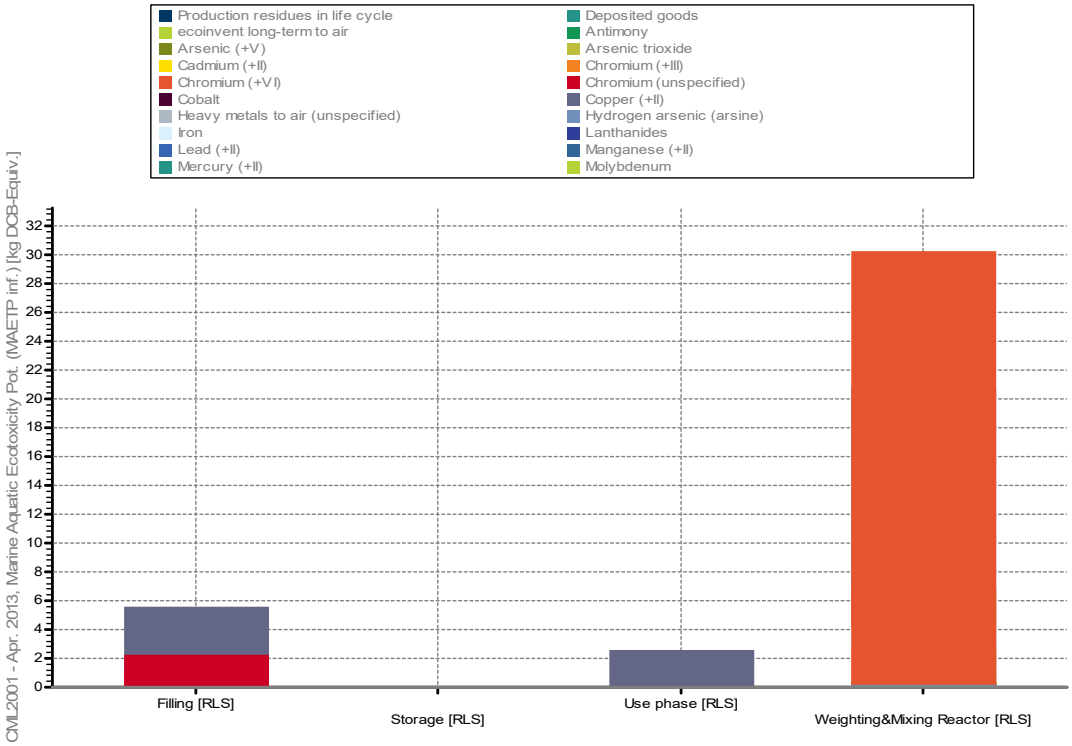
GaBi diagram: freshwater aquatic ecotox_LCA of Rosemary Liquid Soap - Inputs



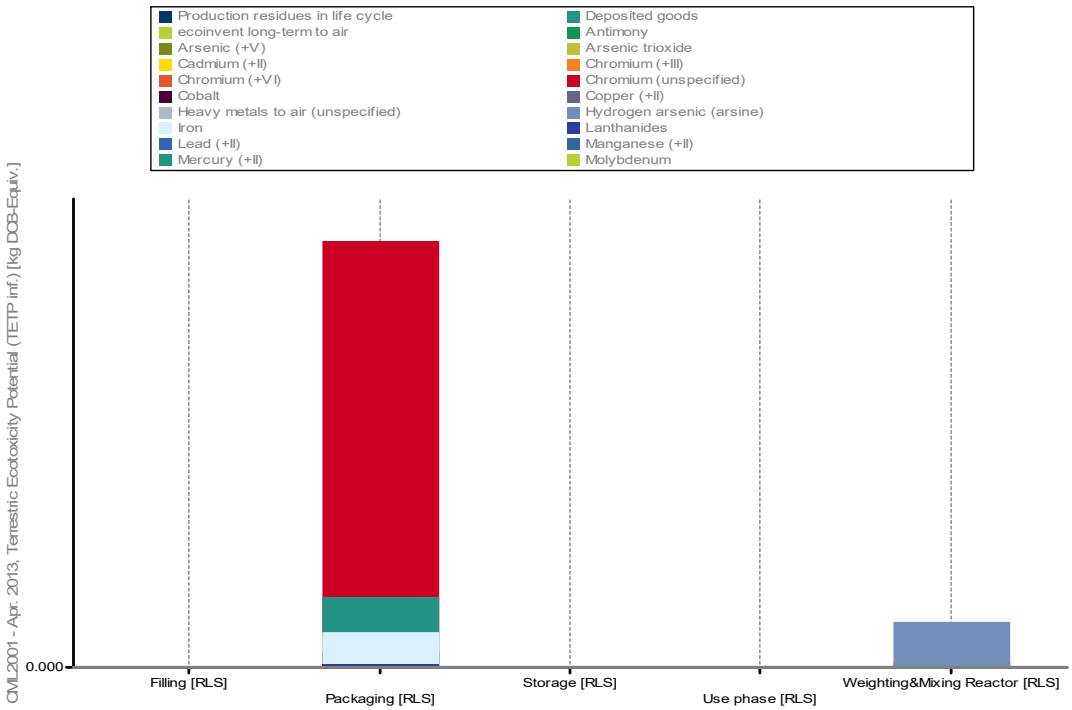
GaBi diagram: marine aquatic ecotox_LCA of Rosemary Liquid Soap - Inputs



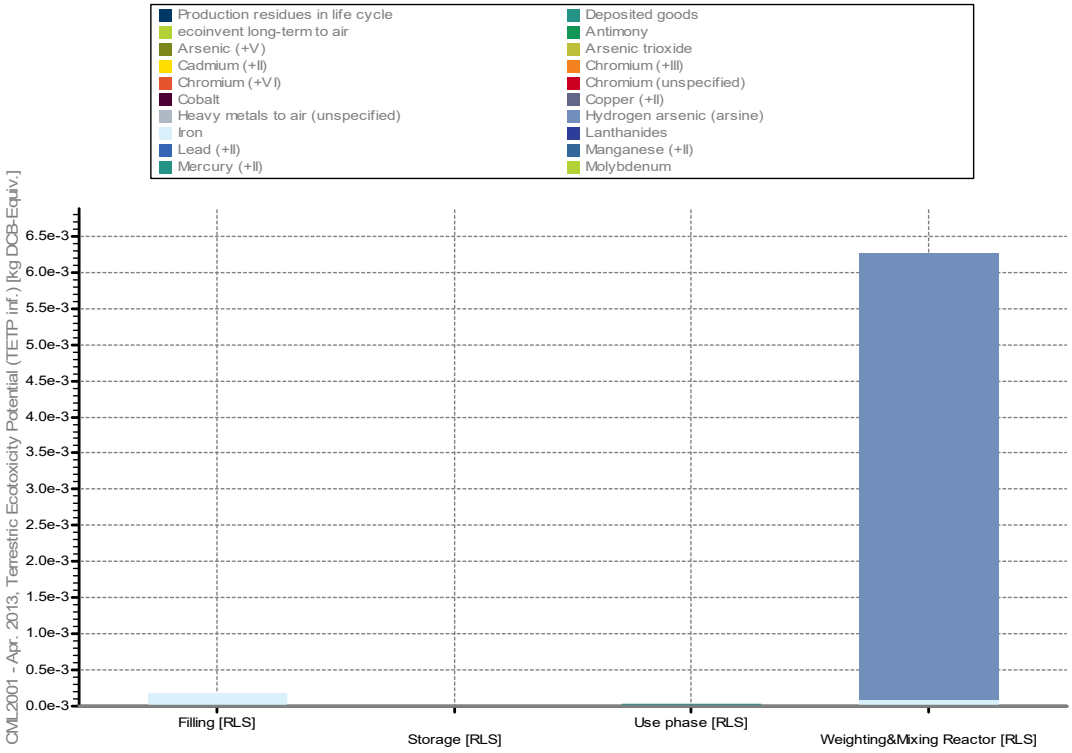
GaBi diagram: marine aquatic ecotox_LCA of Rosemary Liquid Soap - Inputs



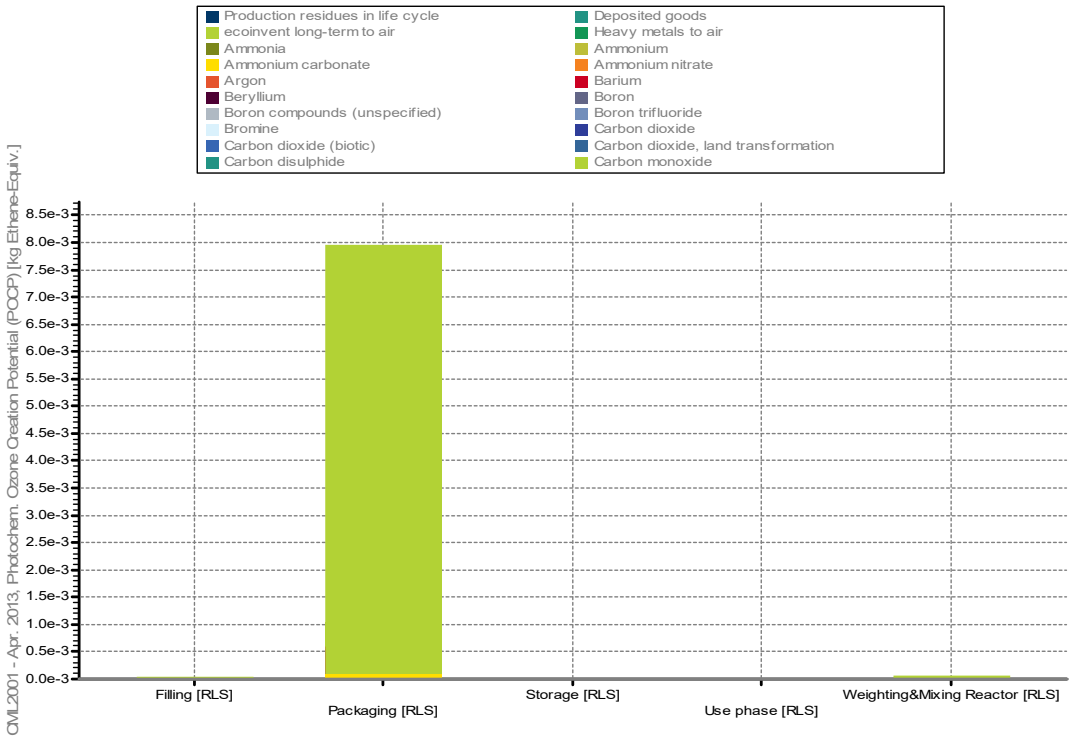
GaBi diagram:Terrestrial ecotox_LCA of Rosemary Liquid Soap - Inputs



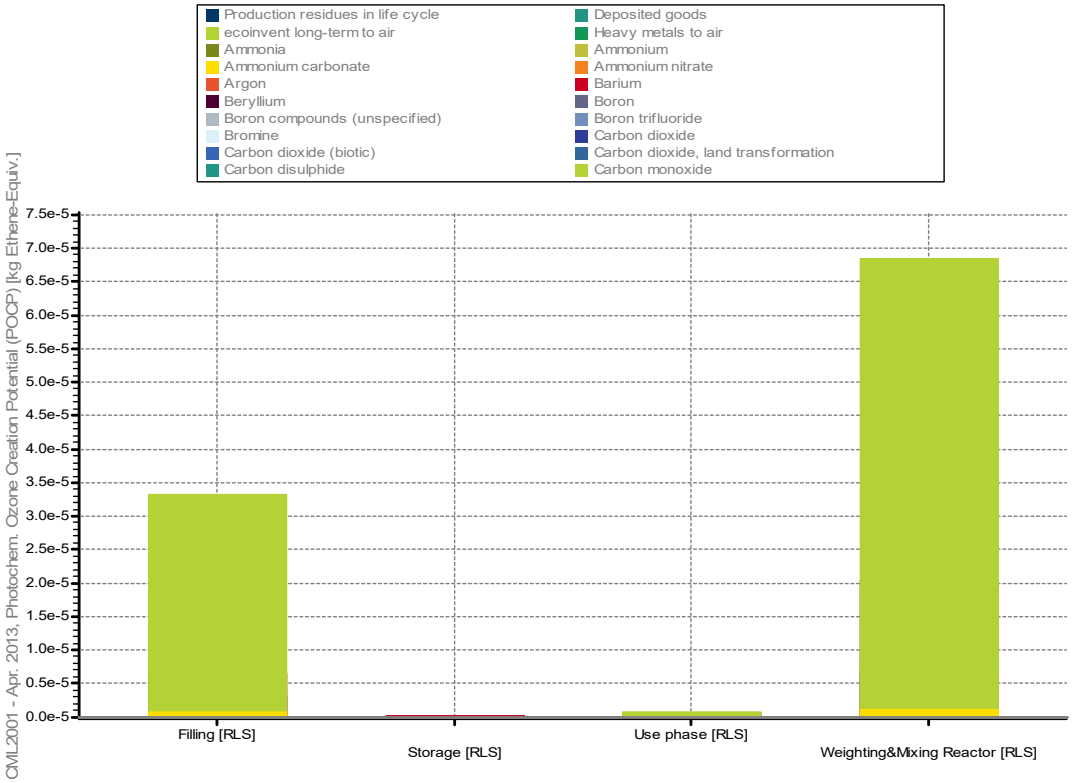
GaBi diagram:Terrestrial ecotox_LCA of Rosemary Liquid Soap - Inputs



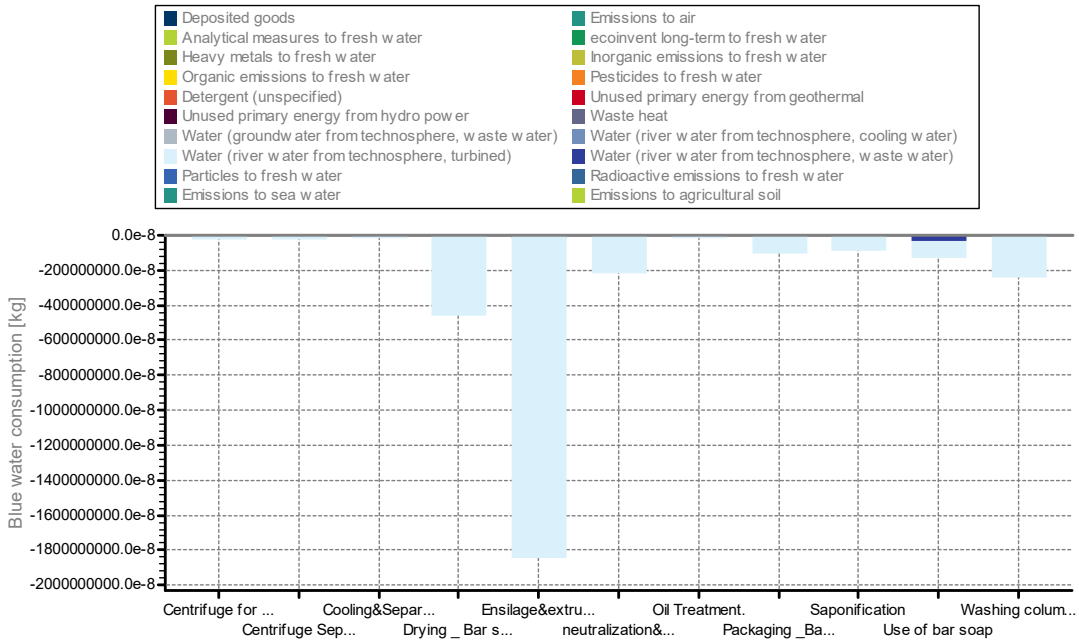
GaBi diagram:Photochemical ozone_LCA of Rosemary Liquid Soap - Inputs



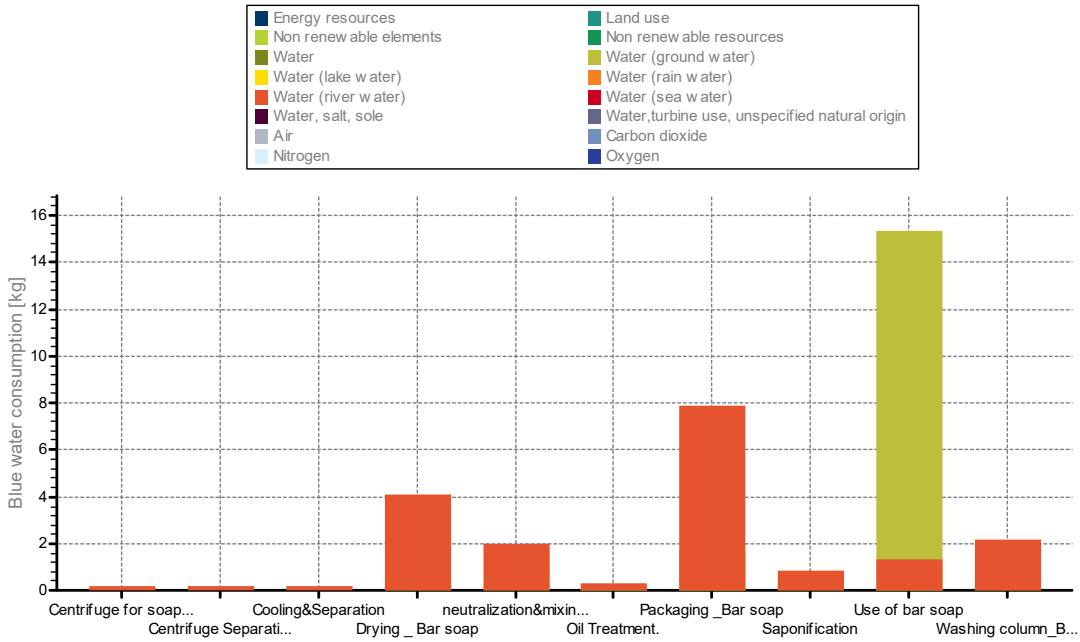
GaBi diagram:Photochemical ozone_LCA of Rosemary Liquid Soap - Inputs



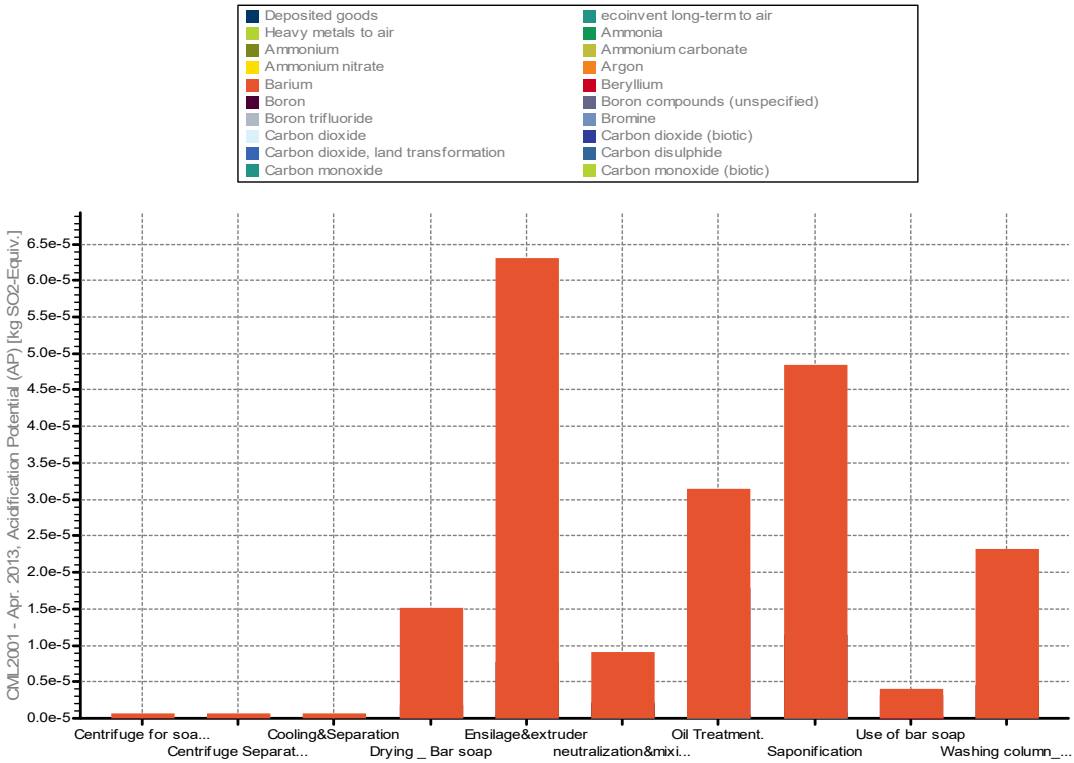
GaBi diagram:Water _ LCA of Bar Soap. - Inputs



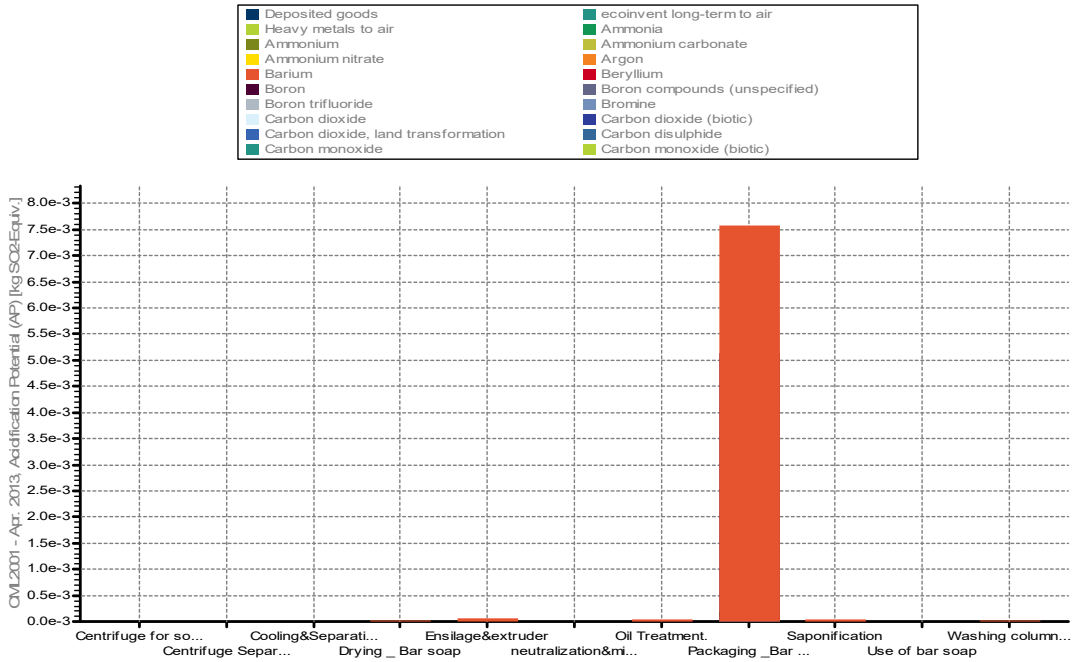
GaBi diagram:Water _ LCA of Bar Soap. - Inputs



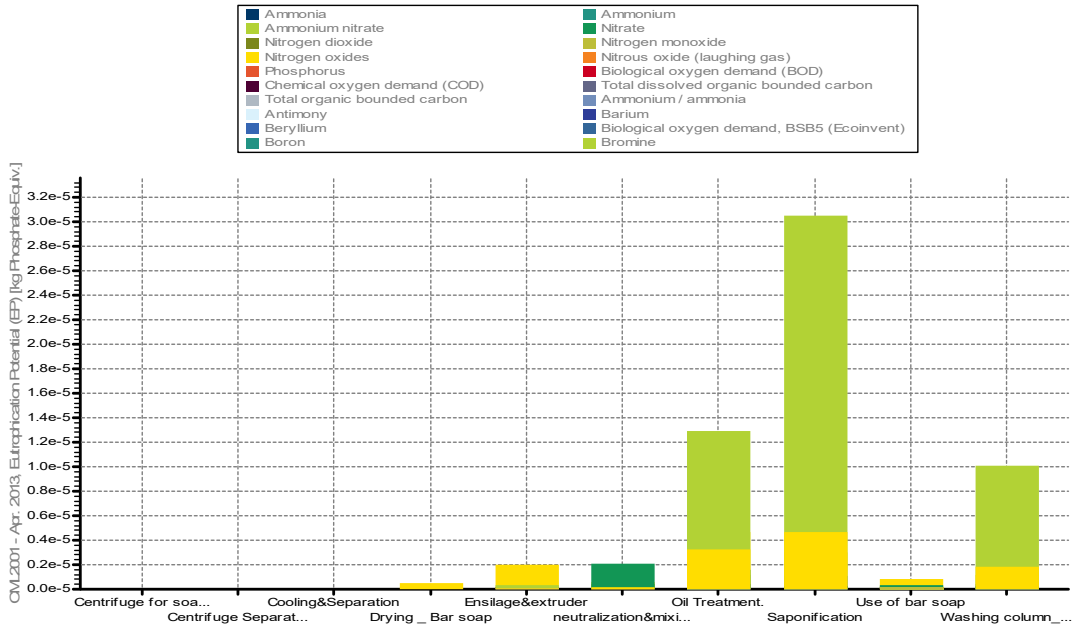
GaBi diagram:Acidification pot_LCA of Bar Soap. - Inputs



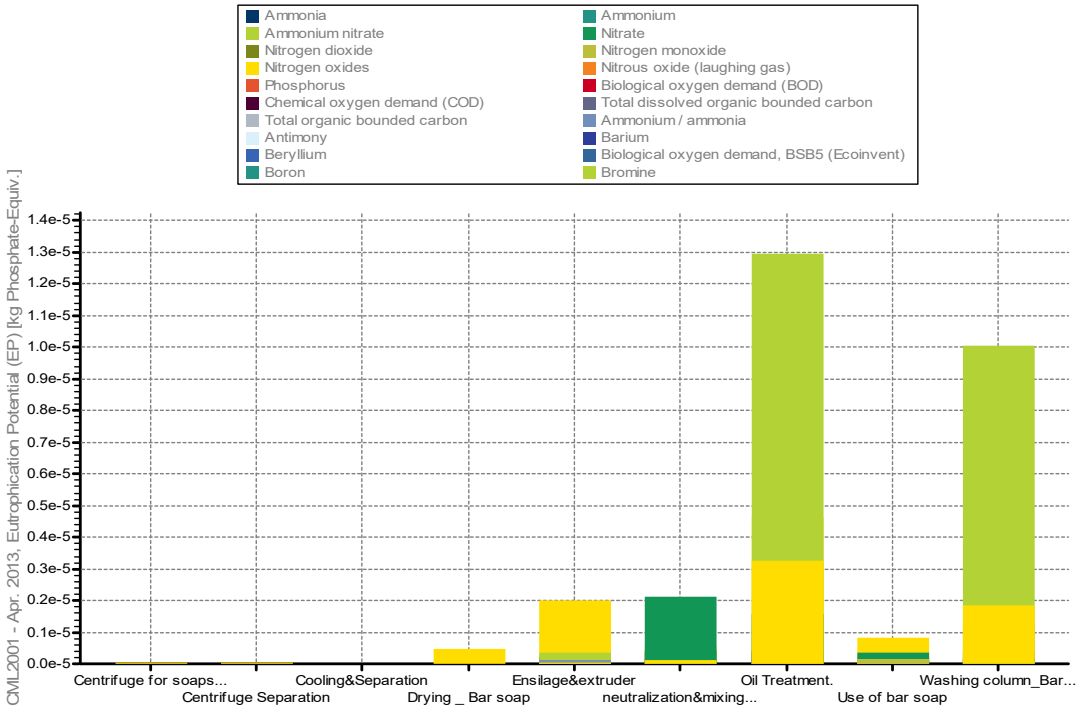
GaBi diagram:Acidification pot_LCA of Bar Soap. - Inputs



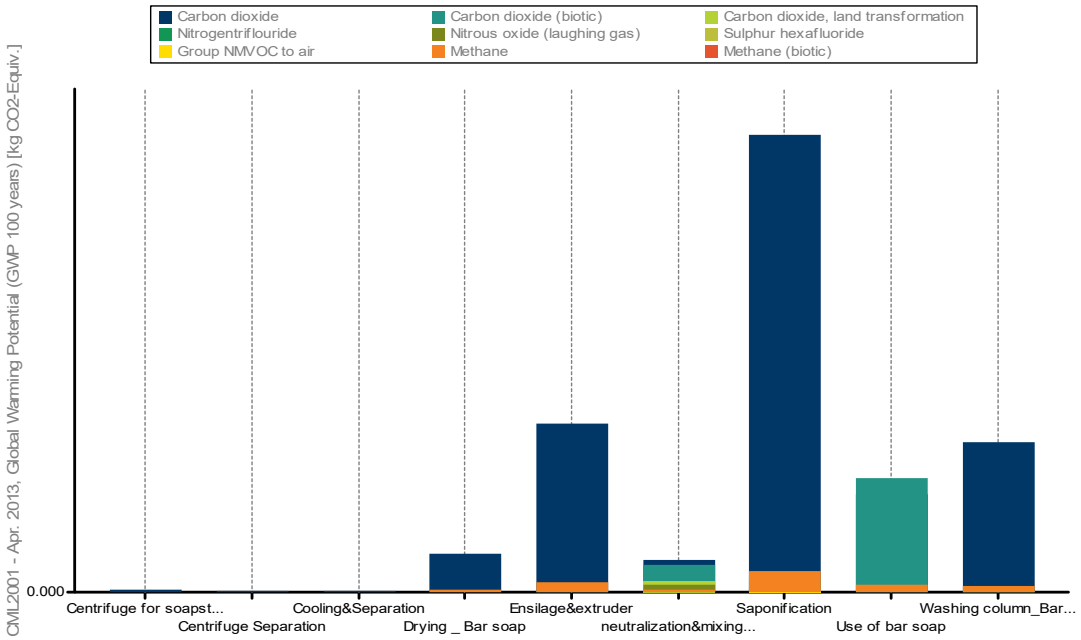
GaBi diagram:eutrophication pot_bar soap - Inputs



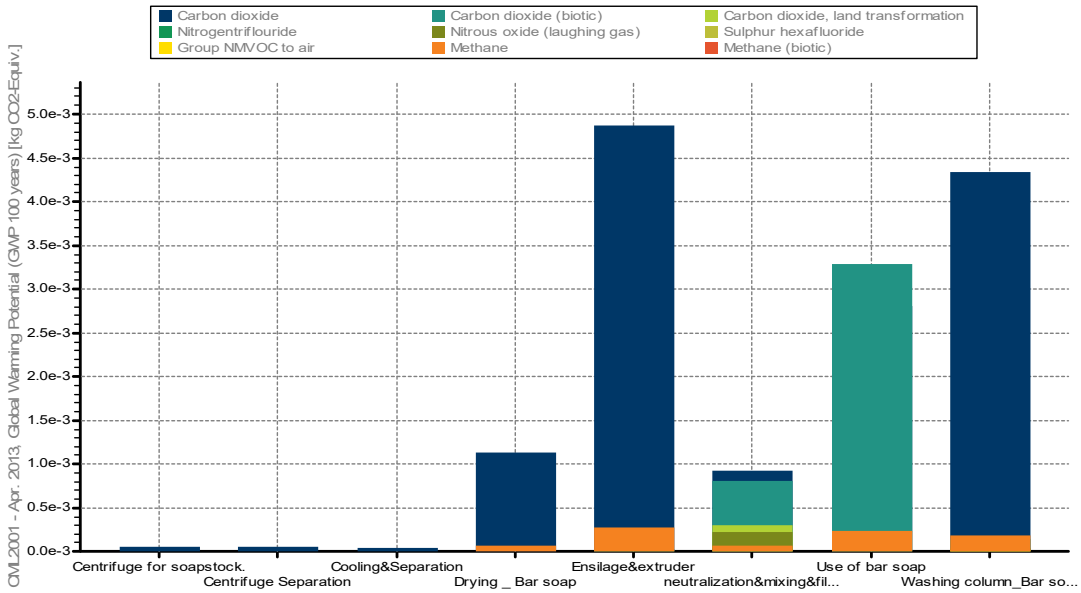
GaBi diagram:eutrophication pot_bar soap - Inputs



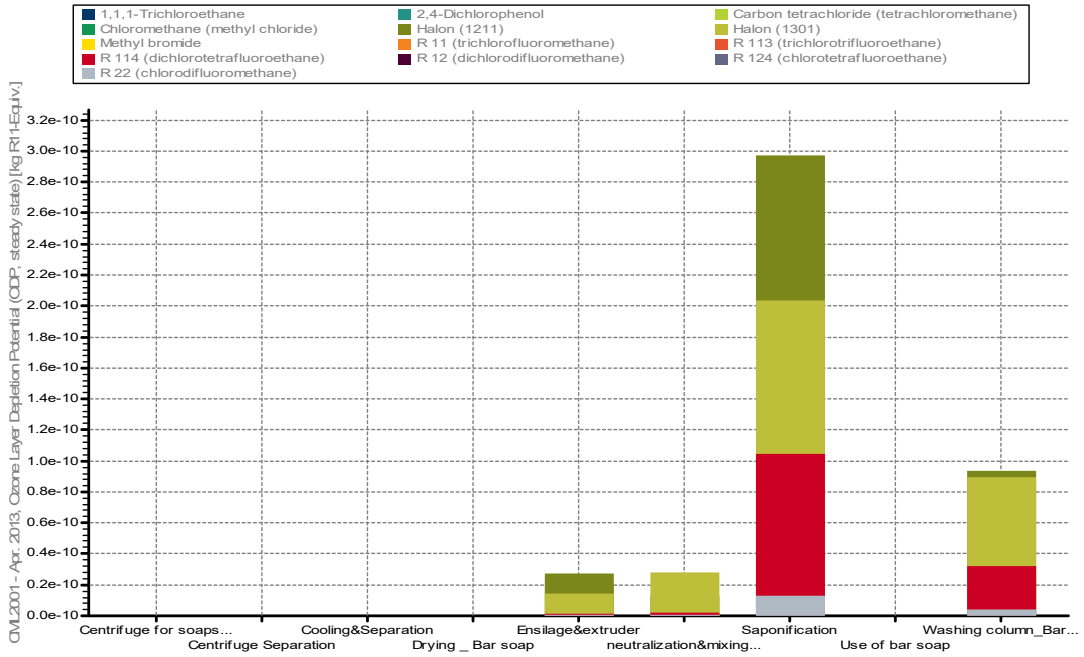
GaBi diagram: Global warming pot_bar soap - Inputs



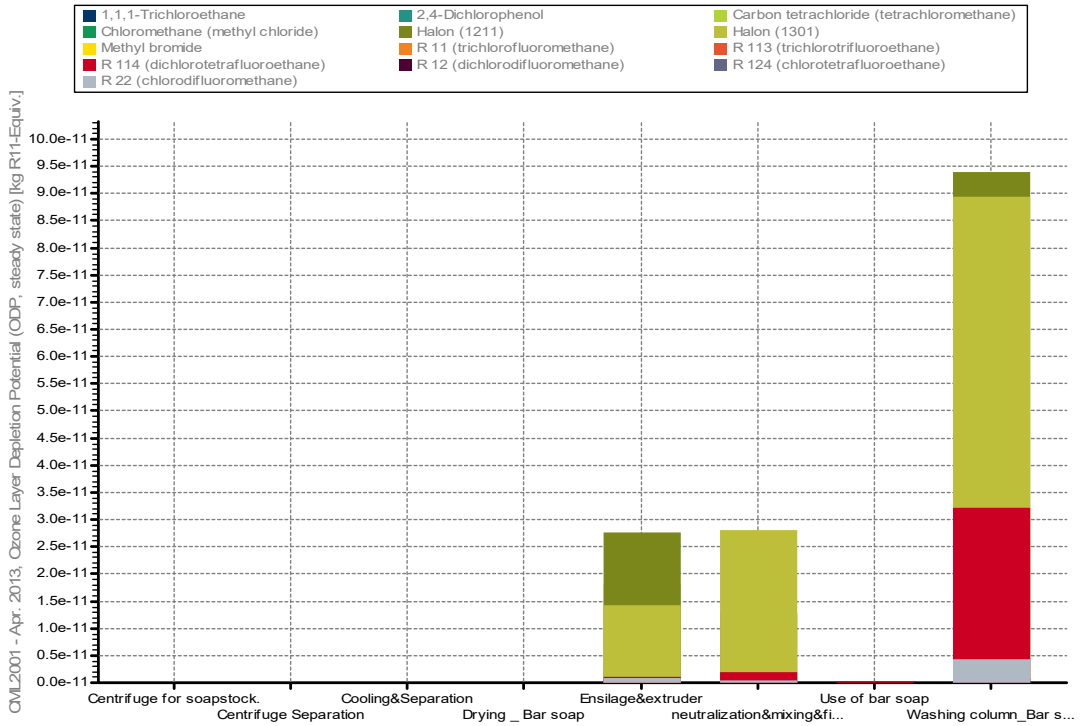
GaBi diagram: Global warming pot_bar soap - Inputs

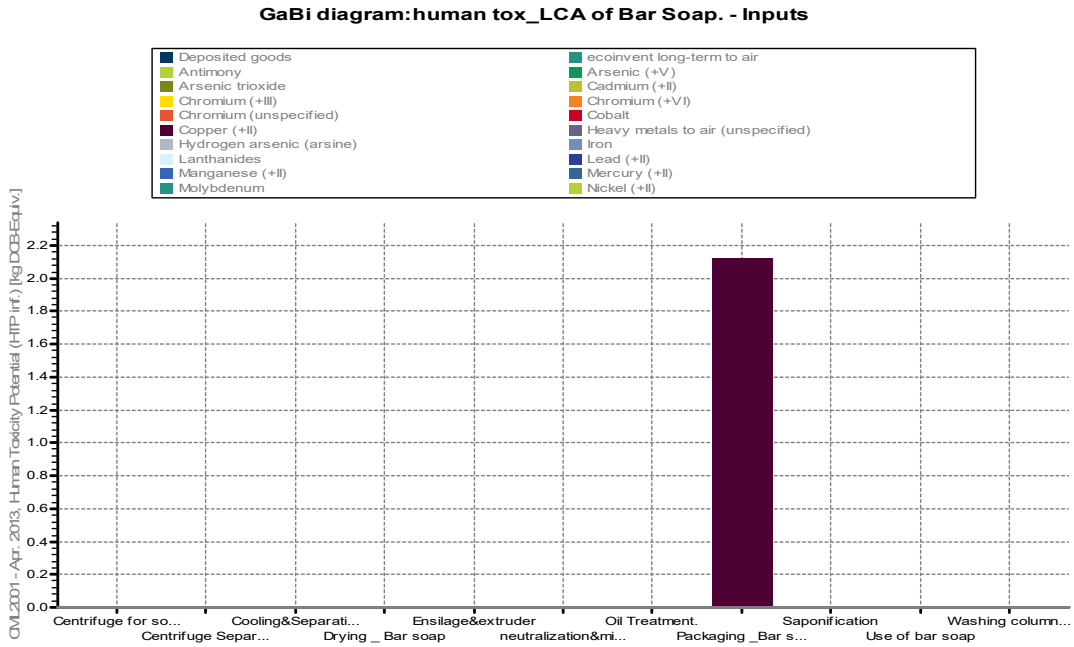


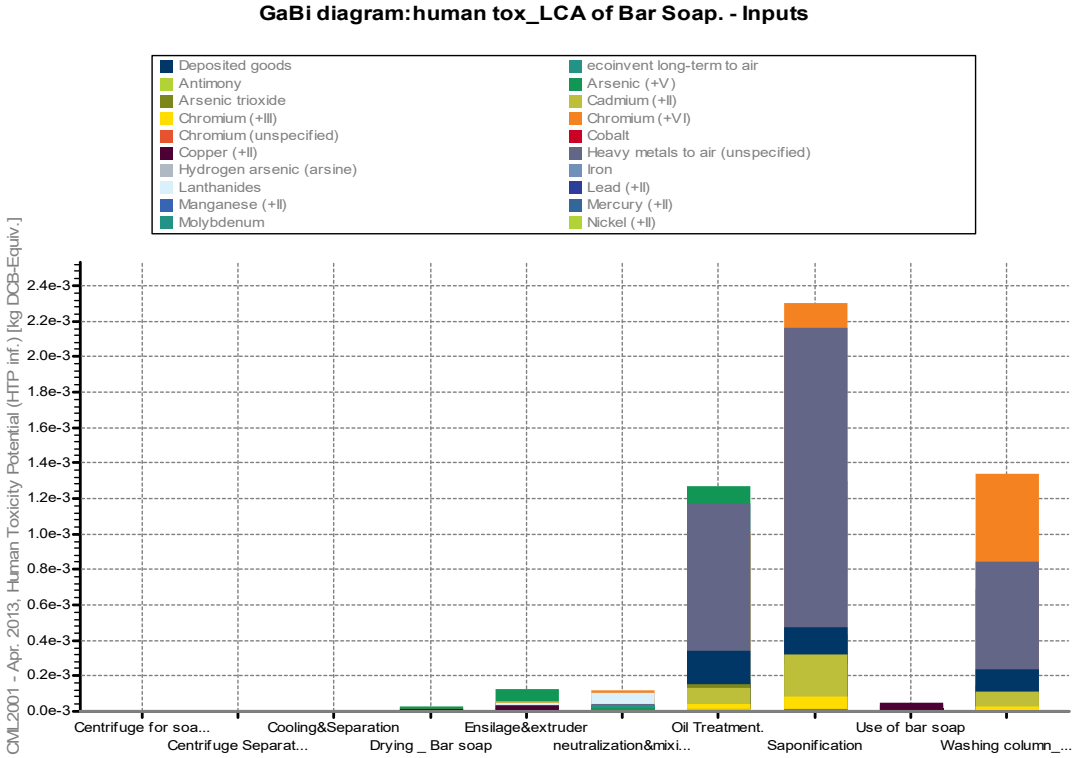
GaBi diagram:Ozone layer depl_bar soap - Inputs



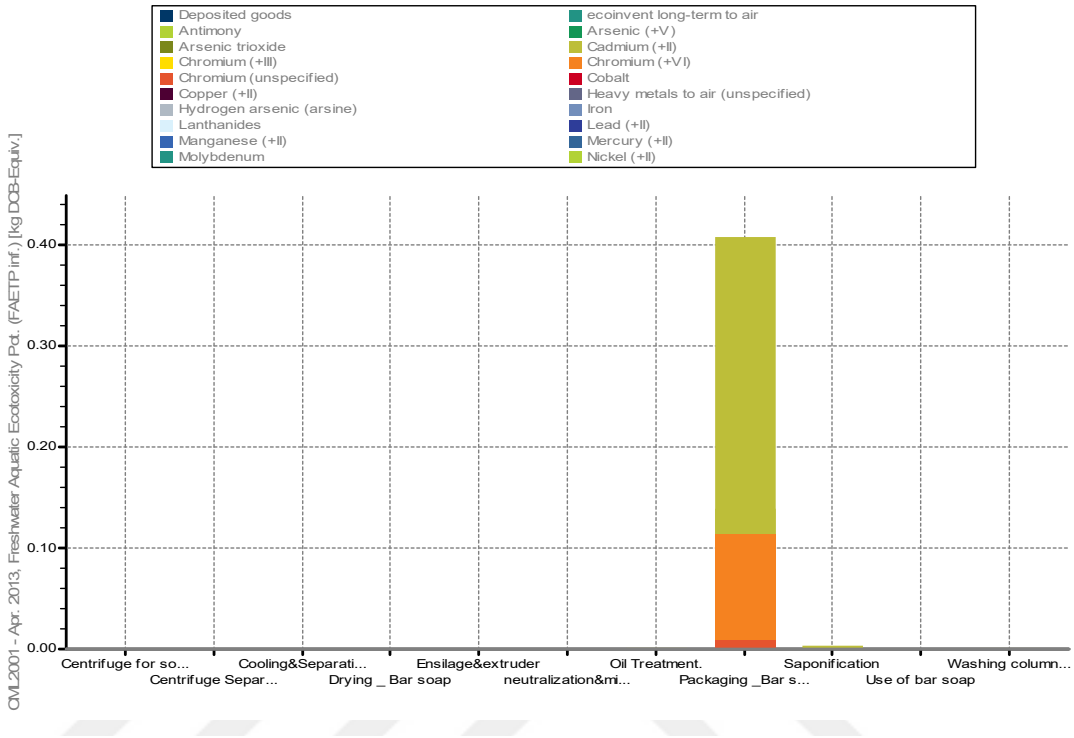
GaBi diagram:Ozone layer depl_bar soap - Inputs



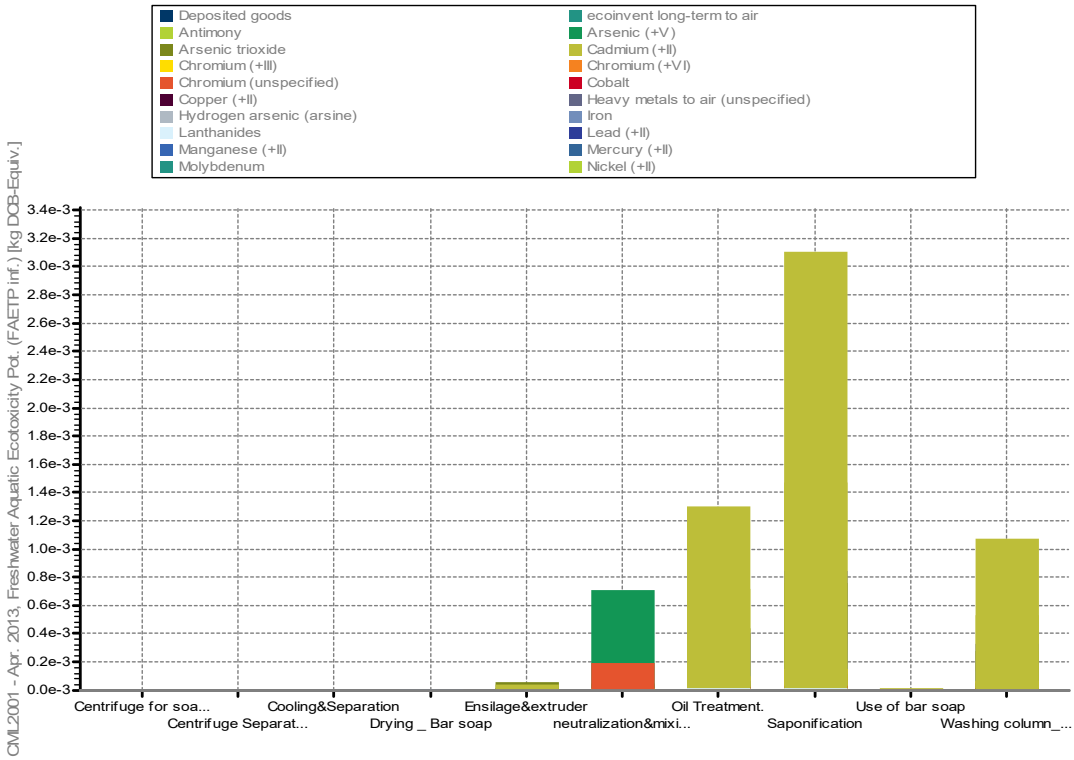

GaBi diagram:human tox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
GWL2001 - Apr. 2013, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Centrifuge for so...
Centrifuge Separ...
Cooling&Separati...
Drying _ Bar soap
Ensilage&extruder
neutralization&mi...
Oil Treatment.
Packaging _Bar s...
Saponification
Use of bar soap
Washing column...

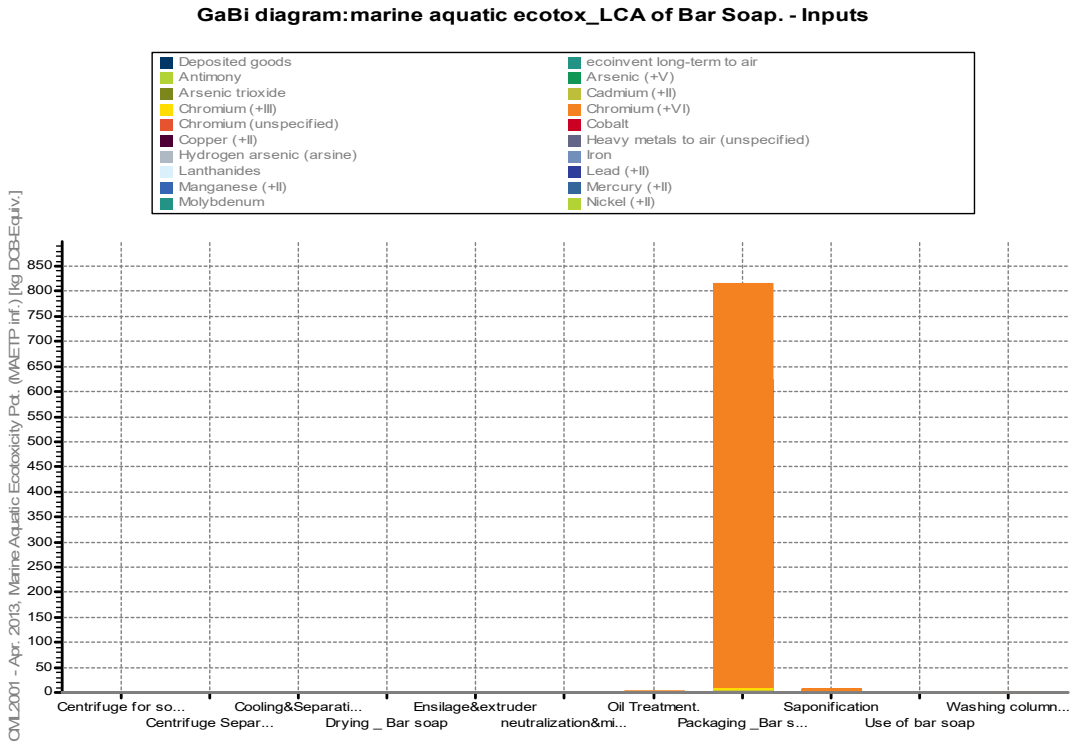

GaBi diagram:human tox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
GWL2001 - Apr. 2013, Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
2.4e-3
2.2e-3
2.0e-3
1.8e-3
1.6e-3
1.4e-3
1.2e-3
1.0e-3
0.8e-3
0.6e-3
0.4e-3
0.2e-3
0.0e-3
Centrifuge for soa...
Centrifuge Separat...
Cooling&Separation
Drying _ Bar soap
Ensilage&extruder
neutralization&mixi...
Oil Treatment.
Saponification
Use of bar soap
Washing column_...

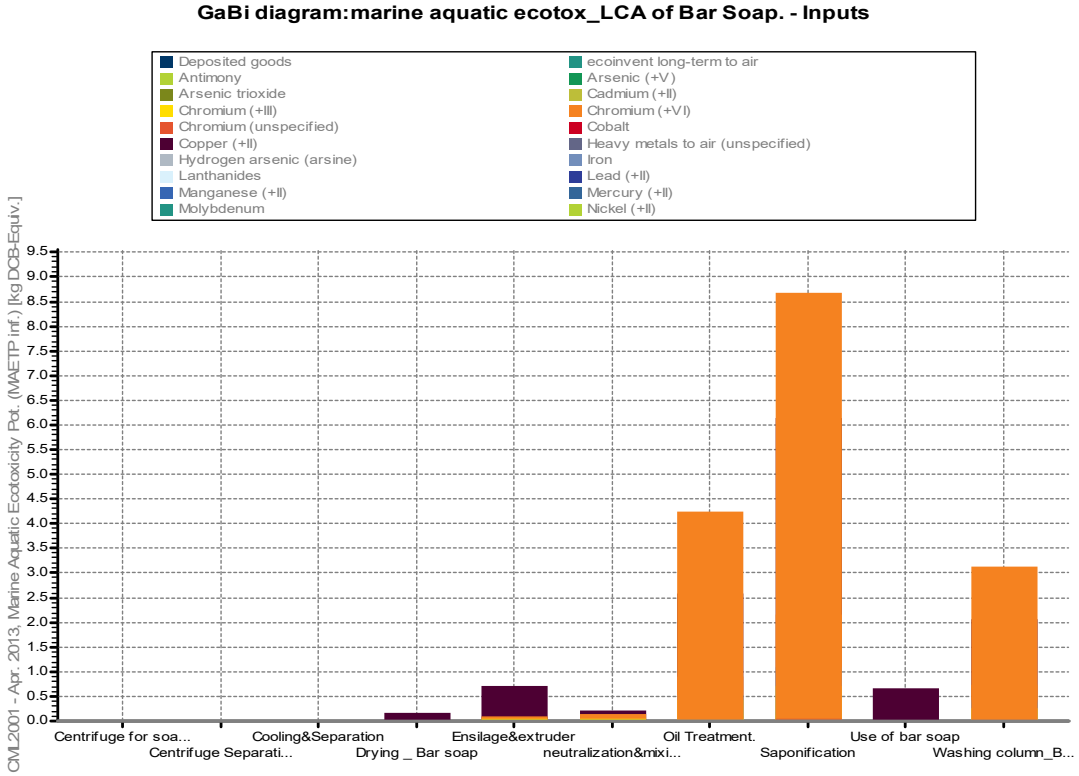
GaBi diagram:freshwater aquatic ecotox_LCA of Bar Soap. - Inputs

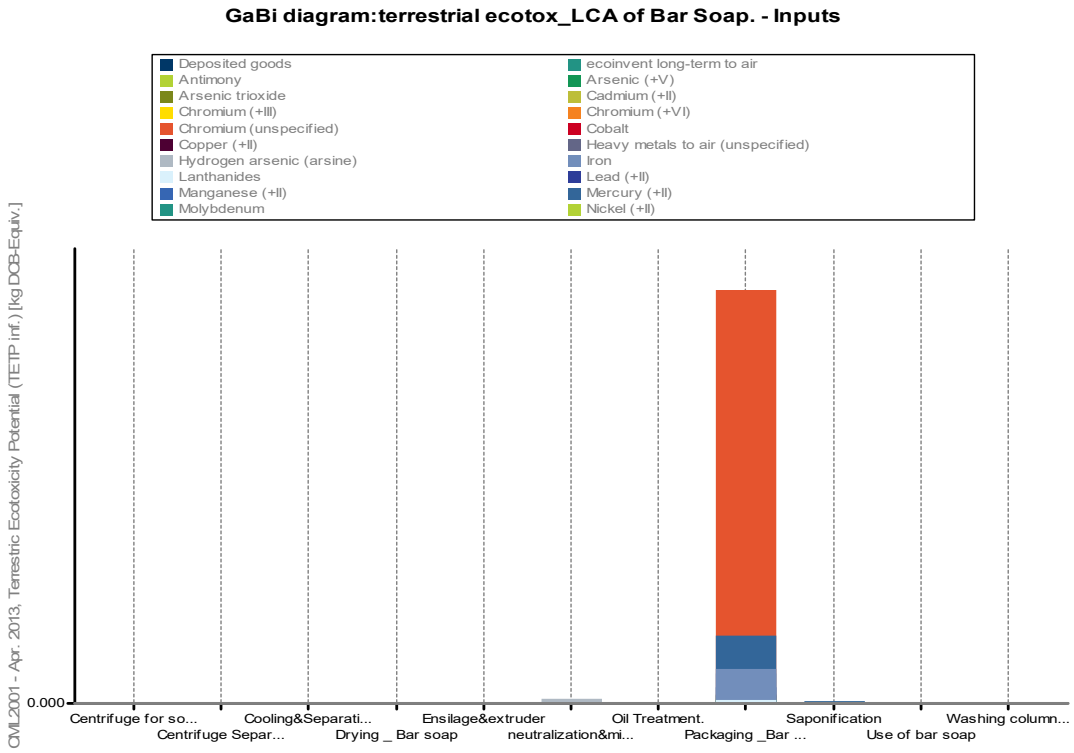


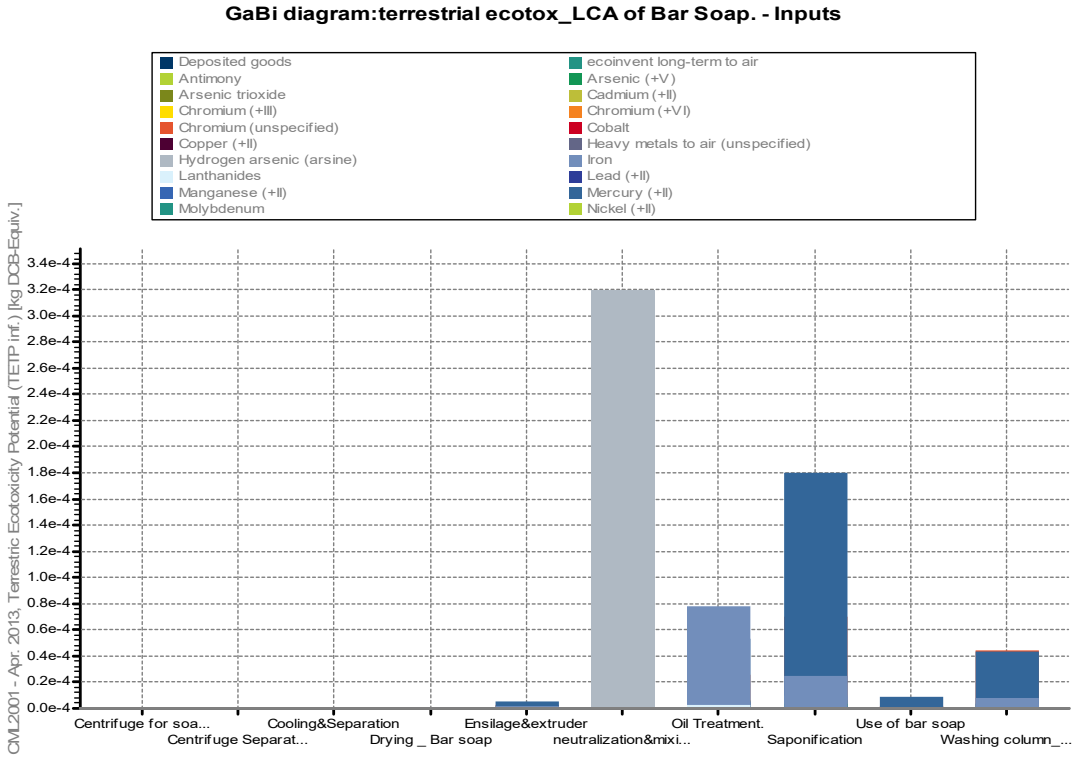
GaBi diagram:freshwater aquatic ecotox_LCA of Bar Soap. - Inputs

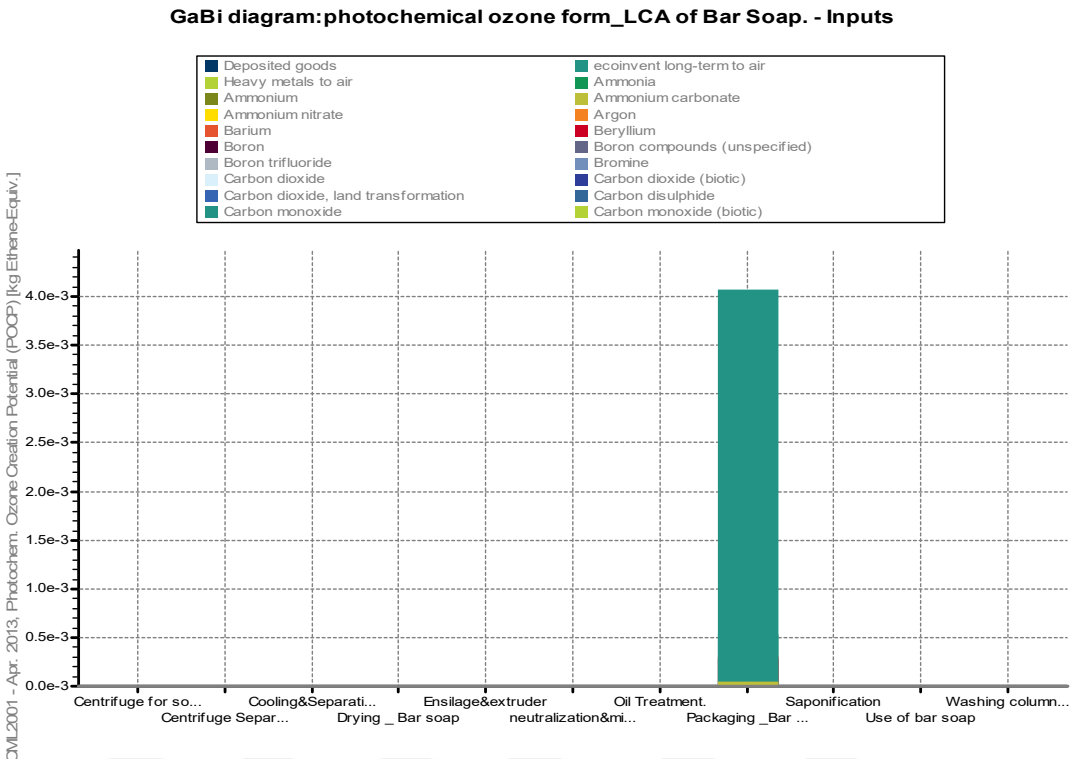


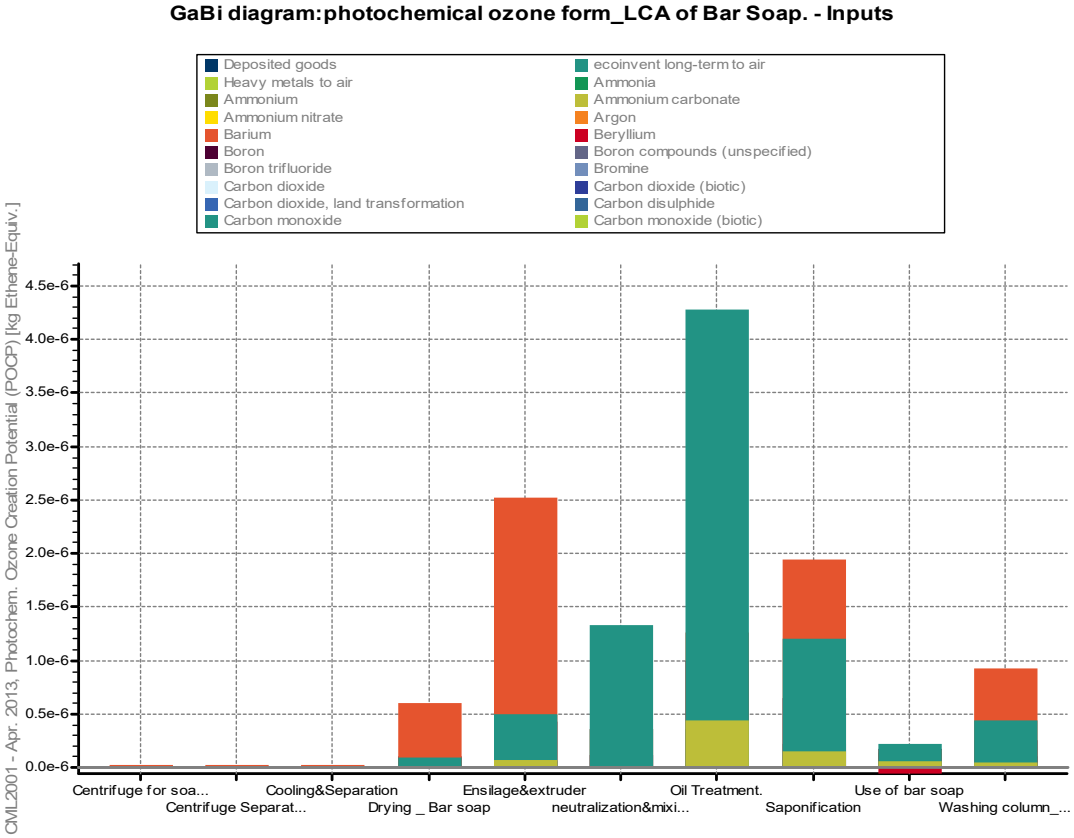

GaBi diagram:marine aquatic ecotox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
CML2001 - Apr. 2013, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
Centrifuge for so...
Centrifuge Separ...
Cooling&Separati...
Drying _ Bar soap
Ensilage&extruder
neutralization&mi...
Oil Treatment.
Packaging _Bar s...
Saponification
Use of bar soap
Washing column...


GaBi diagram:marine aquatic ecotox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
CML2001 - Apr. 2013, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
Centrifuge for soa...
Centrifuge Separati...
Cooling&Separation
Drying _ Bar soap
Ensilage&extruder
neutralization&mixi...
Oil Treatment.
Saponification
Use of bar soap
Washing column_B...

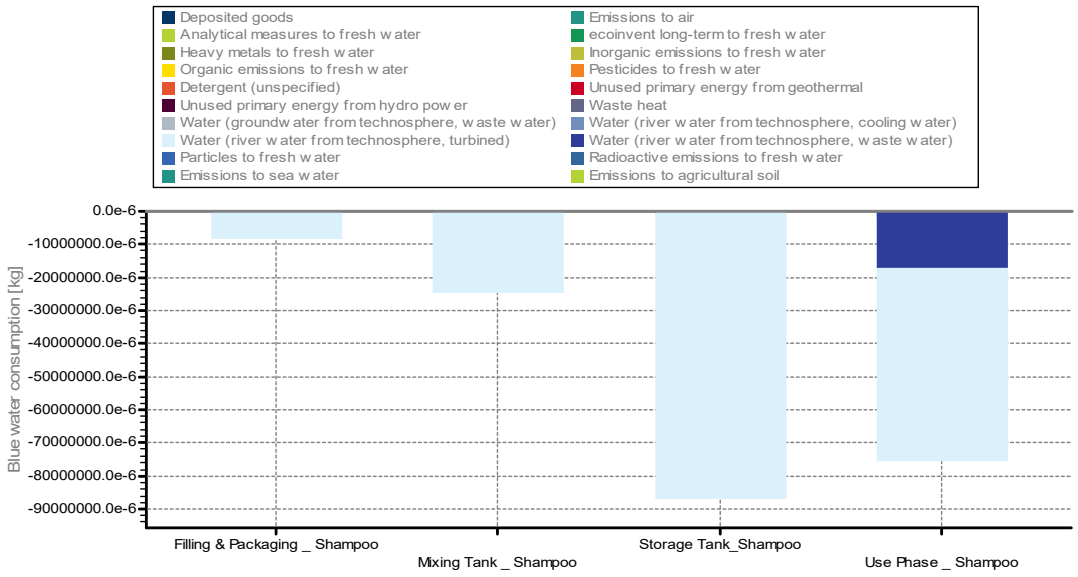

GaBi diagram:terrestrial ecotox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
CML2001 - Apr. 2013, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]
0.000
Centrifuge for so...
Centrifuge Separ...
Cooling&Separati...
Drying _ Bar soap
Ensilage&extruder
neutralization&mi...
Oil Treatment.
Packaging _Bar ...
Saponification
Use of bar soap
Washing column...


GaBi diagram:terrestrial ecotox_LCA of Bar Soap. - Inputs
Deposited goods
Antimony
Arsenic trioxide
Chromium (+III)
Chromium (unspecified)
Copper (+II)
Hydrogen arsenic (arsine)
Lanthanides
Manganese (+II)
Molybdenum
ecoinvent long-term to air
Arsenic (+V)
Cadmium (+II)
Chromium (+VI)
Cobalt
Heavy metals to air (unspecified)
Iron
Lead (+II)
Mercury (+II)
Nickel (+II)
CML2001 - Apr. 2013, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]
3.4e-4
3.2e-4
3.0e-4
2.8e-4
2.6e-4
2.4e-4
2.2e-4
2.0e-4
1.8e-4
1.6e-4
1.4e-4
1.2e-4
1.0e-4
0.8e-4
0.6e-4
0.4e-4
0.2e-4
0.0e-4
Centrifuge for soa...
Centrifuge Separat...
Cooling&Separation
Drying _ Bar soap
Ensilage&extruder
neutralization&mixi...
Oil Treatment.
Saponification
Use of bar soap
Washing column_...

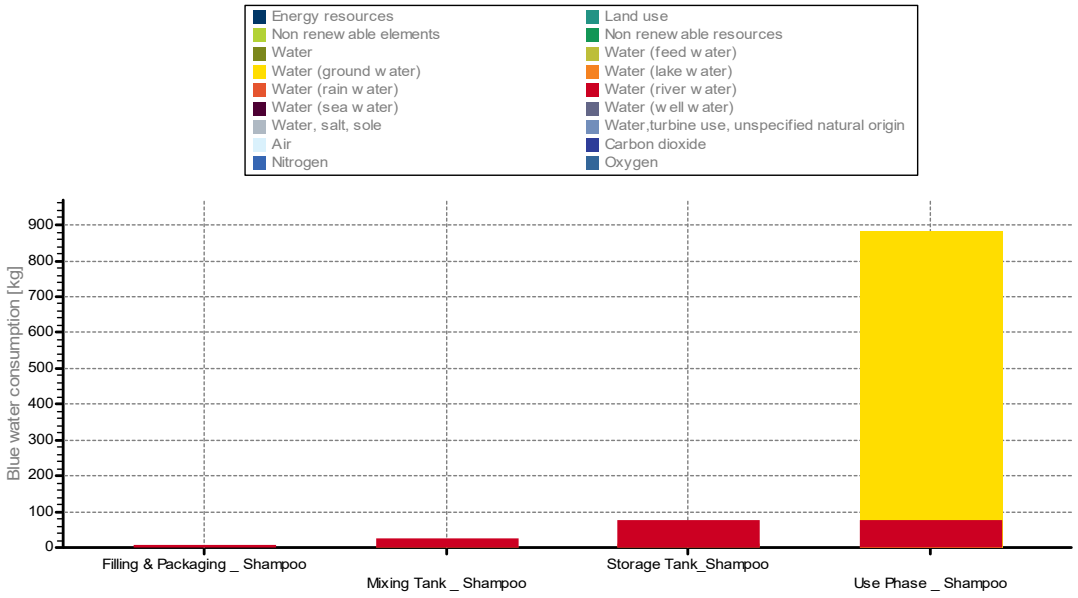

GaBi diagram:photochemical ozone form_LCA of Bar Soap. - Inputs
Deposited goods
Heavy metals to air
Ammonium
Ammonium nitrate
Barium
Boron
Boron trifluoride
Carbon dioxide
Carbon dioxide, land transformation
Carbon monoxide
ecoinvent long-term to air
Ammonia
Ammonium carbonate
Argon
Beryllium
Boron compounds (unspecified)
Bromine
Carbon dioxide (biotic)
Carbon disulphide
Carbon monoxide (biotic)
CML2001 - Apr. 2013, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
4.0e-3
3.5e-3
3.0e-3
2.5e-3
2.0e-3
1.5e-3
1.0e-3
0.5e-3
0.0e-3
Centrifuge for so...
Centrifuge Separ...
Cooling&Separati...
Drying _ Bar soap
Ensilage&extruder
neutralization&mi...
Oil Treatment.
Packaging _Bar ...
Saponification
Use of bar soap
Washing column...


GaBi diagram:photochemical ozone form_LCA of Bar Soap. - Inputs
Deposited goods
Heavy metals to air
Ammonium
Ammonium nitrate
Barium
Boron
Boron trifluoride
Carbon dioxide
Carbon dioxide, land transformation
Carbon monoxide
ecoinvent long-term to air
Ammonia
Ammonium carbonate
Argon
Beryllium
Boron compounds (unspecified)
Bromine
Carbon dioxide (biotic)
Carbon disulphide
Carbon monoxide (biotic)
CML2001 - Apr. 2013, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
4.5e-6
4.0e-6
3.5e-6
3.0e-6
2.5e-6
2.0e-6
1.5e-6
1.0e-6
0.5e-6
0.0e-6
Centrifuge for soa...
Centrifuge Separat...
Cooling&Separation
Drying _ Bar soap
Ensilage&extruder
neutralization&mixi...
Oil Treatment.
Saponification
Use of bar soap
Washing column_...

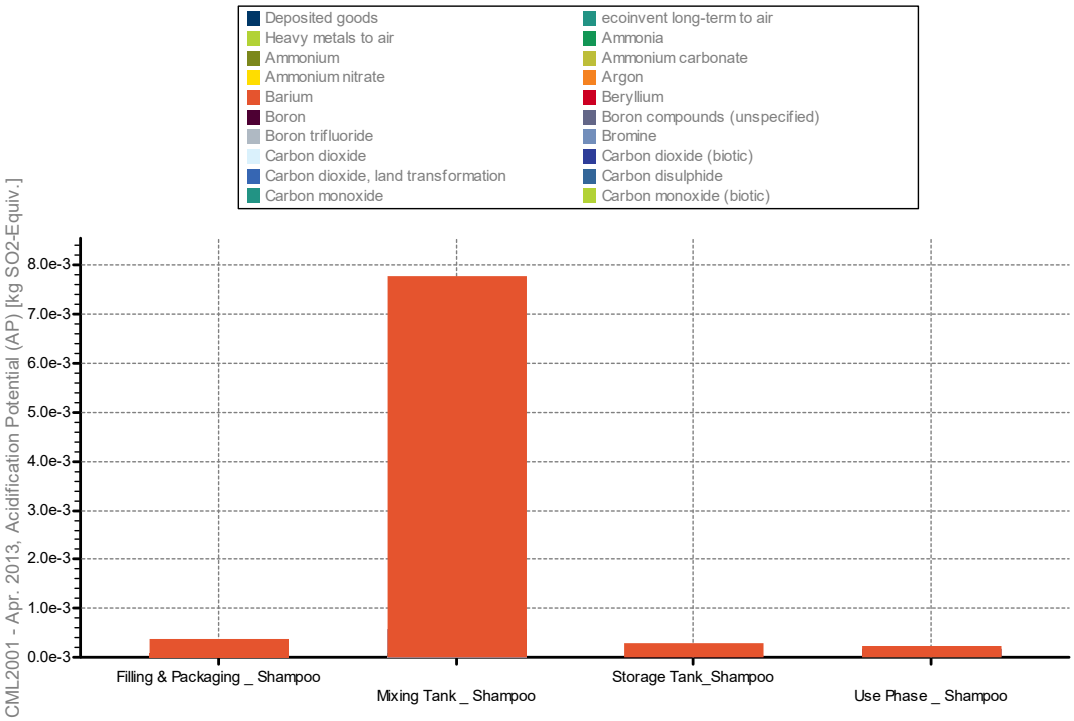
GaBi diagram:Water_LCA of Shampoo - Inputs



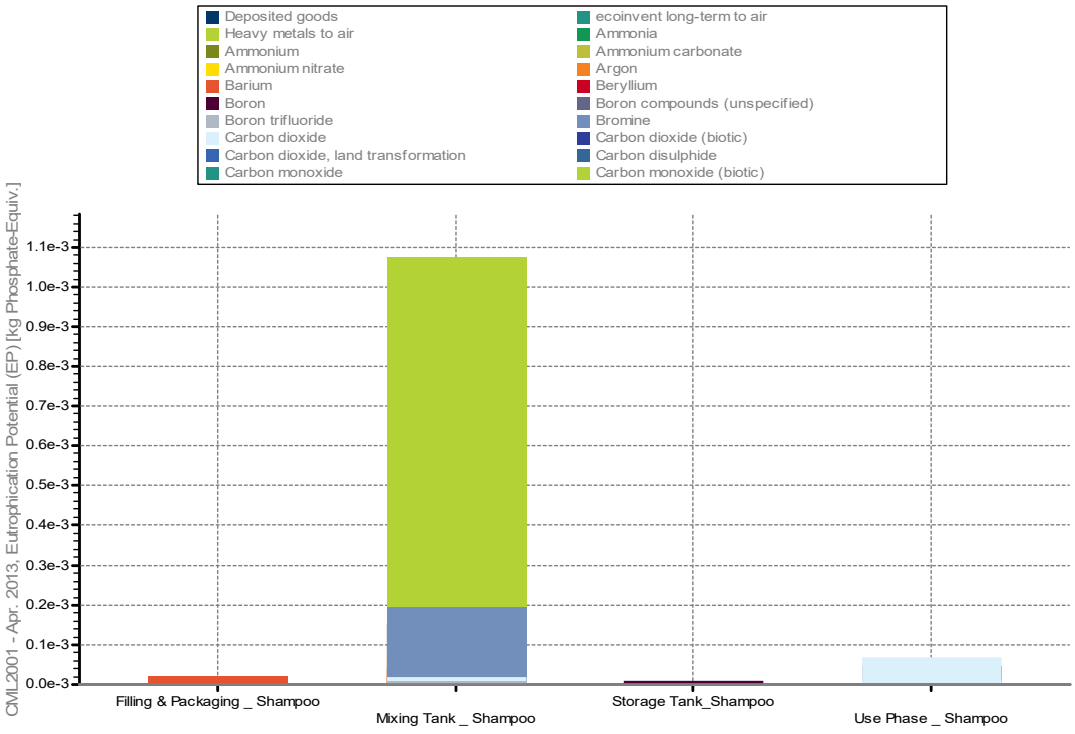
GaBi diagram:Water_LCA of Shampoo - Inputs



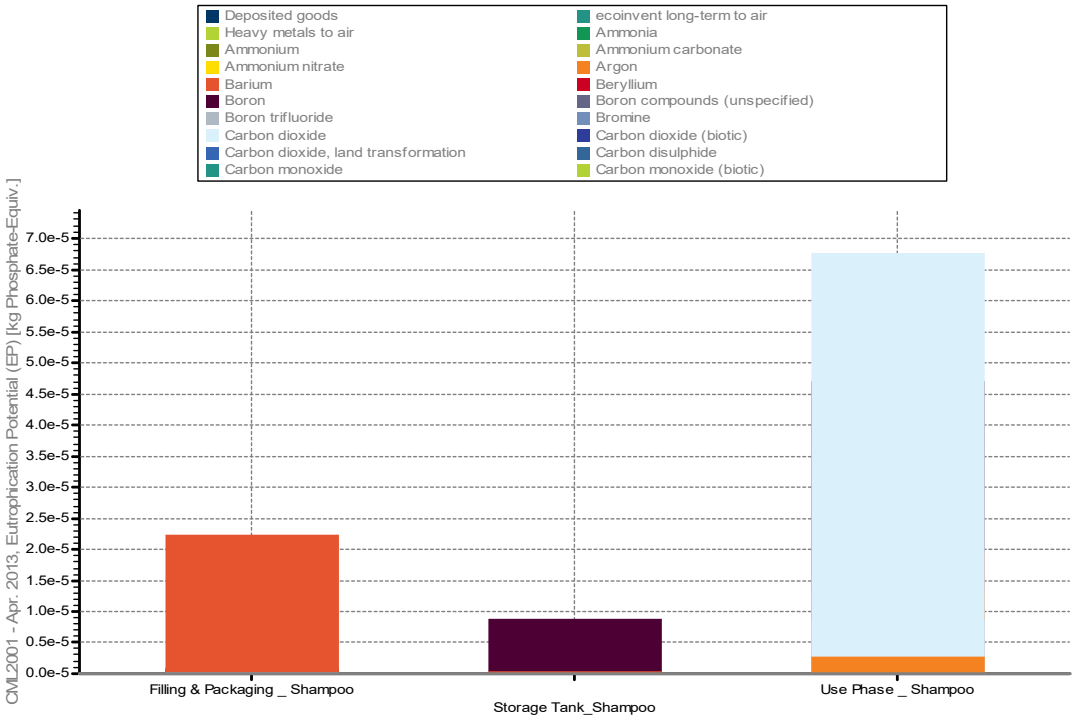
GaBi diagram:acidification pot_LCA of Shampoo - Inputs



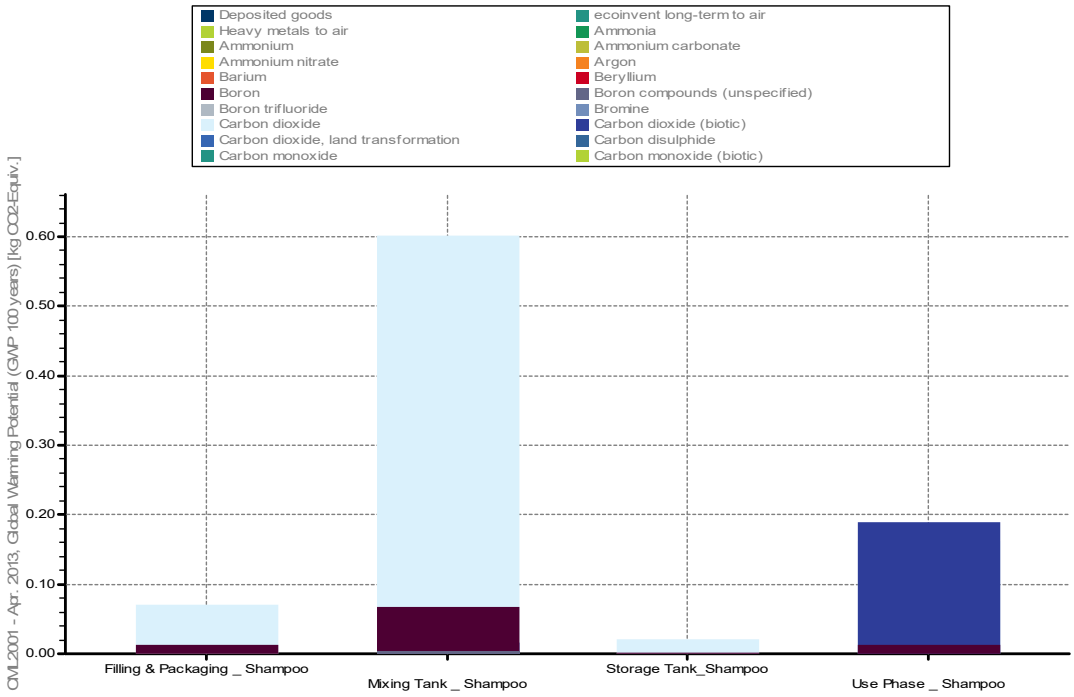
GaBi diagram:eutrophication pot_LCA of Shampoo - Inputs



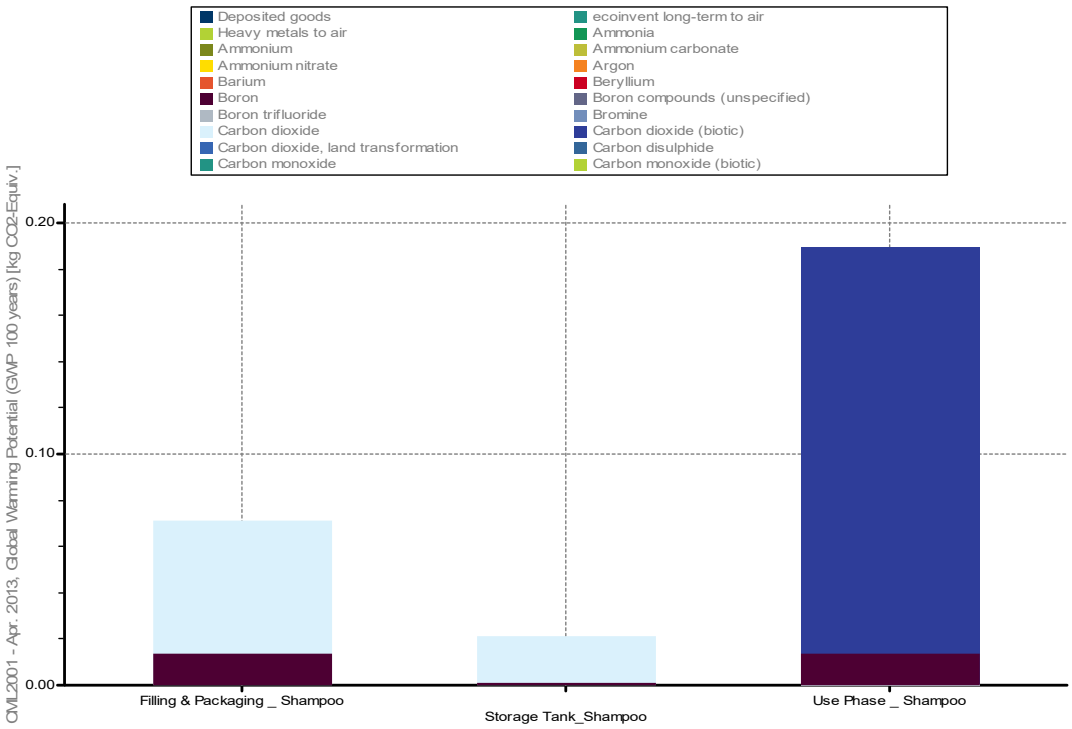
GaBi diagram:eutrophication pot_LCA of Shampoo - Inputs



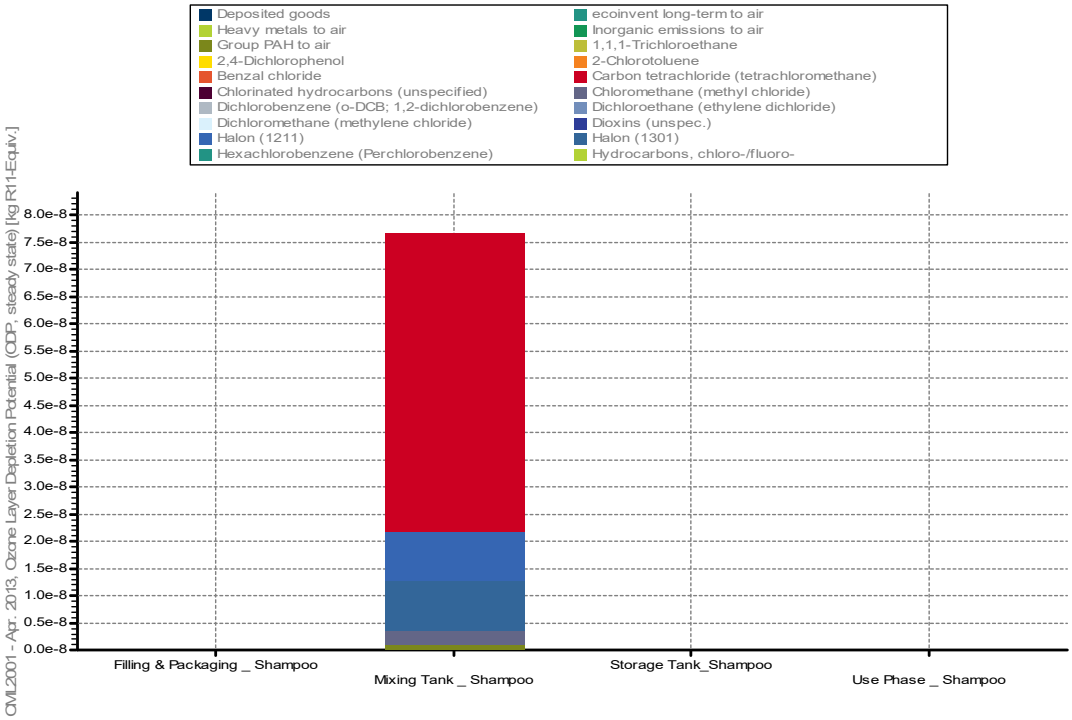
GaBi diagram:GWP_LCA of Shampoo - Inputs



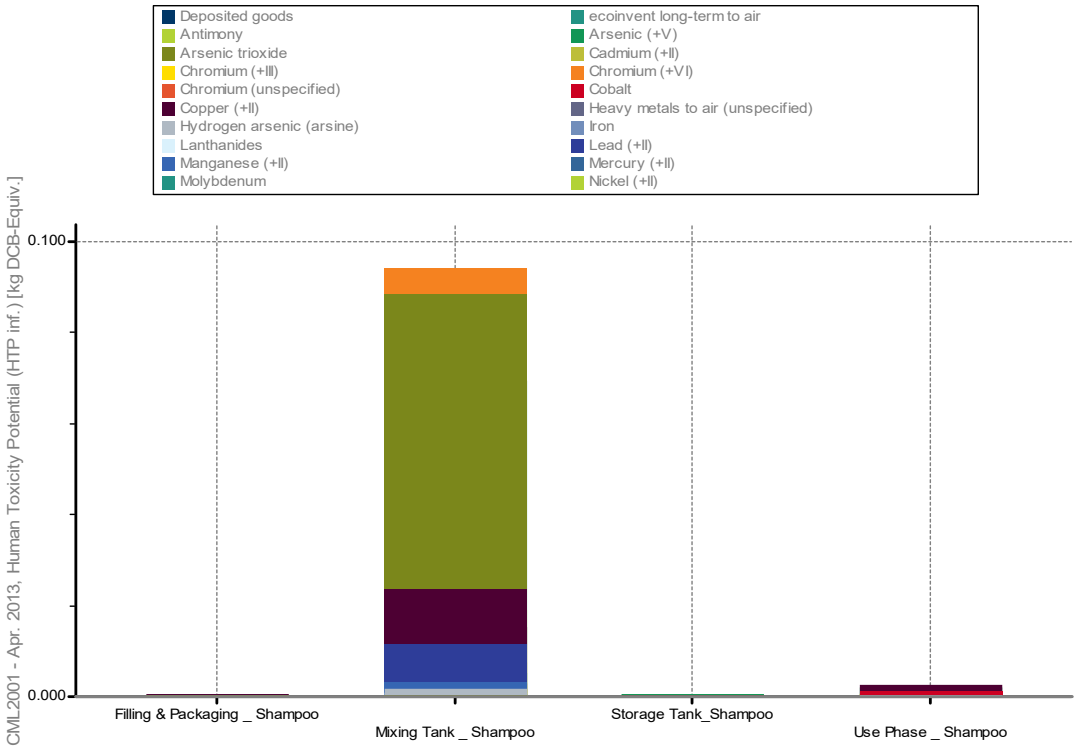
GaBi diagram:GWP_LCA of Shampoo - Inputs



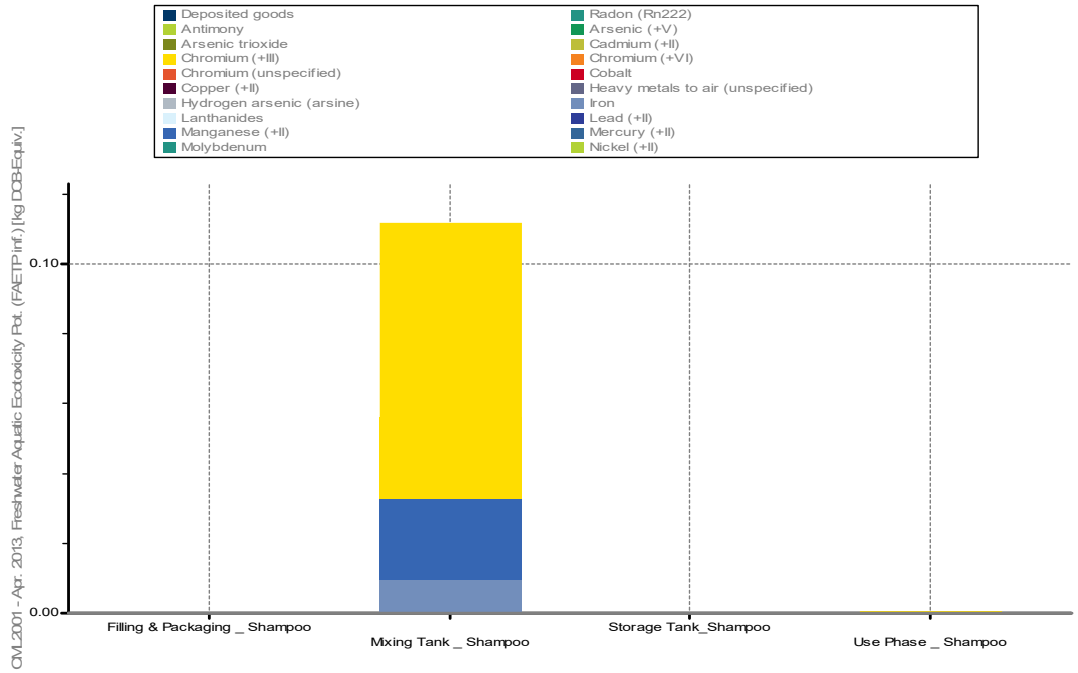
GaBi diagram:ozone layer depl_LCA of Shampoo - Inputs



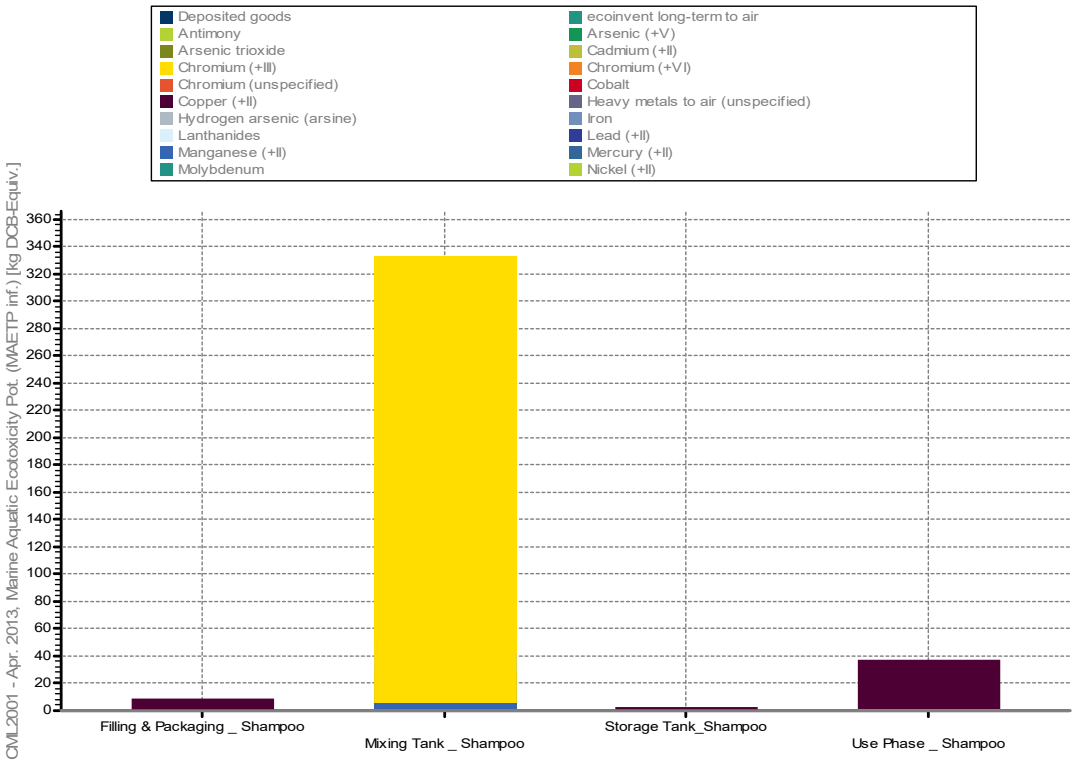
GaBi diagram:human tox_LCA of Shampoo - Inputs



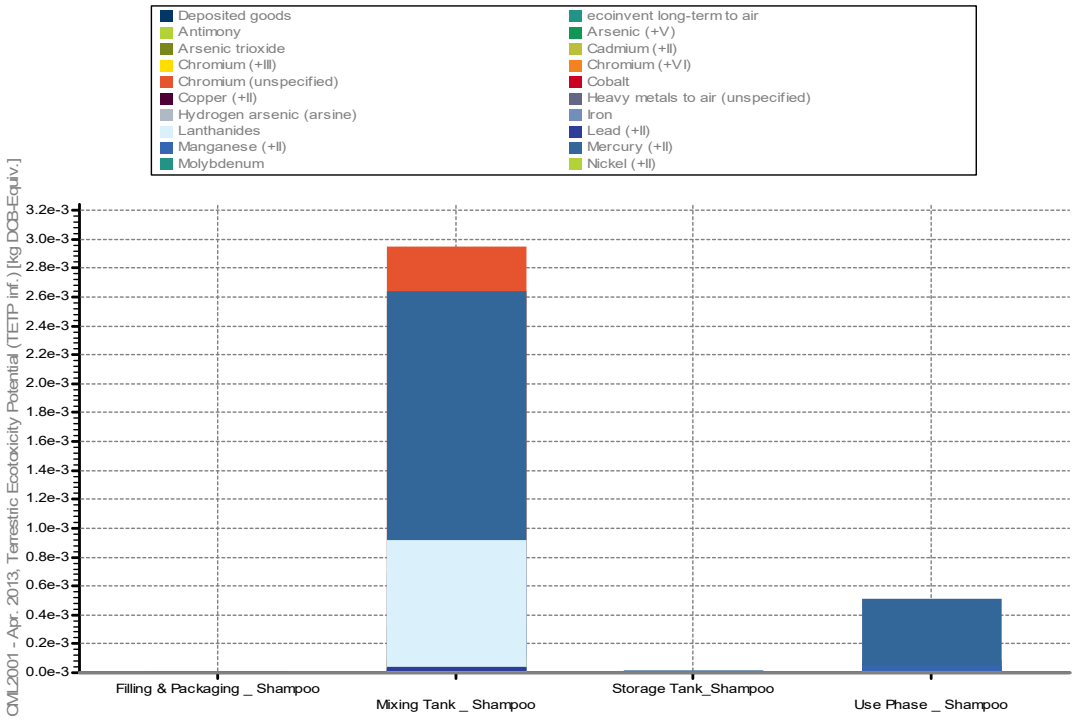
GaBi diagram:freshwater aquatic ecotox_LCA of Shampoo - Inputs



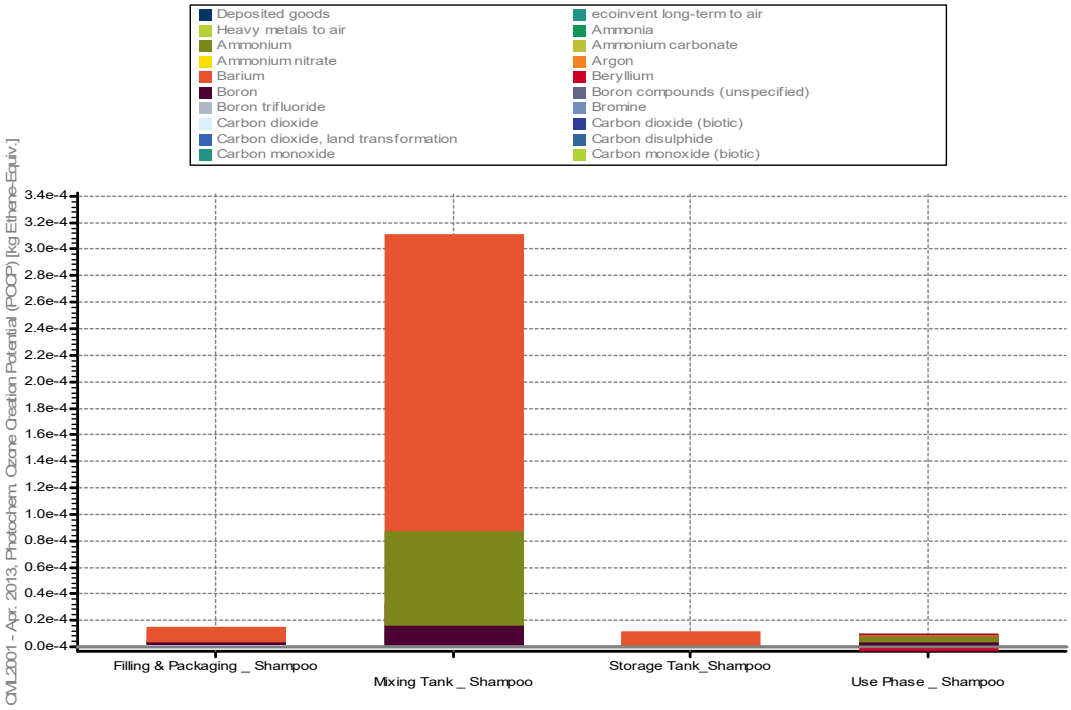
GaBi diagram:marine aquatic ecotox_LCA of Shampoo - Inputs



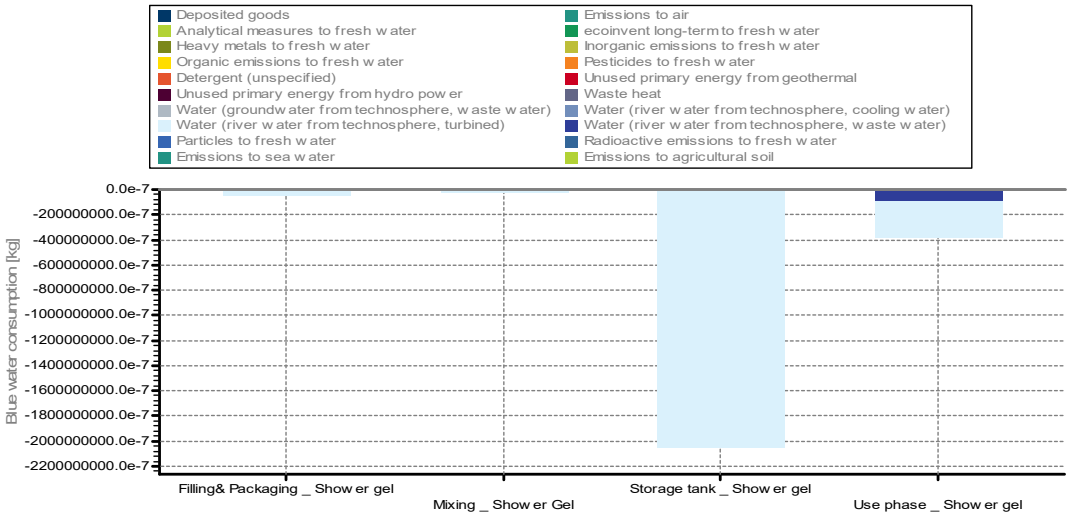
GaBi diagram:terrestrial ecotox_LCA of Shampoo - Inputs



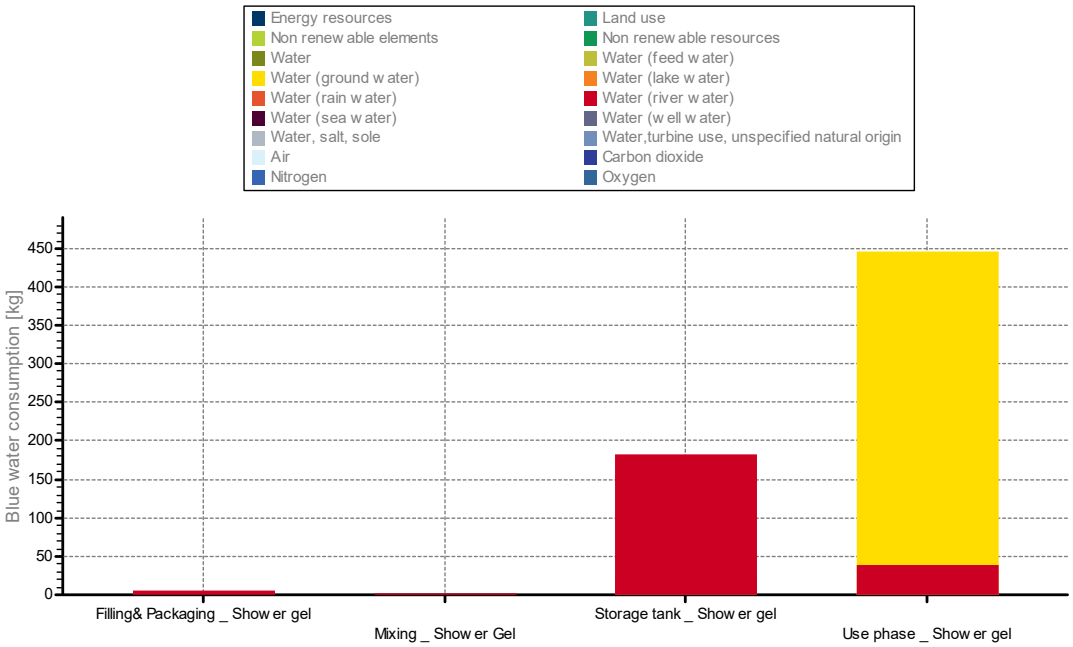
GaBi diagram:photochemical ozone_LCA of Shampoo - Inputs



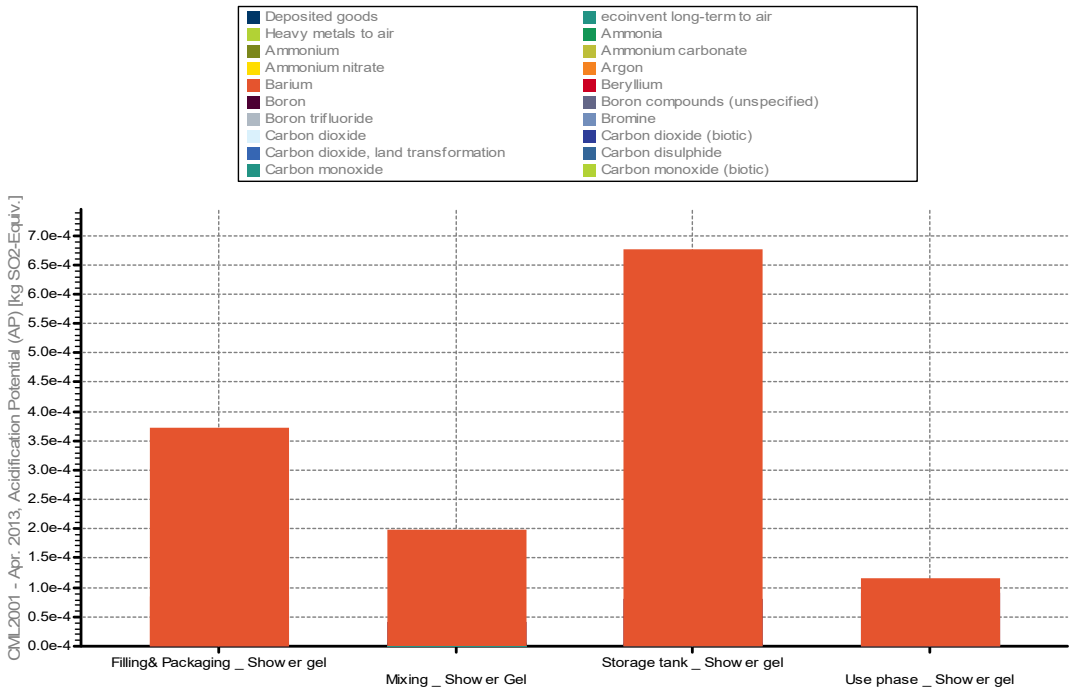
GaBi diagram:water_LCA of Shower Gel - Inputs



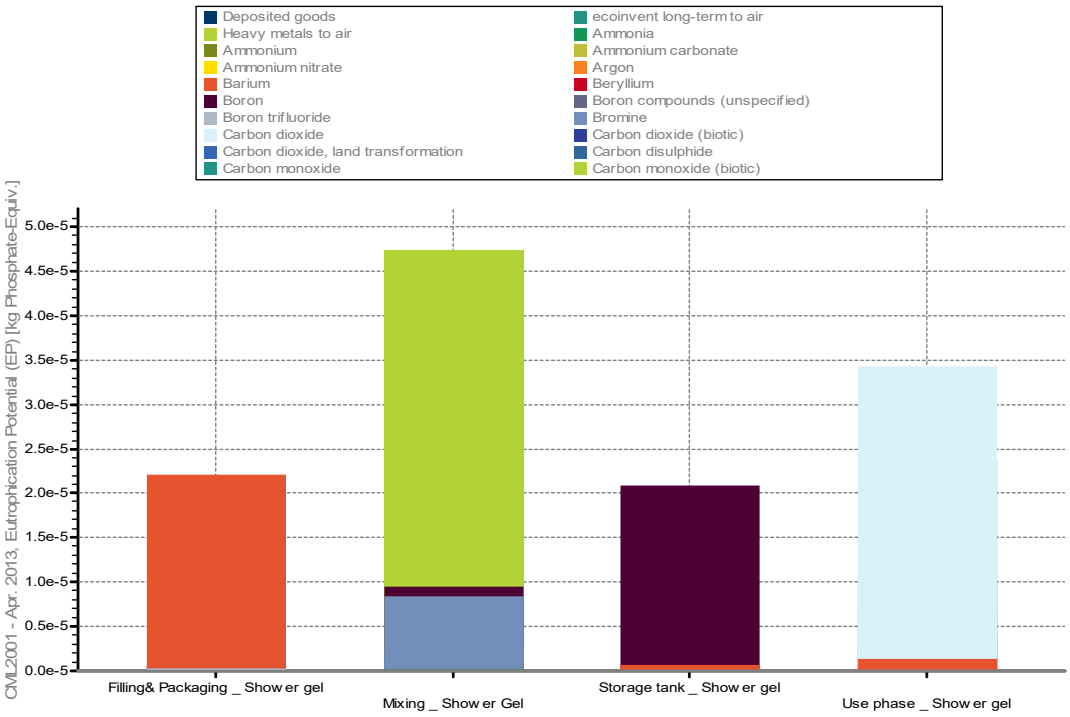
GaBi diagram:water_LCA of Shower Gel - Inputs



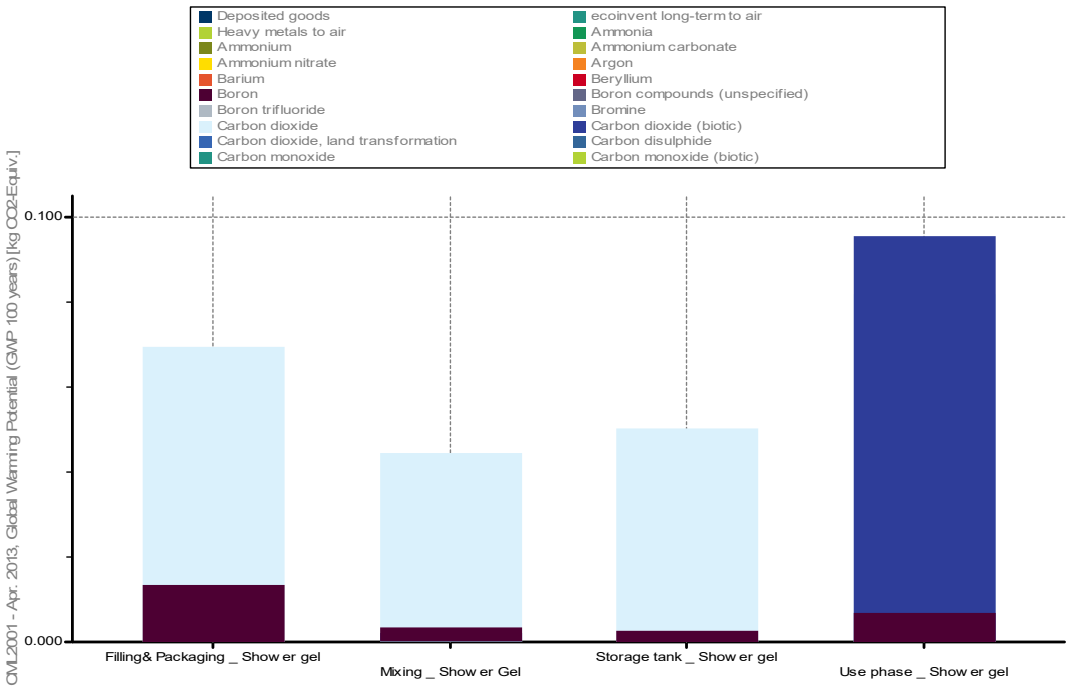
GaBi diagram:acidification pot_LCA of Shower Gel - Inputs



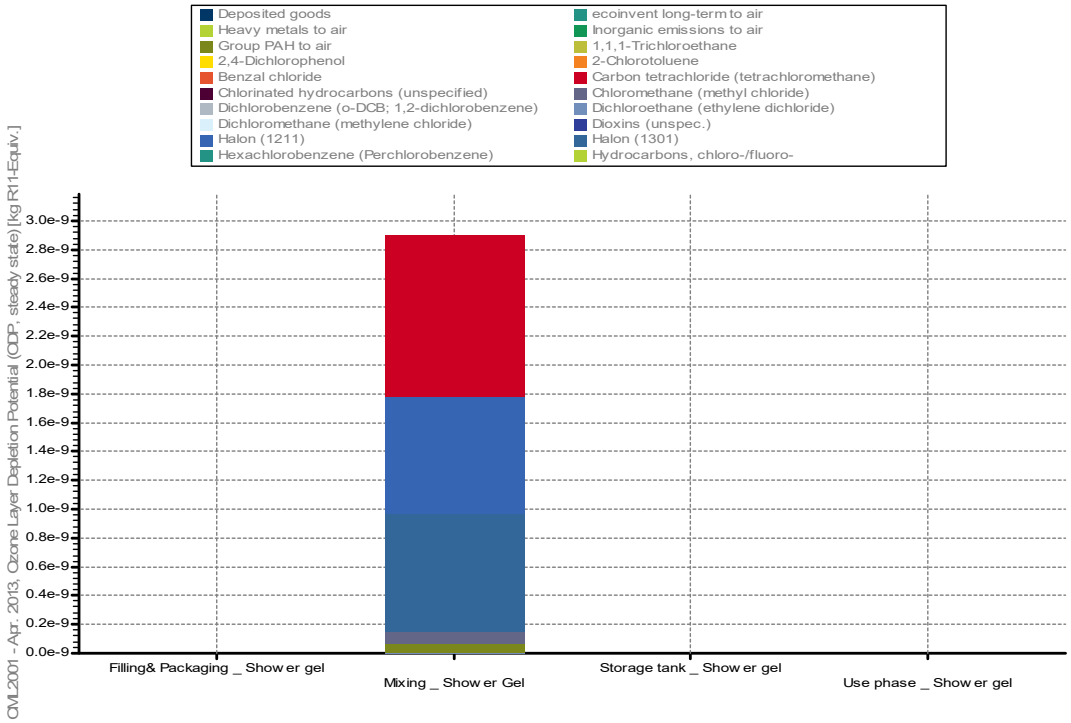
GaBi diagram:eutrophication pot_LCA of Shower Gel - Inputs



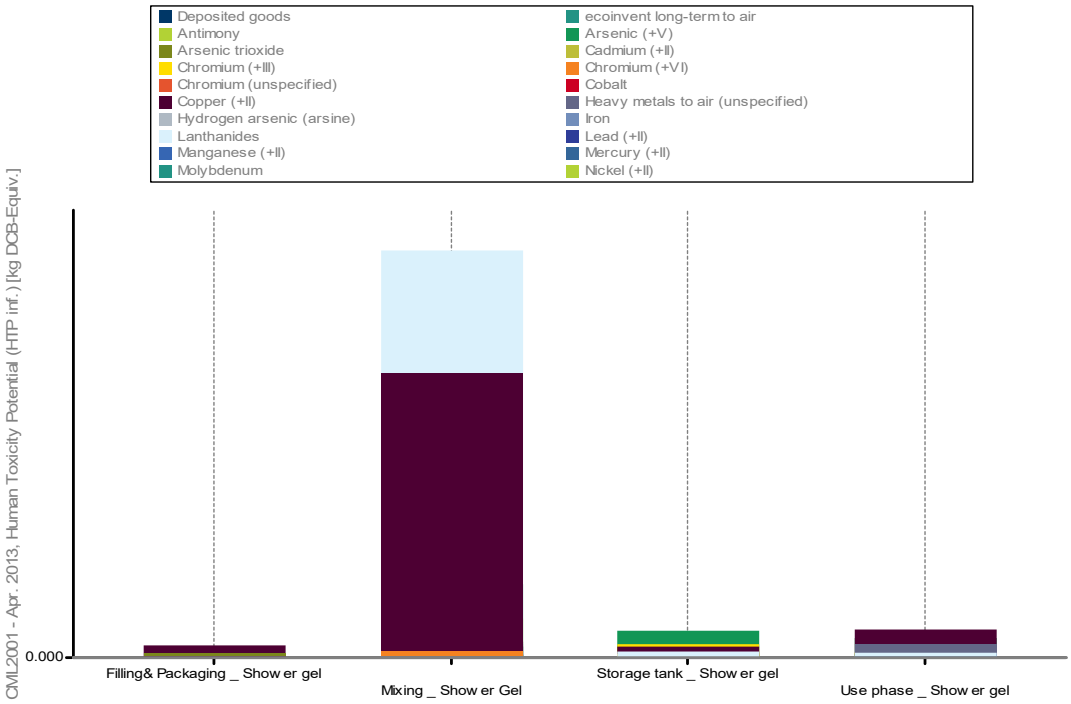
GaBi diagram:GWP_LCA of Shower Gel - Inputs



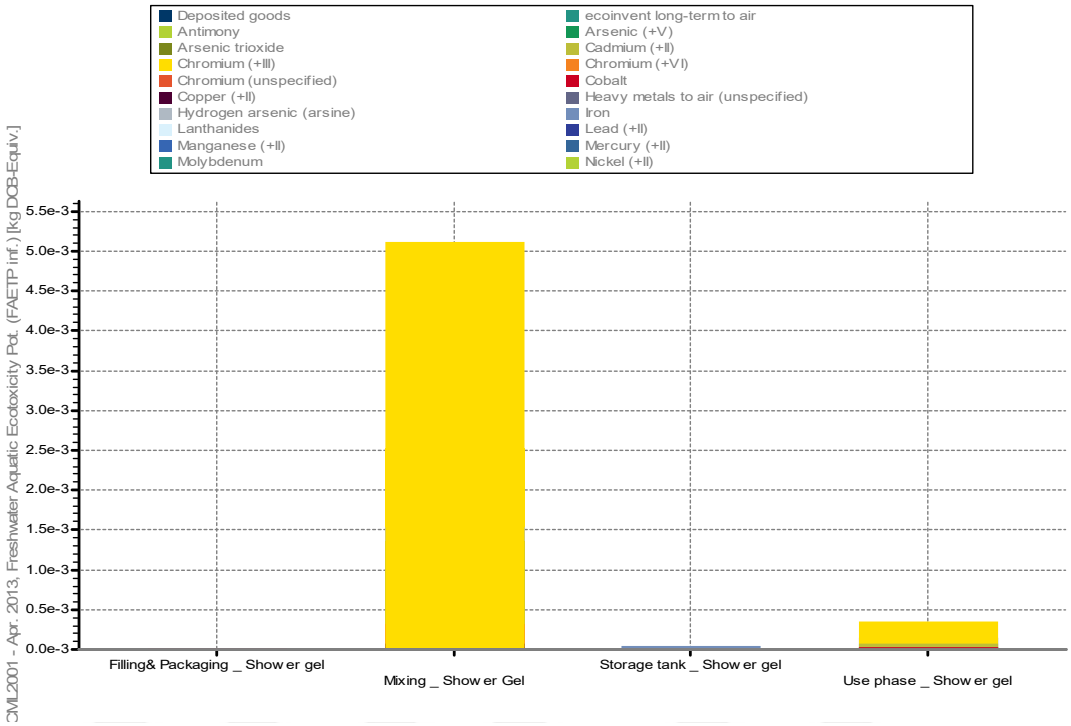
GaBi diagram:ozone layer depl_LCA of Shower Gel - Inputs



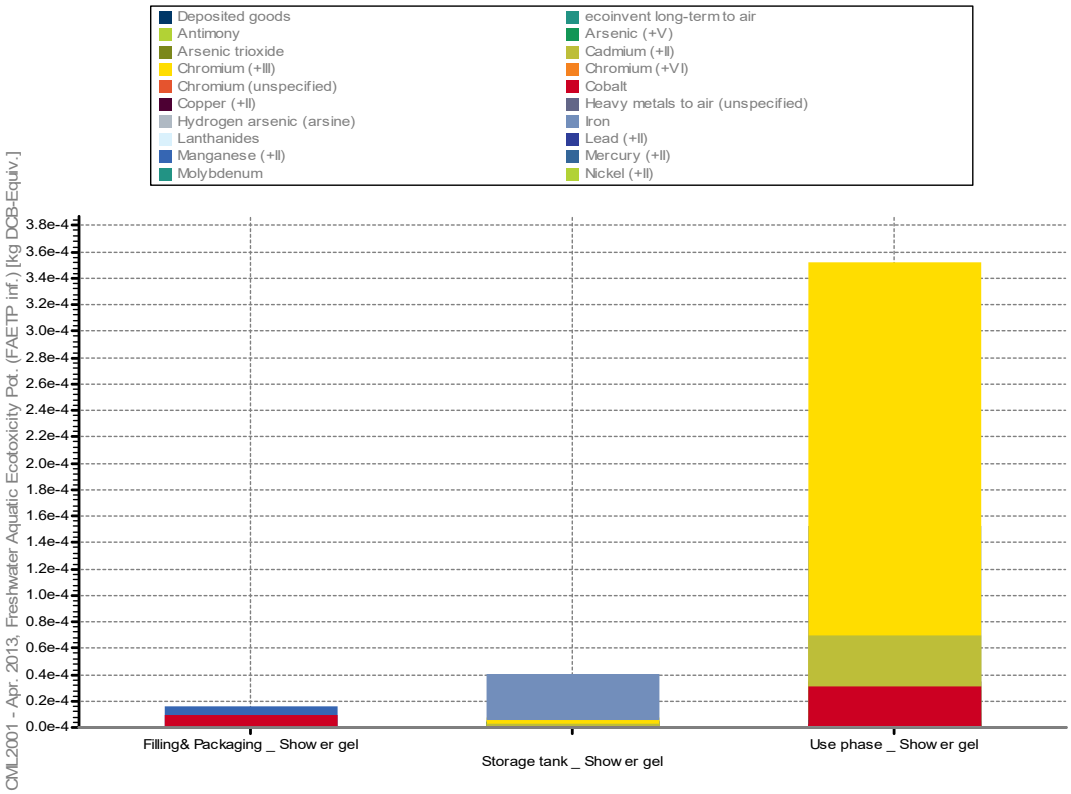
GaBi diagram:human tox_LCA of Shower Gel - Inputs



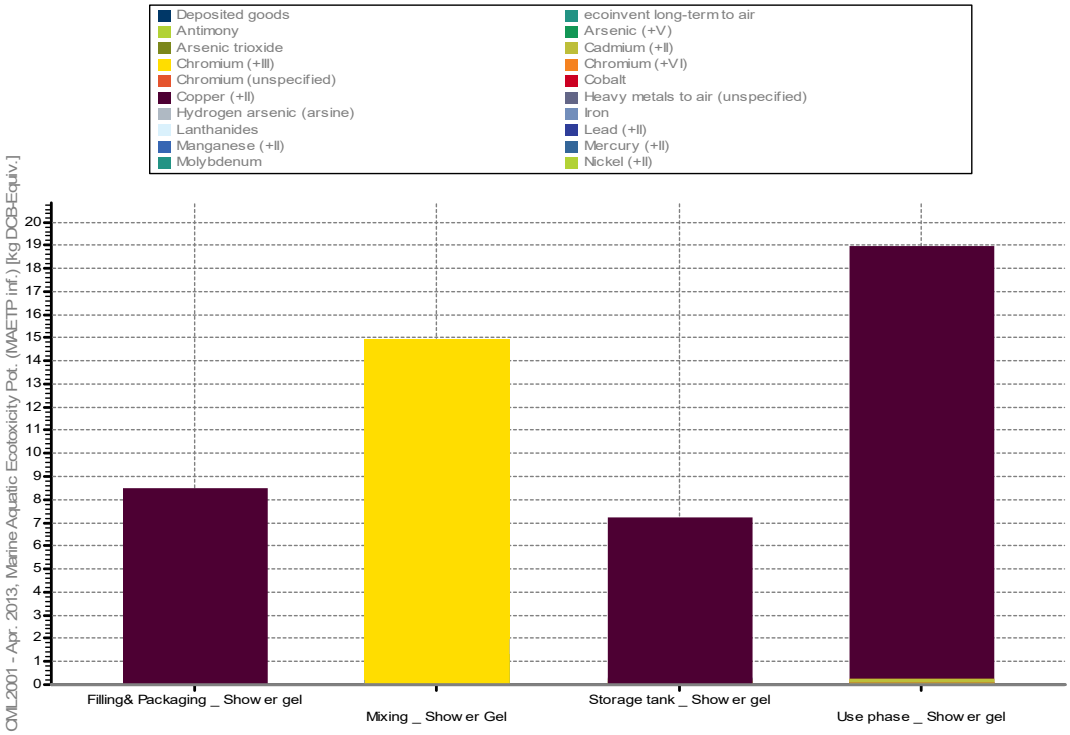
GaBi diagram:freshwater aquatic ecotox_LCA of Shower Gel - Inputs



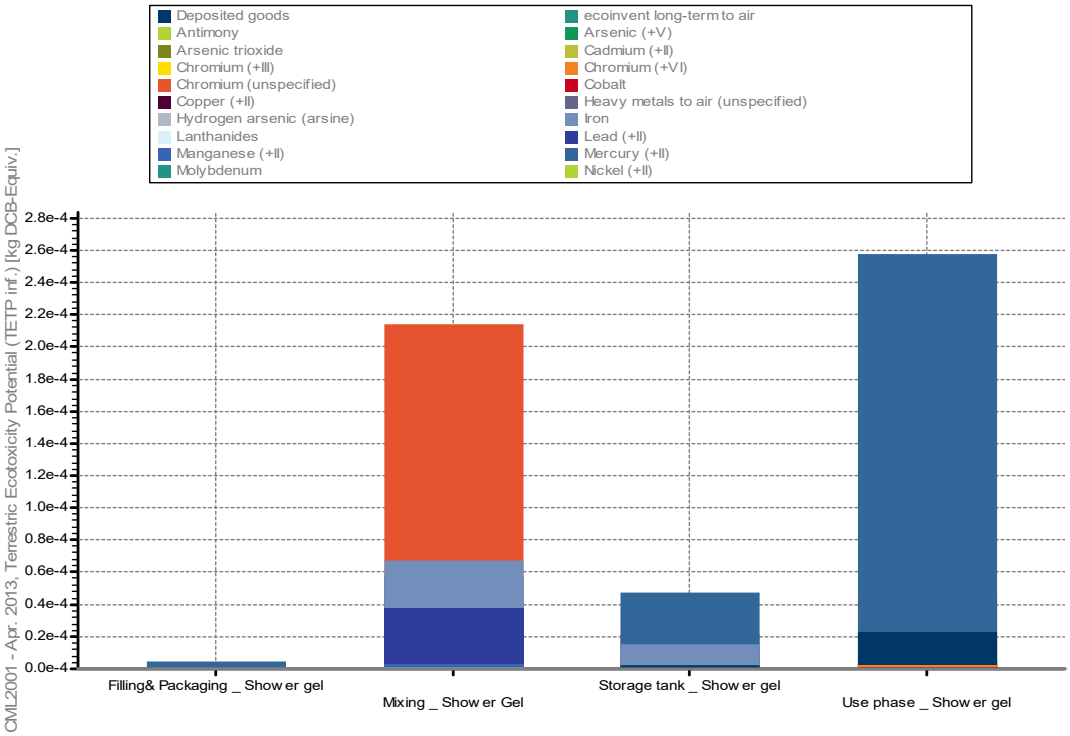
GaBi diagram:freshwater aquatic ecotox_LCA of Shower Gel - Inputs



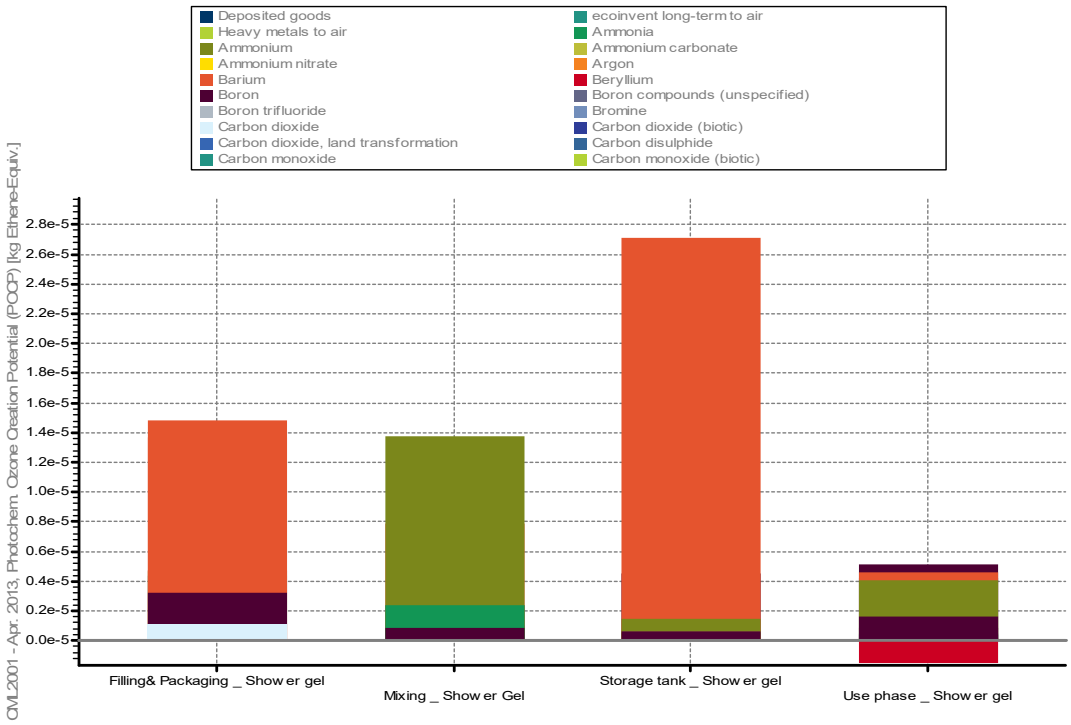
GaBi diagram: marine aquatic ecotox_LCA of Shower Gel - Inputs



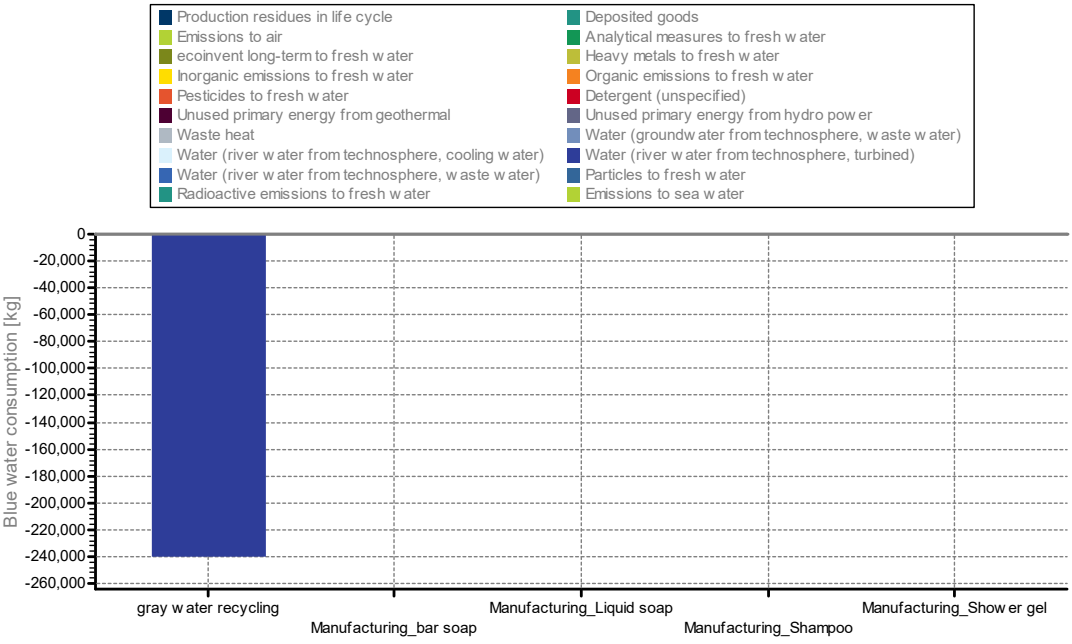
GaBi diagram: terrestrial ecotox_LCA of Shower Gel - Inputs

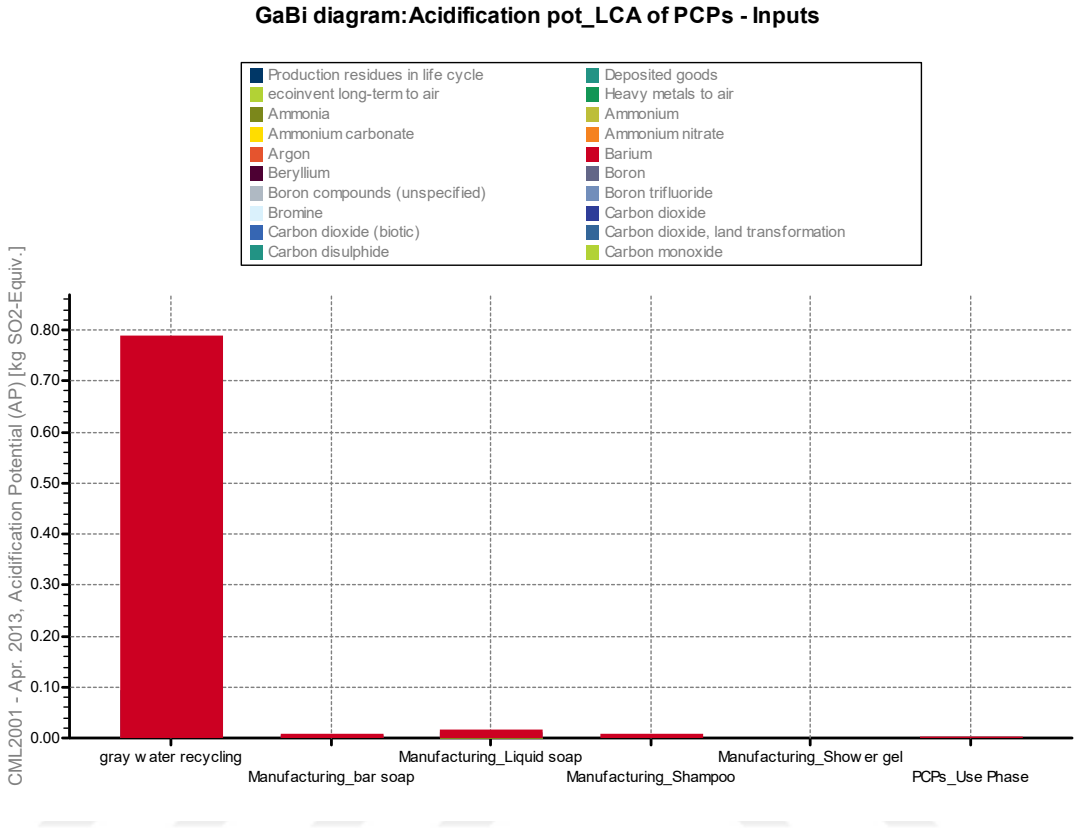


GaBi diagram:photochemical ozone_ LCA of Shower Gel - Inputs

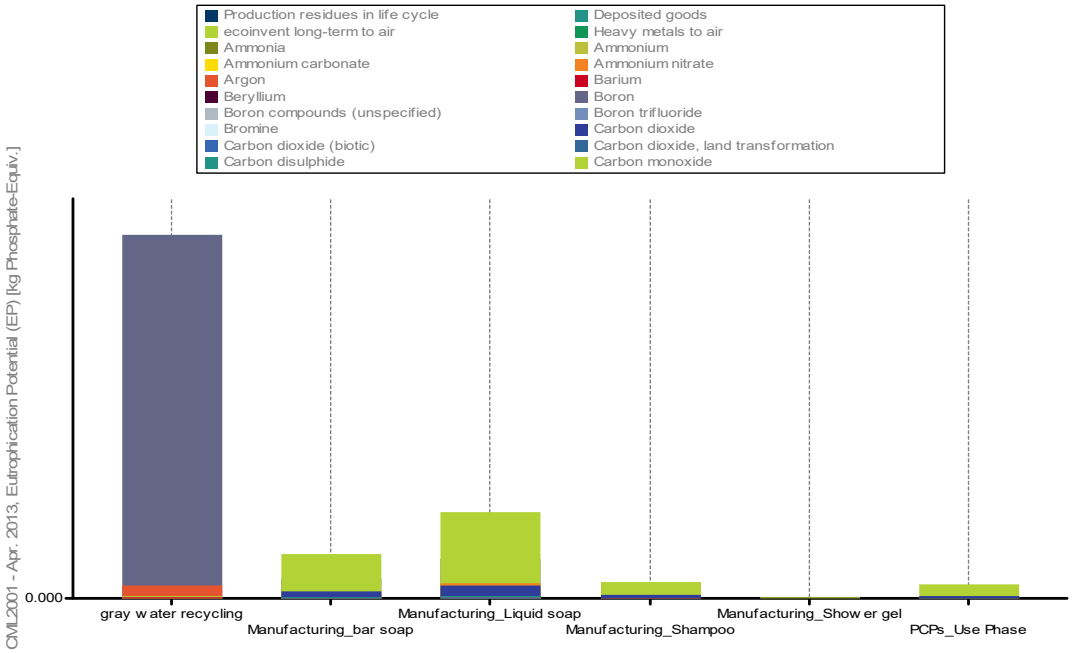


GaBi diagram:Water_LCA of PCPs - Inputs

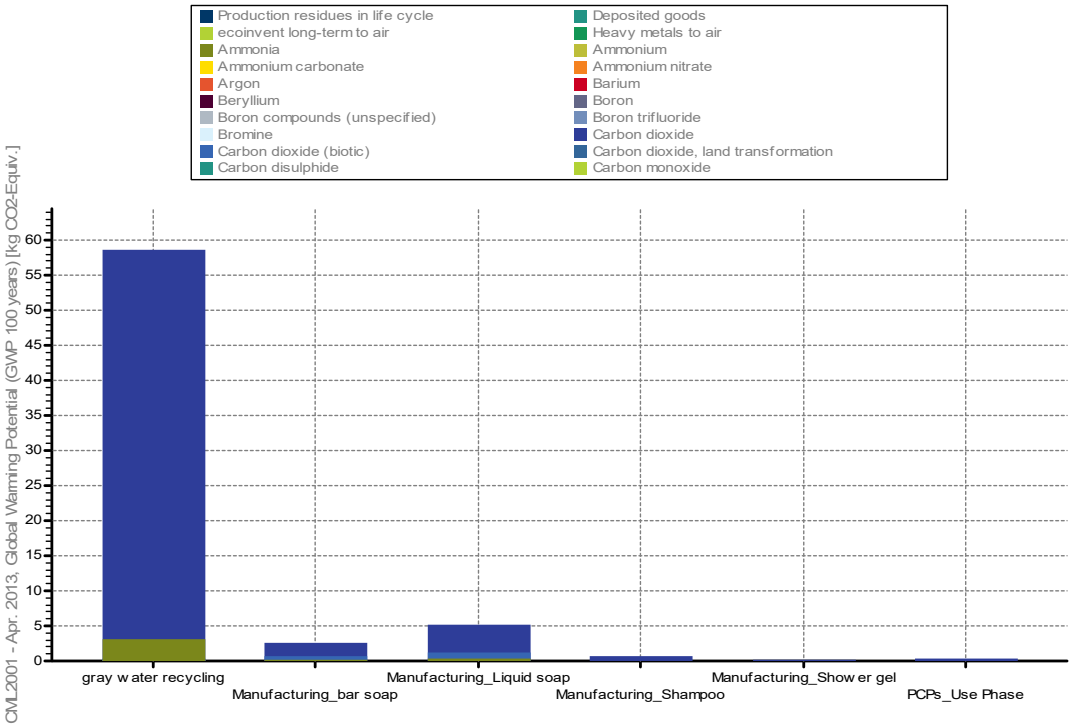



GaBi diagram:Acidification pot_LCA of PCPs - Inputs
Production residues in life cycle
Deposited goods
ecoinvent long-term to air
Heavy metals to air
Ammonia
Ammonium
Ammonium carbonate
Ammonium nitrate
Argon
Barium
Beryllium
Boron
Boron compounds (unspecified)
Boron trifluoride
Bromine
Carbon dioxide
Carbon dioxide (biotic)
Carbon dioxide, land transformation
Carbon disulphide
Carbon monoxide
CML2001 - Apr. 2013, Acidification Potential (AP) [kg SO2-Equiv.]
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
gray w ater recycling
Manufacturing_bar soap
Manufacturing_Liquid soap
Manufacturing_Shampoo
Manufacturing_Show er gel
PCPs_Use Phase

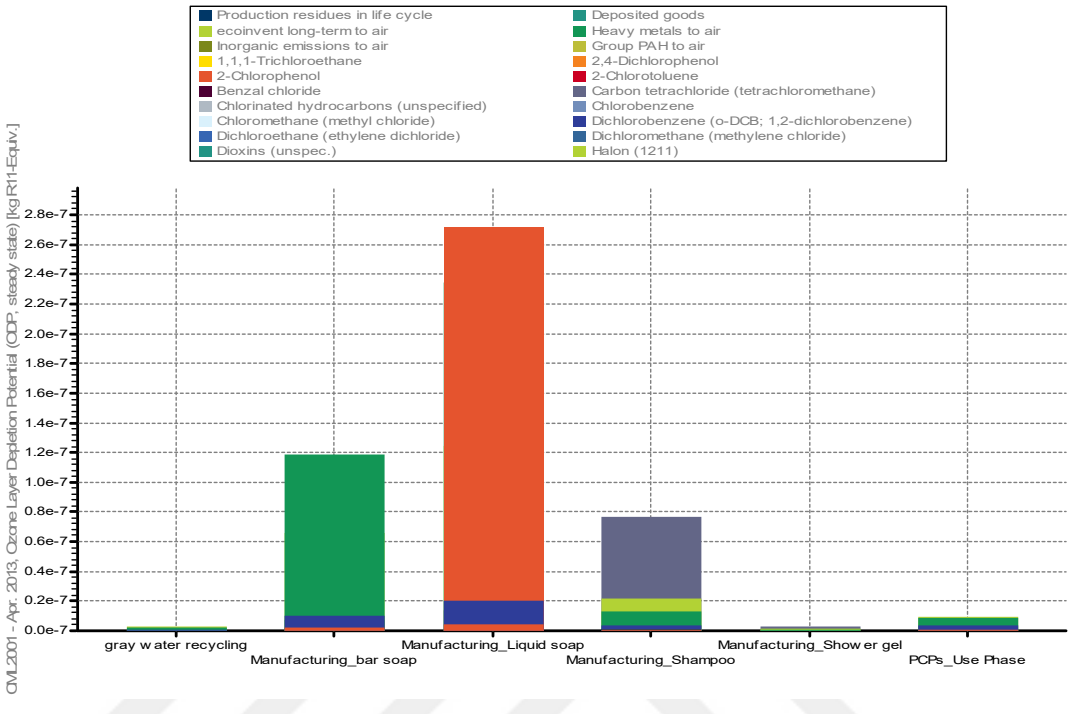
GaBi diagram: Eutrophication pot_LCA of PCPs_1 - Inputs



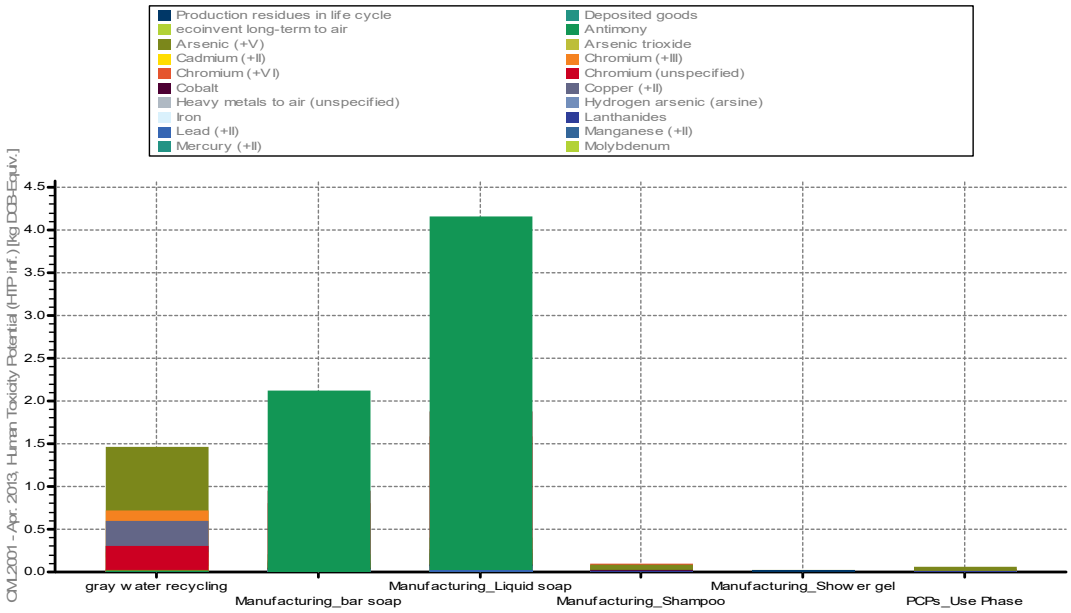
GaBi diagram: GWP_LCA of PCPs - Inputs



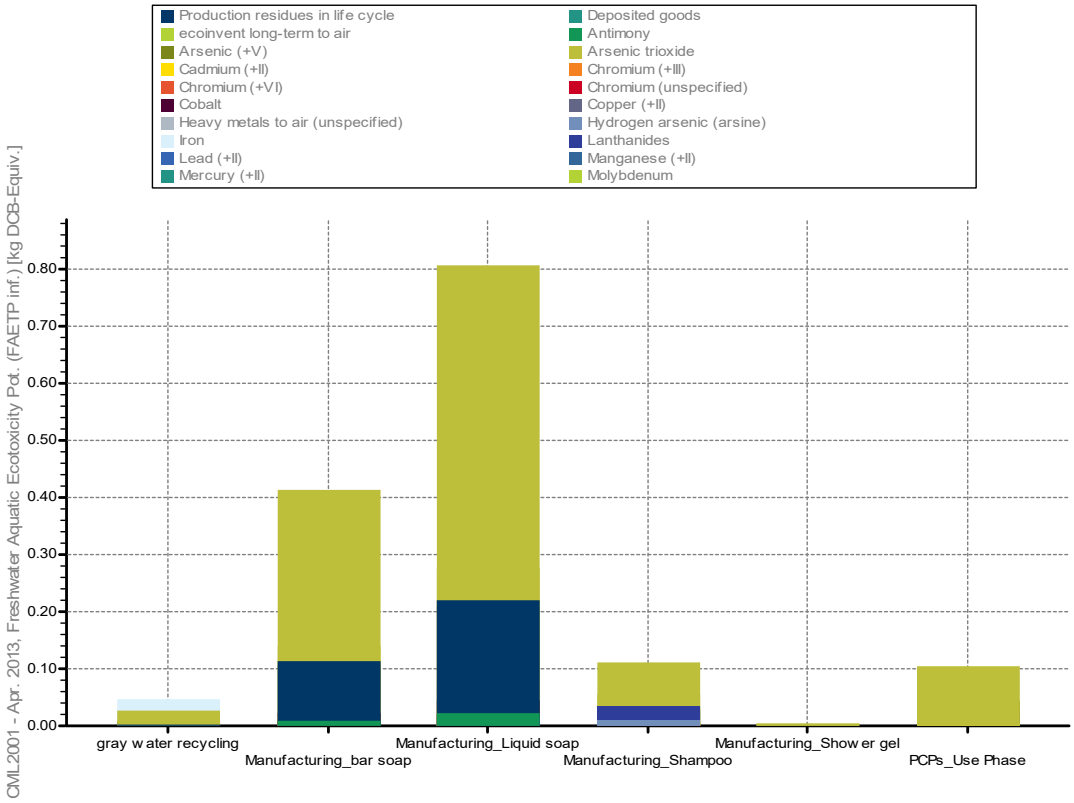
GaBi diagram:Ozone Layer Dep_LCA of PCPs - Inputs



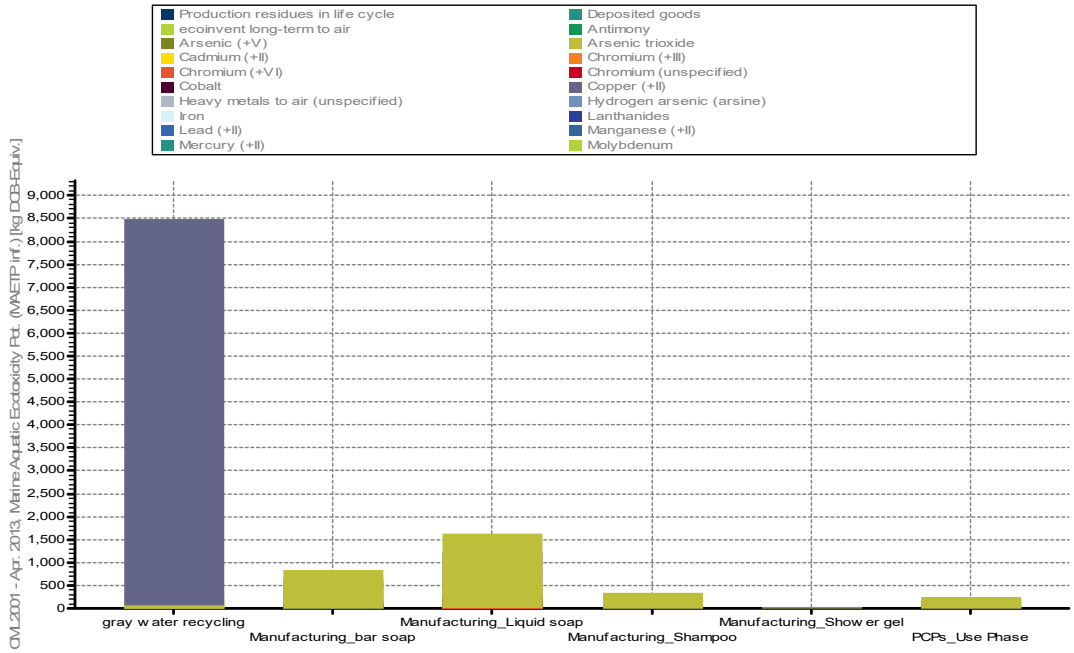
GaBi diagram:Human Tox_LCA of PCPs - Inputs



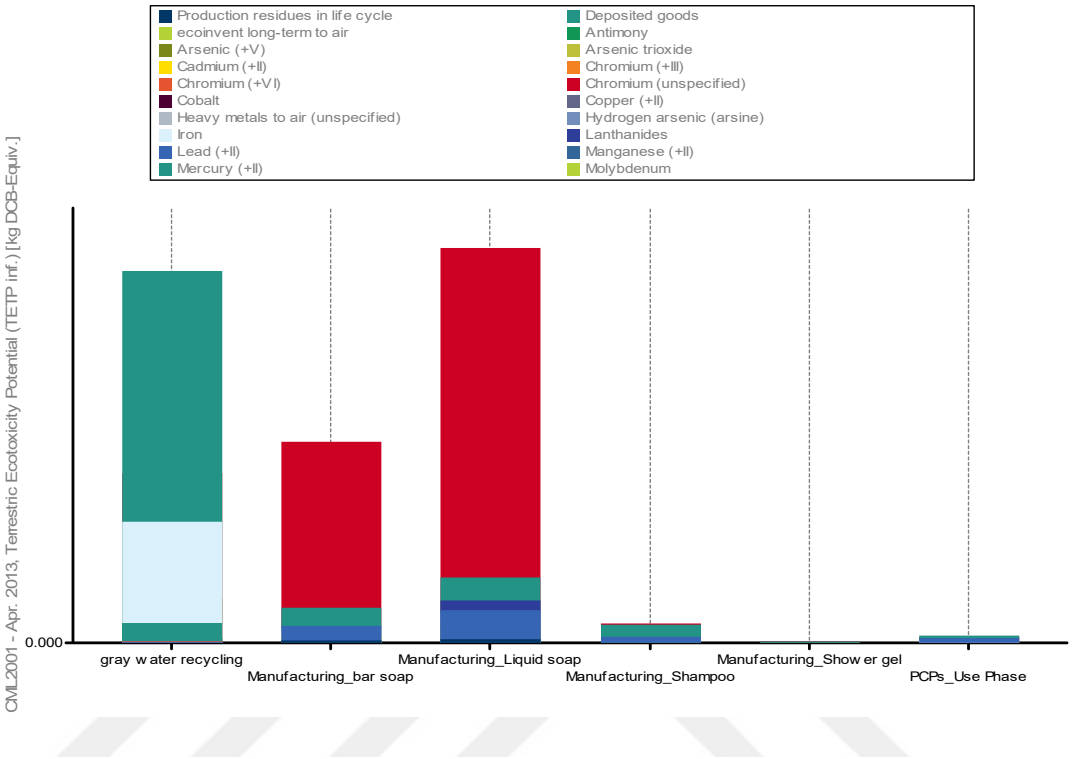
GaBi diagram: Freshwater Ecotox_LCA of PCPs - Inputs



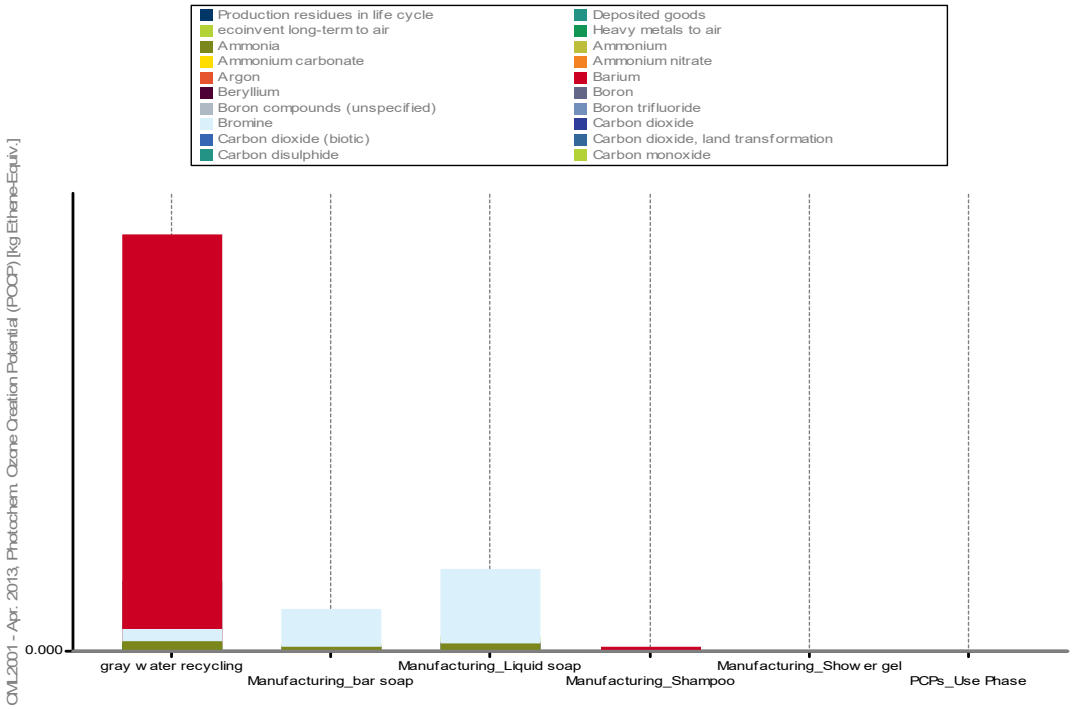
GaBi diagram: Marine Ecotox_LCA of PCPs - Inputs



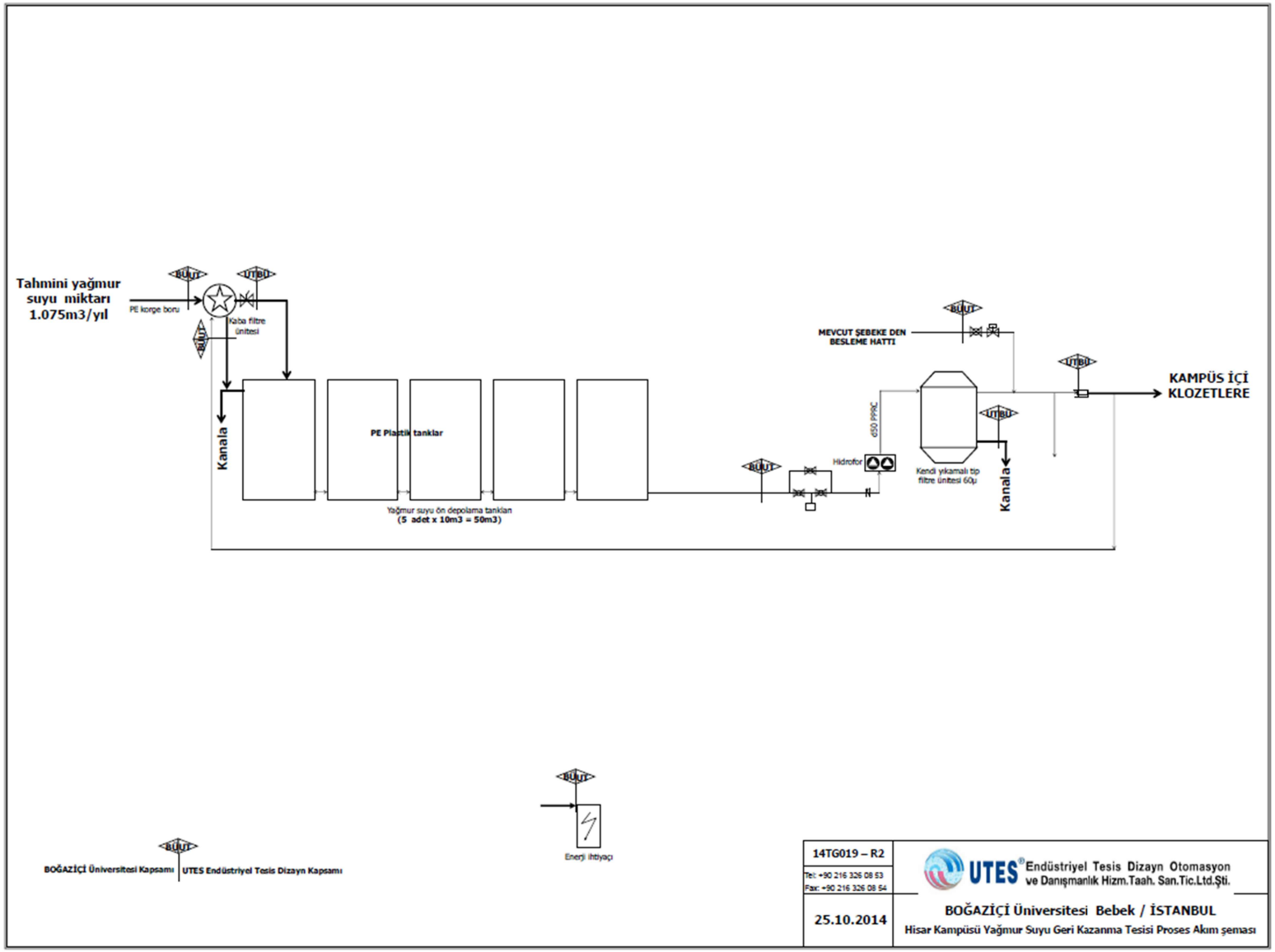
GaBi diagram: terrestrial ecotox_LCA of PCPs - Inputs



GaBi diagram: Photochemical ozone formation_LCA of PCPs - Inputs



APPENDIX B: P&I DIAGRAM OF EXISTING GRAY WATER RECOVERY SYSTEM


Tahmini yağmur suyu miktarı 1.075m3/yıl
PE korge boru
Kaba filtre ünitesi
Kanala
PE Plastik tanklar
Yağmur suyu ön depolama tankları
(5 adet x 10m3 = 50m3)
Hidrofor
d50 PPRC
MEVCUT ŞEBEKE DEN BESLEME HATTI
Kendi yıkamalı tip filtre ünitesi 60µ
Kanala
KAMPÜS İÇİ KLOZETLERE
Enerji ihtiyaçı
BOĞAZİÇİ Üniversitesi Kapsamı
UTES Endüstriyel Tesis Dizayn Kapsamı
14TG019 – R2
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Fax: +90 216 326 08 54
25.10.2014
UTES Endüstriyel Tesis Dizayn Otomasyon ve Danışmanlık Hizm.Taah. San.Tic.Ltd.Şti.
BOĞAZİÇİ Üniversitesi Bebek / İSTANBUL
Hisar Kampüsü Yağmur Suyu Geri Kazanma Tesisi Proses Akım şeması