DECISION MAKING TOOLS IN THE PRODUCTION SYSTEMS OF PERSONAL CARE PRODUCTS

by

ŞİLA TEMİZEL

BS. in Chem., Yıldız Technical University, 2012

BS. in Env.E., Yıldız Technical University, 2013

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Life Cycle Assessment is a method of analyzing the environmental impact of products and services that considers their full life cycle. The goal of this study is to evaluate the ecological footprints and integrate results with ecolabelling approach for selected products. The product and the consumer use data were collected from industry. Environmental impacts of different formulations were conducted by using GaBi 6.0 Software, EcoInvent Database and CML Assessment Methodology. In this study the stages were selected as raw material acquisition, manufacturing, distribution, consumer use and disposal. Additional scenarios were applied to both products to assess the environmental performance improvements. Global warming, acidification, eutrophication, ozone layer depletion and photochemical ozone creation potentials were considered for both hair conditioner and oil spray products. Overall normalized environmental impacts were also assessed.

The results of the study demonstrated that, for hair conditioner life cycle, the highest potential impacts for almost all of the impact categories resulted from consumption stage. In addition, for oil spray, the raw materials acquisition stage has the highest impact in overall life cycle. In the comparison of these two products, environmental impact potential of oil spray is lowered drastically in each category compared to regular hair conditioner.

KİŞİSEL BAKIM ÜRÜNLERİ ÜRETİMİNDE KARAR VERME MEKANİZMALARI

Yaşam Döngüsü Değerlendirmesi (YDD) bir ürünün veya hizmetin tüm yaşam döngüsü boyunca sahip olduğu çevresel etkiyi analiz etmek için kullanılan bir metottur. Bu çalışmanın amacı, seçilen kişisel bakım ürünlerinin çevresel ayak izlerini değerlendirmek ve sonuçları çevresel etiket yaklaşımı ile yorumlamaktır. Ürünler ve tüketici ile ilgili veriler endüstriden alınmıştır. Farklı formülasyonların çevresel etkileri GaBi 6.0 yazılımı, EcoInvent veritabanı ve CML değerlendirme metodolojisi kullanılarak hesaplanmıştır. Bu çalışmada sistem sınırlarına dahil olan aşamalar hammadde eldesi, üretim, dağıtım, tüketim ve yaşam sonu olarak seçilmiştir. İki ürüne de çevresel performanslarının kıyaslanması amacıyla farklı senaryolar uygulanmıştır. Klasik ve çift fazlı saç kremi ürünleri için küresel ısınma, asidifikasyon, ötrofikasyon, ozon tabakasının incelmesi ve fotokimyasal ozon oluşumu potansiyelleri dikkate alınmıştır. Normalize edilen çevresel etkiler geniş kapsamlı olarak hesaplanmıştır.

Çalışmanın sonuçları klasik saç kremi yaşam döngüsünde çevresel tüm kategorilerde en büyük etkinin tüketimden kaynaklandığını kanıtlamıştır. Ek olarak, çift fazlı saç kremi için ham madde eldesi aşamasının ürünün tüm yaşam döngüsü boyunca çevresel etkisi en yüksek aşama olduğu sonucuna varılmıştır. Söz konusu iki ürünün kıyaslanmasında ise, çift fazlı saç kreminin çevresel etki potansiyelinin her kategoride klasik saç kremine kıyasla ciddi bir biçimde azaldığı gözlemlenmiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**	**Units**
Σ	Summation	-
AC	Active Content	-
AI	Active ingredient	-
aNBO	Aerobic Non-Biodegradable Organics	mg/g AI
anNBO	Anaerobic Non-Biodegradable Organics	mg/g AI
AP	Acidification Potential	kg SO_2 Equivalent
APEOs	Alkylphenol ethoxylates	-
BCF	Bioconcentration factor	-
BOD_5	Biochemical Oxygen Demand (5 days of incubation)	-
BOD_{20}	Biochemical Oxygen Demand (20 days of incubation)	-
C_2H_4	Ethene or Ethylene	-
Cd	Cadmium	-
CDV_{tox}	Critical Dilution Volume Toxicity	L/g AC
CFC - 11	Trichlorofluoromethane	-
CFCs	Chlorofluorocarbons	-
CH_3Br	Bromomethane or methyl bromide	
CH_4	Methane	-
CO	Carbon monoxide	-
CO_2	Carbon dioxide	-
COD	Chemical Oxygen Demand	-
DCB	Dichlorobenzene	-
DIN	German National Standard	-
DOC	Dissolved Organic Carbon	-
DTPA	Diethylene triamine pentaacetic acid	-
EC_{50}	Half maximal effective concentration	-

EDTA	Ethylenediaminetetraacetic acid	-
EP	Euthropication Potential	kg PO_4 Equivalent
EPA	Environmental Protection Agency	-
EU	European Union	-
FU	Functional Unit	-
GHG	Greenhouse Gases	-
GWP	Global Warming Potential	kg CO_2 Equivalent
h	Hours	h
ha	Hectare	ha
HCl	Hydrochloric acid	-
HCFCs	Hydro chlorofluorocarbons	-
HF	Hydrofluoric acid	-
Hg	Mercury	-
HHCB	Galaxolide	-
IFRA	International Fragrance Association	-
ISO	International Organization for Standardization	-
İKMİB	Istanbul Chemicals and Chemical Products Exporters' Association	-
ITC	International Trade Center	-
kg	Kilogram	kg
K_{ow}	Octanol-Water Partition Coefficient	-
L	Liter	L
LC_{50}	Lethal Concentration 50%	mg/L
LCA	Life Cycle Assessment	-
LCI	Life Cycle Inventory	-
LD_{50}	Lethal Dose 50%	mg/kg
m^3	Cubic meter	m^3
ME	Middle East	-
mg	Milligram	mg
mL	Milliliter	mL
NAFTA	The North American Free Trade Agreement	-
NH_4	Ammonium	-
NO	Nitrogen monoxide	-
NO_2	Nitrogen dioxide	-

NOx	Nitrogen oxides	-
NTA	Nitrilotriacetic acid	-
ODP	Ozone Layer Depletion Potential	kg R11 Equivalent
PO4	Phosphate	-
POCP	Photochemical Ozone Creation Potential	kg Ethene Equivalent
ppmV	Parts per million by volume	-
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals	-
SETAC	Society of Environmental Toxicology and Chemistry	-
SO_2	Sulfur dioxide	-
SO_x	Sulfur oxides	-
SVHC	Substance of very high concern	-
ThOD	Theoretical Oxygen Demand	-
UK	United Kingdom	-
UNEP	United Nations Environment Programme	-
US	United States	-
VOC	Volatile Organic Carbon	-
YDD	Yaşam Döngüsü Değerlendirmesi	-
yr	Year	yr

1. INTRODUCTION

“The best way to predict the future is to design it.”

- Buckminster Fuller

Buckminster Fuller tried to understand whether humanity has a chance to live longer and more successfully on Earth, throughout his life. His famous quote drives my approach to design environmentally friendly products. An engineer must think of the environment and design the processes and products with this mentality.

Environmental life cycle assessment (LCA) is a tool for assessing the environmental impacts of a product, or more precisely, of a product system required for a particular unit of function. The term “product system” means the product throughout its entire life cycle, from cradle to grave, in terms of all processes involved. The stages in the product system are raw material extraction, production of materials, manufacturing, consumption, disposal (landfilling, recycling) and transportation between each step. The results of the LCA studies may be used for assessing the pressure of industrial products on the environment, strategic planning, marketing, setting ecolabeling criteria, environmental policy making, priority setting, and designing environmentally friendly products.

Increasing demand and production capacity will lead to many more environmental impacts related to emissions release, resource depletion and waste generation. These impacts will force the chemicals industry to develop more sustainable solutions. This thesis presents a study on the comparison of two hair conditioners, analyzing and discussing which happens to be the more environmentally friendly one. Within this frame, as an alternative to the conventional frame; three life cycle scenarios, namely manufacturing with different raw materials, adapting alternative transportation plans, and applying refillable packaging systems are evaluated by Life Cycle Assessment (LCA) methodology in order to identify the hair conditioner life cycle with minimum environmental footprint. The results will demonstrate the environmental savings through the integrated approach.

2. LITERATURE REVIEW

2.1. Usage of Personal Care Products

Personal care products extensively include a number of compounds that are used in daily life. These products range from soaps, detergents, perfumes, cleaning agents; to disinfectants, sprays, deodorants, and lotions. General aim of personal care products is to provide cleanliness and hygiene in order to stay healthy. With improved hygiene, life expectancy is doubled and infectious diseases are greatly reduced. Nevertheless, because of the effects of personal care products and other pollutants in the environment, deaths due to cancers, strokes, heart disease and diabetes exponentially increase (Jiemba, 2008).

Fragrances, which provide joy, confidence and sense of well-being, are generally used in perfumes, cosmetics, deodorants, washing and cleaning agents and a whole range of personal care products. For most of the personal care products, fragrances are directly applied on the skin. Typical amounts of fragrances used in various personal care products are presented in In Table 2.1. Obviously, after the use stage these compounds are poured from the drain pipes, both directly and indirectly (Cadby et al., 2002).

Table 2.1. Upper limit fragrance concentrations in various personal care products.

Types of Product	**Fragrance Level (%)**
Bath Products	2
Fragrance Cream	4
Toilet Soap	1.5
Shower Gels	1.2
Hair Spray	0.5
Shampoo	0,5
Body Lotion	0.4
Deodorants/Antiperspirants	1

Fragrances are used mostly in detergents, fabric softeners and personal care products. Figure 2.1 demonstrates the use of fragrances for various purposes in the European Union (HERA, 2004).

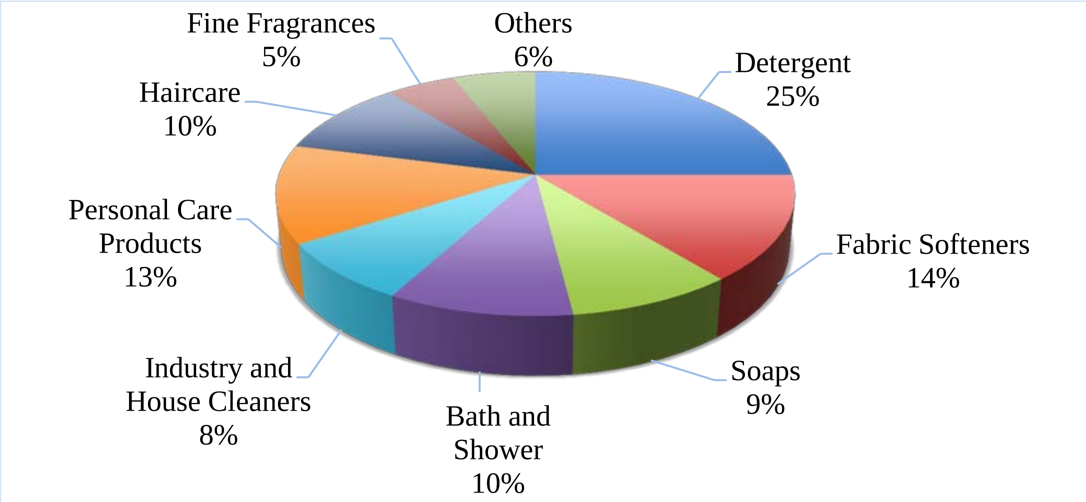


Figure 2.1. Use of fragrances for various purposes in the European Union.

It is quite apparent that personal care products are essential to our well-being. Their presence in the environment and their importance in a complete evaluation of environmental impacts is irrefutable. For this reason, the existence of personal care products in the environment will be examined within the scope of life cycle assessment, with a “cradle to grave” approach.

2.2. Environmental Impacts of Personal Care Products

Energy is a key resource for the use of a wide variety of inputs that are used in production of personal care products; especially for synthetic ingredients, fossil fuels and the raw material inputs for the chemical processing that serves the majority of the industry. Likewise; the production of plant-based ingredients, such as essential oils, colorants, surfactants, emulsifiers and moisturizers, consume energy throughout the production cycle. Manufacturing personal care products requires energy for the transportation of ingredients from suppliers around the world to production plants by truck, air cargo and/or tanker. There are several types for several production processes. For instance, products such as conditioners contain material with a high melting point which need heat processing and flash cooling. On the other hand, the packaging process of the products is another critical issue which needs to be overseen. Generally, all personal care products are delivered to the consumer in packaging, such as plastic bottles, tubes or jars. All of these packaging materials require energy while producing. On top of these factors, consumer use stage is also very crucial since most of the energy consumed comes from heating the water to rinse off the product. The life-cycle environmental impacts of consumer products get to be mentioned increasingly in discussing sustainable product design, environmental consumer information or product policy making. This indicates a very high demand for environmental data.

Different softwares and guidelines may be used in order to accomplish this study. For instance; SimaPro 4.0 software was used in a consulting company's work with Impact 2002+ and the EcoInvent Unit process libraries, both of which are the primary tools used globally. This methodology allows the results to be presented as both mid-point characterization, and end-point damage assessment. Additionally; in David Glew's study "Life cycle analysis of shea butter use in cosmetics: from parklands to product, low carbon opportunities", British Standard PAS2050 LCA guideline and EcoInvent's CML 2001 methodology for climate change impact category were applied (Glew and Lovett, 2014). British Standard PAS2050 LCA guideline has been developed by the British Standards Institute (BSI), and is a measurement tool/protocol for companies to make credible reduction commitments and ensure achievements on life cycle GHG emissions of products, under a Product Related Emissions Reduction Framework (PERF), in relation with ISO 14040 and ISO 14044. There is another study by Francke, named "Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics," which has also used PAS2050 to assess the GHG emissions of goods and services throughout their lifecycle (Francke and Castro, 2013).

In a different study by Alfonsin, named "PPCPs in wastewater – Update and calculation of characterization factors for their inclusion in LCA studies," USES-LCA 2.0 database is used. This database (USES – Uniform System for the Evaluation of Substances) is an effective methodology with an easy-to-use model. In addition, it gives broad information about the environmental and health effects of the substances on stratosphere, urban air, rural air, sewage treatment plant, freshwater, seawater; as well as on natural, agricultural and industrial soil. Generally, the results are important not only for human toxicity and freshwater ecotoxicity, but also for marine and terrestrial ecotoxicity (Alfonsin et al., 2014).

2.3. ISO Standards and Ecolabel Criteria for Personal Care Products from Different Regions

2.3.1. ISO Standards

ISO14020 defines guiding principles for the development and use of environmental labels and declarations. This is not intended for use as a specification for certification and registration purposes; however other applicable standards in the ISO14020 series (ISO14024, ISO14021 and ISO14025) have to be used in conjunction with it.

ISO14024 defines Type I environmental labeling programs. These programs award a license authorizing the use of environmental labels on products, indicating overall environmental preference of a product within a particular product category based on life cycle considerations. Type I ecolabels are the indicator of overall environmental preference in the product category. They are based on publicly available specifications, are operated by third parties, involve independent audits and consider life-cycle environmental impacts. They provide a "seal of approval," where a Type I environmental labeling program issues a license for the use of their ecolabel logo on products or services which meet the program's published specifications.

ISO14021 defines Type II environmental labeling programs which are self-declarations not liable to independent audit. These requirements cover the use of particular words and symbols, along with specific requirements about accuracy, relevance, explanation and substantiation/verification of claims.

ISO14025 defines Type III environmental labeling programs providing 'eco-profiles' or 'report cards'. These profiles summarize the quantified data using predetermined parameters. Buyers can compare the data between competing products to see which of these products performs best in that area. Type III ecolabels are based on publicly available product category rules, are operated by third parties and involve independent audits.

In 2007, when ecolabel criteria were defined, the consensus was that some aspects in the use stage such as the water consumption and the energy to heat water were not to be included; and that ecolabel should be focusing on product characteristics. This agreement originated mainly as a consequence of the excessive resource consuming implemented by these processes, and their huge impact which would alter the results. Moreover, the environmental impacts concerned with associated activities, such as heating water, are difficult to reduce by ecolabelling of soaps and shampoos. Experience has shown that ecolabelling is most efficient in reducing the environmental impact of soaps and shampoos after use, and to a lower extent, the negative health effects during use. This is done by regulating the inherent properties of the ingredients of the products and the packaging weight and material. Nevertheless, this thesis will consider relevant inputs needed for the use of the products in order to have a vision of the whole life cycle. Some stages such as the water consumption during use or distribution are not parameters likely to be regulated by ecolabelling. However, it is important to include them in the initial consideration while obtaining a global environmental profile of a product, with regard to a relative contribution of each stage to the global environmental impact.

2.3.2. Ecolabel Criteria for Personal Care Products from Different Regions

In this section, different ecolabelling programs will be examined. A research was held in Duke University called “An Overview of Ecolabels and Sustainability Certifications in Global Marketplace” to determine the most commonly used ecolabels throughout the world. According to the results of that study, most commonly used ecolabels are EU Ecolabel (Europe), Green Choice Philippines (Asia), Green Seal (America) and Nordic Ecolabel/Swan (Nordic Countries), all of which are detailed in this study (Duke, 2010).

2.3.2.1. Europe – EU Ecolabel

The EU Ecolabel is the premier European award for products and services which meet the highest environmental standards. An ecolabel product delivers high performance and environmental quality, verified by a formidable and independent certification process. An ecolabeled product is noticed as it carries the flower logo, making it very simple for buyers and consumers to get wisely in the marketplace.

The soaps, shampoos and hair conditioners with The EU Ecolabel meet strict limits on the use of dangerous substances, have a lower impact on the aquatic environment, set high standards of biodegradability, limit packaging waste and have a high level of performance. All points of interests are listed in Appendix A for European EU Ecolabel (European Comission, 2013).

2.3.2.2. Asia – Green Choice Philippines

Soaps and shampoos consist of various surfactants and other chemical compounds, which are mainly non-biodegradable compounds. When discharged, these substances not only accumulate in water bodies receiving them; but also change the ecological balance with impact on the living organisms. The key considerations are bioaccumulation, biodegradability and toxicity in aquatic environments because of the discharge to water. Additionally, they contact with skin directly. Therefore, the harmful chemical components should be as low as possible.

The Green Choice Philippines ecolabelling program is compiled from Good Environmental Choice Australia, Japan Environment Association: Eco Mark, Nordic Ecolabelling: Swan and Thai Green Label. The Green Choice Philippines sets various requirements for soaps and shampoos to have ecolabel. The main categories are product quality performance and product environmental performance. Compliance to environmental regulations and legislations for production, transport and disposal stages is a must. Additionally; the use of preservatives, builders, fragrances, coloring agents, UV absorbers, pH regulators, formaldehydes and harmful substances are limited. There are other requirements including the packaging materials used in production. For instance; in case of plastic packaging, the packages must have a sign indicating the kind of plastic used for producing the package. The primary package should be recyclable or refillable (Asean Directive, 2013).

2.3.2.3. America – Green Seal Standard

America's Green Seal Standard is the first standard that wholly addresses the health, environmental, and labeling concerns for a wide variety of leave-on personal care products.

Hair styling products are designed or labeled for their applicability to wet, damp, or dry hair; in aiding the hair to be defined, shaped, lifted, styled or sculpted. Green Seal standard establishes the environmental, health, and social requirements for products that are intended to enhance the appearance, cleanliness, health, well-being and the general feel of the body and hair, or that may provide other personal care and hygiene functions. Furthermore, there are other requirements that include the packaging of the product. Primary and secondary packagings must reduce the use of new packaging material, be recyclable and contain 25% post-consumer content; or should be accepted through a take-back program. Heavy metals, phthalates, bisphenol A, and chlorinated packaging and applicators are prohibited in this standardization (Green Seal, 2013).

2.3.2.4. Nordic Countries – Nordic Ecolabel/Swan

Nordic Ecolabel is a very well-known and favored brand in Nordic Countries, which is officially employed since 1989 by the Nordic Council of Ministers. The main focus of this label is to contribute to sustainable production and consumption, mainly providing a sustainable society. It guarantees that not only general environmental requirements, but also product specific climate requirements are taken into account while evaluating the products.

Personal Care Products that are encompassed by the Directive 76/786/EEC and Regulation 1223/2009/EG are allowed to carry this label. To be awarded with the Nordic Ecolabel, there are environmental and health requirements, packaging criteria, consumer and performance/quality requirements and quality and regulatory requirements. There are additional criteria for packaging of the product. Quantity of packaging (which may require an extended calculation process) and type of packaging (such as paper, cardboard, plastic, metal and additional dispensing devices) are taken into account while evaluating the product in terms of ecolabel (Nordic Ecolabelling, 2010).

2.3.3. Ecolabel and Consumer Behavior

The environmental characteristics of the products have become increasingly important to consumers and producers. Companies have decided to place information on products that indicate its environmental behavior. Moreover; should that product has already a renovation to become greener, newly placed information will also emphasize this (US EPA, 1991). One important function of ecolabelling is to provide information to consumers and try to guide them for product purchase behaviors. These will also lead to changes in producer behaviors. Eventually, these changes will hopefully lead to a reduction in negative environmental impacts and increase in correction of market failures in product production.

Some industries have adopted environmental certification and labelling approaches for their products, and integrate this attitude in their business strategies to their advantage in product markets and profits (Irland, 2002). Aforesaid certification and labelling approach is not costless. Consequently, consumers may not prefer labelled products unless they believe and understand the information the manufacturer presents them. Since verifying the improvements is impossible for most consumers, the success of ecolabelling is mostly on behalf of companies, who have means to communicate with the consumer on the production practices which have been modified in a better way (Krarup and Russell, 2005).

Labelling attempts to provide embedded information to the consumer, it may be evaluated as a transfer of information from the product’s label to the consumer. The effectiveness of the label is essentially influenced by the way the information is presented, and the capability of the consumer to comprehend the given information (Grankvist and Biel, 2001). It depends on many factors; such as the rate of product information that the firms are required to provide, the amount of information detail presented to consumers, the rate to which information is required to appear in a uniform format across products and the organization that is seen as providing the information (Ross and Creyer, 1992).

Ultimately, consumers care about the environment and they tend to pay more for environmentally friendly products. However, the current level of certification and labelling slows down the development of this approach. Simple and effective labelling may definitely amend consumer and producer behavior.

In the last couple of decades, ecolabels, which identify green products, have grown significantly throughout the world. Some well-known eco labels for personal care products and cosmetics all over the world are shown in Table 2.2 (Ecolabel Index, 2016).

Table 2.2. Ecolabels used in cosmetics and personal care products industry.

Organization	**Where this ecolabel is found?**	**Year**
ABNT (the Brazilian Association of Technical Standards) Ecolabel	Brazil	1993
AIAB (Italian Association for Organic Agriculture)	Italy	1998
Anbefalt	Norway	2006
Australian Certified Organic	Cook Islands	2002
BASF Eco-Efficiency	Brazil, Germany, US	2002
B Corporation	Canada, US	2007
Bioforum Biogarantie and Ecogarantie	Belgium	2002
CarbonFree Certified	Australia, Brazil, Canada, US	2007
Carbon Neutral Certification	Brazil, India, US	2008
Carbon Neutral Product Certification	Australia, Chile, Japan, Singapore	2006
Carbon Reduction Label	Australia, Canada, Israel, EU, US	2007
Certified Natural Cosmetics	Germany	1996
Certified Wildlife Friendly	Africa, US	2007
China Environmental Labelling	China, New Zealand	1993
Climatop	Switzerland	2008
COOP Naturaline: Switzerland	Switzerland	1993

Table 2.2. Ecolabels used in cosmetics and personal care products industry (continued).

COSMetics Organic Standard	EU	2008
Cradle to Cradle Certified (CM) Products Program	International	2005
Degree of Green	Canada, US	2008
Demeter Biodynamic	US	1940
Earthsure	Canada, US	2006
EcoCert	International	1991
EcoLogo	North America, UK	1988
Ecomark: India	India	1991
Environmental Choice New Zealand	New Zealand	1990
Environmental Product Declaration	International	1999
Fair for Life	Virgin Islands, US	2006
FairTrade	International	1997
FairWild	Canada, Germany, Switzerland, US	2007
Global GreenTag Certified	Australia, South Africa, US	2010
Global Packaging Protocol on Sustainability	Global	2011
Good Environmental Choice Australia (GECA)	Australia	2001
Good Shopping Guide Ethical Award	UK, Norway, Sweden	2001
Green Crane: Ukraine	Ukraine	2002
Green Choice Philippines	Philippines	2002
Green Good Housekeeping Seal	US	2009
Green Products Standard	Canada, US	2007
Green Seal	International	1989
Green Tick	US, Australia, New Zealand	2001
Hungarian Ecolabel	Hungary, Romania	1993
IMO Certified	International	1991
International Organic and Natural Cosmetics Corporation BDIH Standard	Germany	2001
Korean Ecolabel	Republic of Korea	1992
Leaping Bunny	International	1998
LowCO_2 Certification	Australia, Chile, Japan, Singapore	2006
National Green Pages™ Seal of Approval	US	2004
Natrue-Label	International	2007
Natural Products Association	US	2008
Naturally Sephora	International	-
Naturland e.V.	Germany, Mexico, Sri Lanka	1982

Table 2.2. Ecolabels used in cosmetics and personal care products industry (continued).

$NoCO_2$	Australia, Chile, Japan, Singapore	2006
Nordic Ecolabelling or “Swan”	The Nordic Countries, South Africa	1989
NSF Sustainability Certified Product	US	2010
NPA Natural Seal	US	2008
OASIS	US	2008
Oregon Tilth	US, China, Canada	1982
Organic Content Standard (OCS)	US	2013
Organic Farmers & Growers Certification	UK	-
Roundtable on Sustainable Biomaterials	Australia	2007
SEE What You Are Buying Into	UK	2009
SIRIM Certified	Malaysia	1997
SmaRT Consensus Sustainable Product Standards	EU, US, New Zealand	2002
Soil Association Organic Standard	UK	1973
Sourcemap	-	2011
SustentaX	EU, US	2008
TerraCycle	EU, US	2005
Texas Certified Organically Produced	US	1988
Thai Green Label	Thailand	1994
USDA “Organic”	USA	2002
Vitality Leaf	Russian Federation	2001
Whole Trade™ Guarantee	Canada, UK, US	2007
WindMade	-	2011

As indicated before, ecolabel is a mark, indicating that the product was produced in an environmentally conscious attitude, either public or private. However, both public and private labels state that the production methods have followed some particular set of production standards. For environmental issues, public intervention is generally crucial in choosing among different suggestions that reduce pollution and/or environmental damage. Since ecolabelling approach has broad consumer and producer endorsement, it provides great consequences, such as welfare of both producer and consumer, as well as the structure of the marketplace. Hence, if regulatory involvement is assumed as decisive, governments need to consider more fully the economic impacts of the label. Governments should be playing an active role in showing the credibility of the label and providing standards and guidelines for the path (Krarup and Russell, 2005).

Various surveys have been made about the use of eco-products and ecolabels, the consequences may be considered as pleasant. In Moscow, participants were expected to answer a question: *“How important is the ecolabel on the product?”* and 74% replied with *“very important/important”*, 15% replied with *“don’t care”* while 11% replied with *“were undecided”*. The results of this survey manifested that customers are ready to pay more for products and material which do not emit harmful chemicals. Protecting one’s health is the primary reason why people choose green products (Smirnova and Voronina, 2008).

European Commission Directorate-General for Environment held another study in which attendees were invited to answer if they were willing to buy environmentally friendly products despite their slightly heightened costs, and the results were presented for the years 2011 and 2014, in Figure 2.2 and Figure 2.3, respectively (EC, DG ENV, 2014).

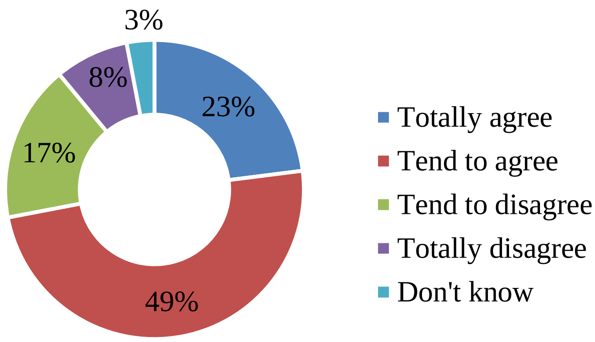


Figure 2.2. Willingness to pay more for eco-products in 2011.

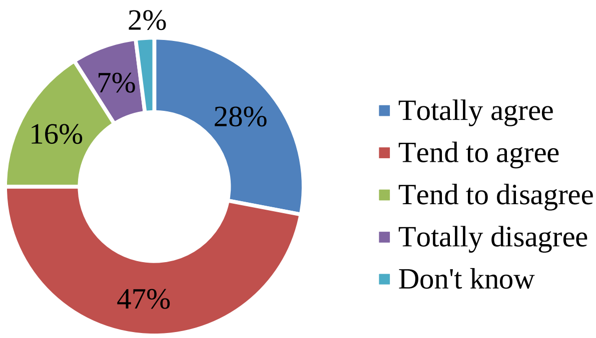


Figure 2.3. Willingness to pay more for eco-products in 2014.

The findings of the aforementioned research show that the ecolabel had significant impact on both brand perception, and on product perception or expectations. Ecolabel invests the brand with a feeling of being more trustworthy and reliable, conscious and aware, modern and up to date, responsible and considerate, and finally, qualified to be a premium brand. Nevertheless, it has also a negative perceptual impact on products. The product may be considered as less effective, more expensive, dull and nerdy. The ecolabelling has a substantial impact on the brand perception whilst strongly adding to build up an image of a premium brand. It also has an impact on the pre-experience expectations about the product. In this aspect, ecolabel brings both positive and negative attributes to the product in terms of expectations (Belin and Olsson, 2006).

2.4. Current Situation and the Future of Personal Care Products Industry

Turkish chemicals industry is composed of facilities where mainly production of various chemical raw materials and consumer goods; such as petro-chemical products, soap, detergent, fertilizer, medicine, dye, varnish, synthetic fibre, and soda takes place. A great number of firms operating in the sector are mostly small and medium size enterprises; however, there are also big size enterprises and multinational corporations in business. As of 2009 there are over 21 thousand firms in chemicals industry, and 6.8% of firms active in manufacturing industry is from chemicals industry.

Majority of the enterprises are located in cities like Istanbul, Izmir, Kocaeli, Sakarya, Adana, Gaziantep and Ankara. Chemicals sector has a wide product range and it is mostly dependent on imports – 70% of the raw materials are imported, whereas only 30% is provided through local production. Should the chemicals industry throughout the world be analyzed, it would be clear that in developed countries it is one of the top three industries. Chemicals industry provides input to sectors like automotive, information and communication technologies, mechanics, investment and consumer goods; all of which are going to be active in near future in global production and trade sectors. Throughout the world; scientific advances in chemicals industry is mostly observed in fields such as nanotechnology, biochemistry, catalyst, genetics, organic chemistry and polymer chemistry. Studies in these fields have produced some results recently. World chemicals industry exports summed up approximately to 5.2 trillion dollars in 2011, and the ratio of the industry in world’s total exports (17.9 trillion dollars) was 28,9%. On the other hand, the examination of the geographical distribution of the foreign trading in chemicals industry worldwide demonstrates that the European Union is still in dominating position and has the biggest volume of trade. 2011 world chemicals industry imports and exports distribution is given in the figure below (İKMİB, 2014) (Figure 2.4).

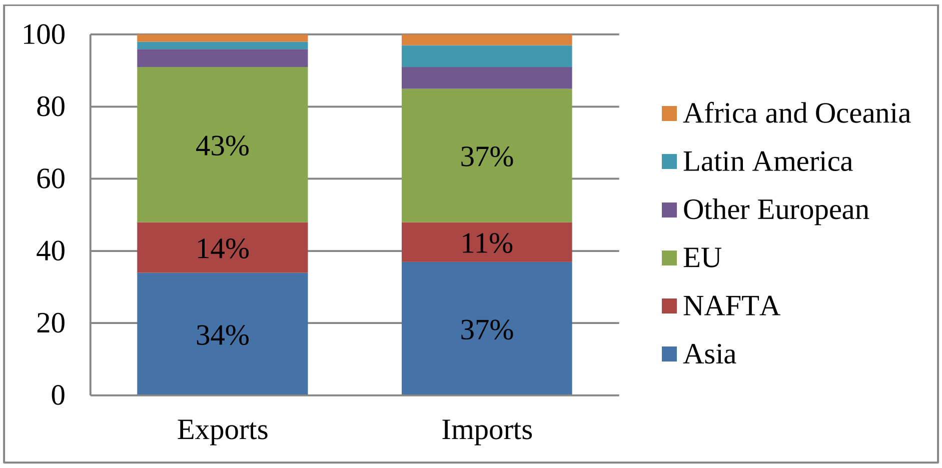


Figure 2.4. 2011 world chemicals industry imports - exports distribution.

2.4.1. Cosmetic Products Export

The countries to which Turkey exported cosmetic products the most in 2013 are Iraq, Iran, Russia, Libya, France, UAE, Azerbaijan, Ukraine, Germany and Saudi Arabia, respectively. The biggest share in cosmetic products exported from Turkey belongs to shaving products and deodorants. Export rate was 11% higher in 2013 than the previous year in this product class, and approximately 277 million dollars worth of export occurred. In Figure 2.5 the cosmetic product exports by categories and in Figure 2.6 2013 exports shares by countries are expressed (ITC – Trade Map).

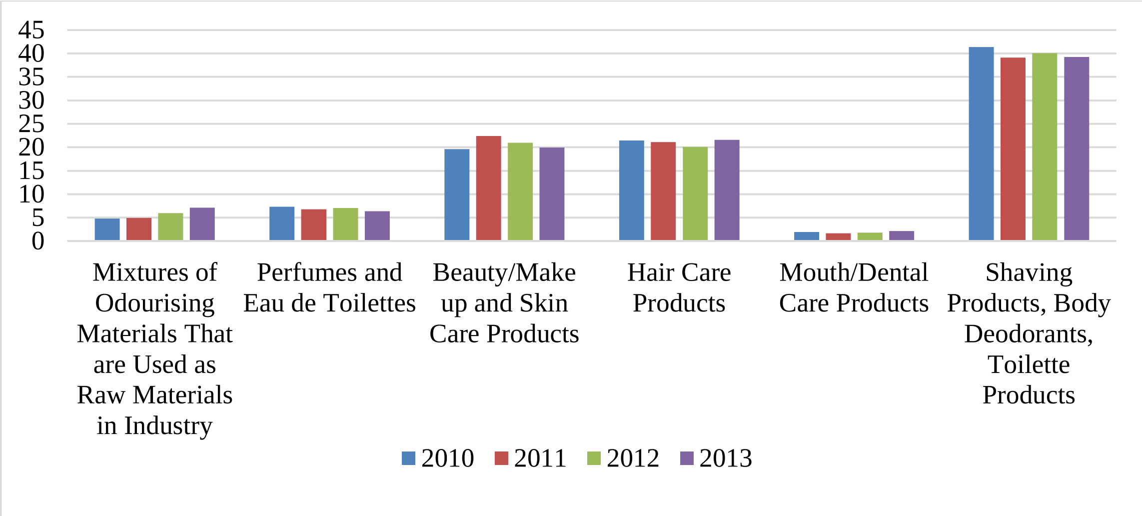


Figure 2.5. Cosmetic products exports (%).

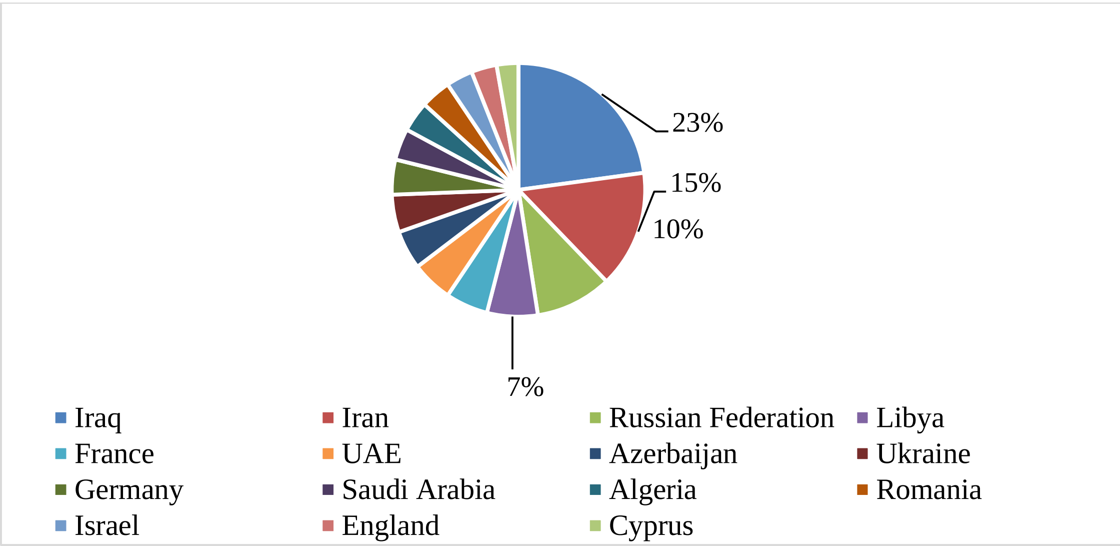


Figure 2.6. 2013 export shares by countries (%).

2.4.2. Cosmetic Products Import

Turkey mostly imported cosmetic products in 2013 from Germany, France, Ireland, Poland and Switzerland. Mixtures of odorizing materials used as raw materials in the industry had the highest number of imports, and beauty/make up, skin and hair care products followed the lead. In Figure 2.7 the cosmetic product imports by categories and in Figure 2.8 2013 import shares by countries are expressed (ITC – Trade Map).

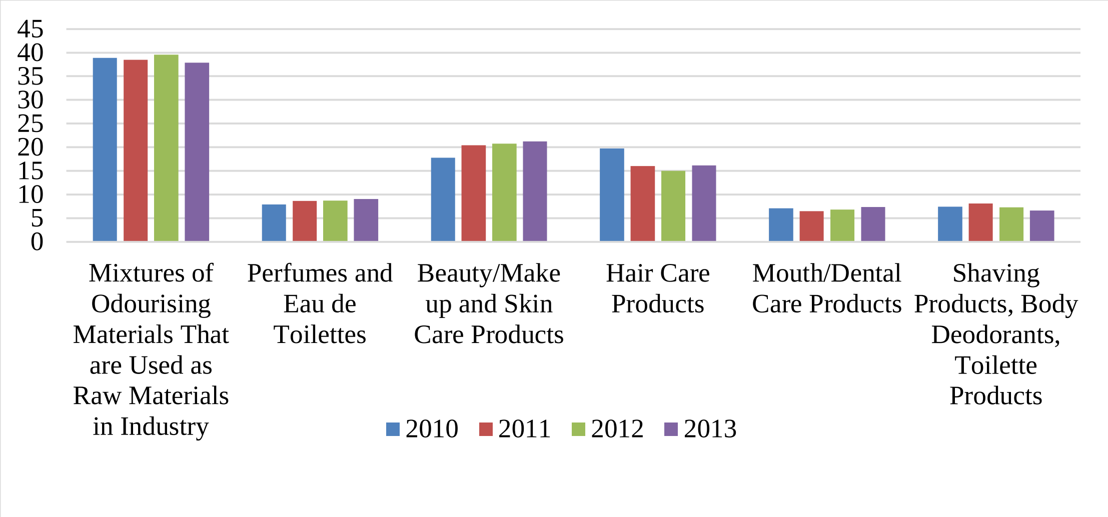


Figure 2.7. Cosmetic products imports (%).

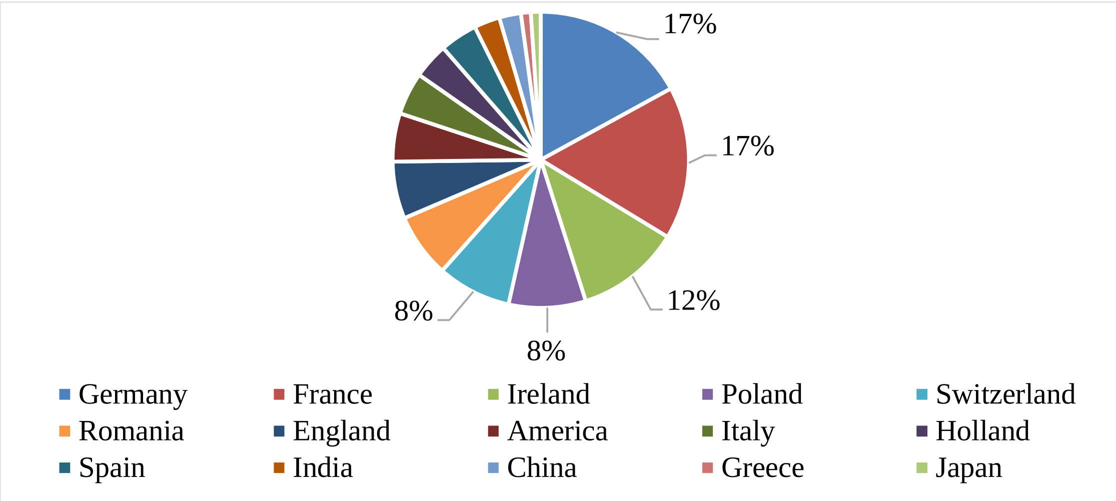


Figure 2.8. 2013 import shares by countries (%).

2.5. Life Cycle Assessment

Life Cycle Assessment (LCA) is defined as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (ISO, 2006a). Around the world, LCA has become a well-known instrument for studying environmental effects. LCA is a an evaluation tool of environmental performance throughout the activities in creating a product or performing a service. It does so by identifying and quantifying extraction and consumption of resources and releases to air, water, and soil. It enables to assess those energy and material uses and releases on the environment, implement opportunities to effect environmental improvements, and describe how the environmental exchanges of the system can be expected to change as a result of actions taken in the system as well. The potential contribution of the activities in creating a product or performing a service is assessed by environmental impact categories. These categories include climate change, resource depletion, human toxicity, photochemical ozone depletion, acidification and eutrophication (UNEP, 2011).

For the life cycle assessment, the analysis is done based on ISO standards 14040:2006 and 14044:2006. Also, the referenced literature data are used to have foresighted vision on cosmetic products. The LCA study conducts an analysis of how using alternatives for hazardous substances with high environmental impact could change the outcome. These technical findings are especially taken into consideration when it comes to the identification of chemicals of high concern, and possible substances which may replace them. The results of an LCA quantify the potential environmental impacts of a product system over the life cycle, help to identify opportunities for improvement and indicate more sustainable options where a comparison is to be made (Beer et al., 2007).

2.5.1. Structure of Life Cycle Assessment

According to the ISO 14040 series, LCA is structured in four phases; goal and scope definition, inventory analysis, impact assessment and interpretation. These are indicated in Figure 2.9 (UNEP, 2011).

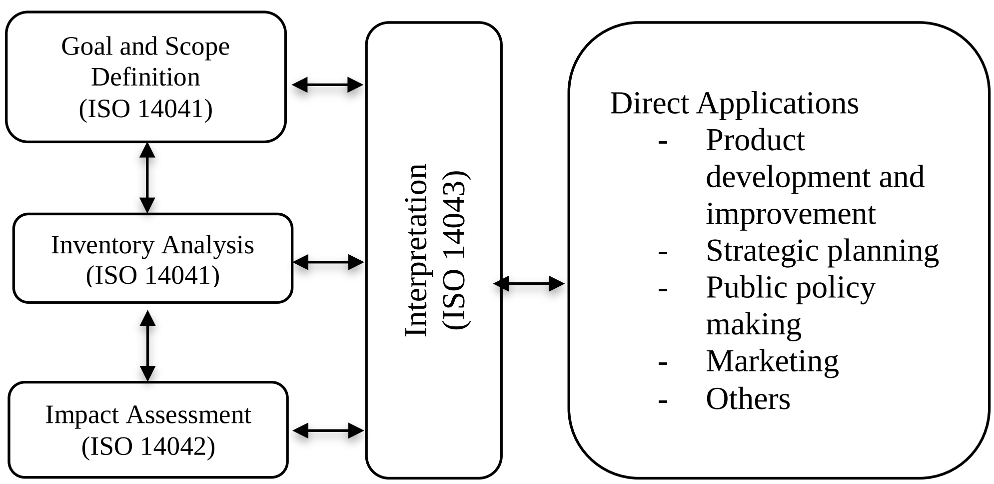


Figure 2.9. Structure of life cycle assessment.

The UNEP/SETAC Life Cycle Initiative divides the environmental impacts into categories in the UNEP/SETAC Life Cycle Impact Assessment Midpoint-Damage Framework (Jolliet et al., 2004) (Figure 2.10). Within this framework, resource consumption and emissions in the life cycle inventory (LCI) analysis are linked to midpoint impact categories such as climate change, resource depletion, human toxicity, photochemical ozone depletion, acidification and eutrophication; and final damage categories such as human health, ecosystem quality, and resource depletion.

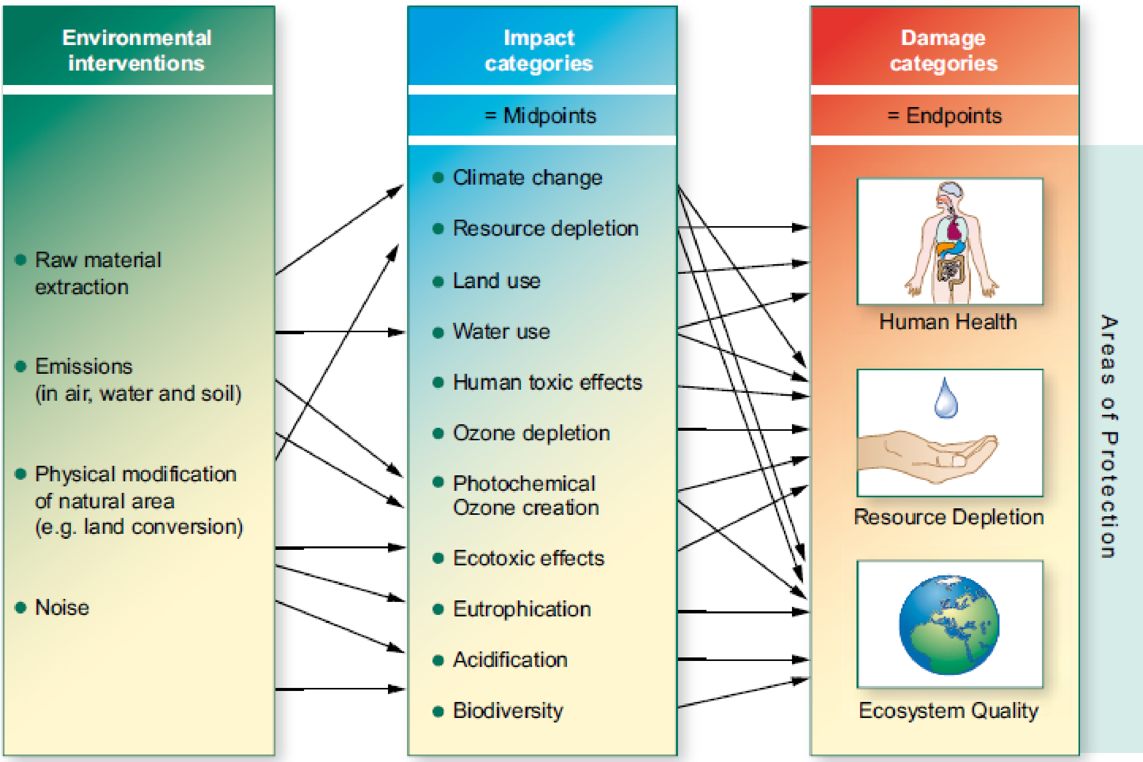


Figure 2.10. UNEP/SETAC LCIA Midpoint-Damage Framework.

2.5.2. Methodology Selection

In LCA methodologies, different aspects can be considered, such as midpoint and endpoint point of view. Endpoint modeling enables more structured and defined weighting. However, extending the models to endpoints reduces their level of comprehensiveness since a significant number of assumptions or values choices are used for extensions from mid- point to end-point methods. Moreover, that extensions may not reflect the viewpoint of other experts and/or the user. the user would be able to see the comparative results at the midpoint level, as well as at the endpoint level, and can provide both sets of information to decision makers within a consistent framework (Hofstetter et al., 2000). In LCA methods, overall impact classes, impact categories, normalization references and weighting factors can be considered (Bey, 2000). LCA methodologies can be divided into two groups due to the choice of an impact category indicator result. The result can be selected either at the midpoint or endpoint level.

Midpoint impact category methodology is the problem-oriented approach, which converts impacts into environmental themes such as climate change, acidification, human toxicity, etc. A midpoint indicator can be defined as a parameter in a cause- effect chain or environmental mechanism for a particular impact category that is between the inventory data and the category endpoints. Although in general this definition will hold true, such as in categories like climate change and acidification, it may not be fully adequate in others (Ekici, 2000). Endpoint impact category methodology, also known as the damage-oriented approach, converts environmental impacts into issues of concern such as human health, natural environment, and natural resources. Endpoint characterization factors are calculated to reflect differences between stressors at an endpoint in a cause-effect chain. This may be of direct relevance to society's understanding of the final effect, such as measures of biodiversity change. In some impact categories, more than one endpoint measure exists (Bare et al., 2000). For evaluations, endpoint results have higher level of uncertainty compared to midpoint results, however the complexity of the analysis is lower than midpoint results (PE International, 2011). The user can see the comparative results at the midpoint level, as well as at the endpoint level and can provide both sets of information to decision makers within a consistent framework.

According to selection of tools used for LCA Analysis, there are certain requirement categories which LCA software should be able to fulfill. It should be user friendly, stable, accurate, compatible with other softwares, flexible and automatized. Further, it should have an understandable documentation system, a quick support and maintenance opportunity and an affordable cost (Brunner and Rechberger, 2004). GaBi 6.0 Software, which was developed by Institute for Polymer Testing Science (IKP) at the University of Stuttgart in cooperation with PE Europe GmbH in Germany, is used in industrial, academic and consultancy purposes. This tool can provide solutions for different problems regarding cost, environment, social and technical criteria, optimization of processes.

3. MATERIALS AND METHODS

The LCA methodology according to ISO 14040–44 (ISO 14040, 2006; ISO 14044, 2006) is used to draw a comprehensive environmental picture of the defined integrated approach for the assessment and comparison of the environmental impacts of the hair conditioner and oil spray production scenarios. Additionally, alternative scenarios on the manufacture of each product are weighted to reduce environmental footprint, and both products are evaluated in terms of EU Ecolabel criteria for hair care products.

This study aims to analyze and compare the environmental impacts of different formulations by using EcoInvent database and CML assessment methodology. LCI datasets used in EcoInvent are based on industrial data. This database is internationally used and updated regularly, culminating in high quality results. Moreover, several eco-design tools use it as a background database, helping to list all the factors needed for ecolabelling (Frischknect et al, 2005).

The CML methodology developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands in 2001, contains more than 1700 different flows. This methodology groups the life cycle impact consequences into midpoint categories, according to common mechanisms or groupings. Besides providing baseline impact category groups (such as acidification potential-average Europe, climate change-GWP100 and depletion of abiotic resources-elements/fossil fuels), it also provides a variety of non-baseline categories (such as acidification potential-generic, climate change-GWP20 and depletion of abiotic resources-economic reserve) (Acero et al, 2004). In CML methodology, normalization is applicable; although being an optional step in LCA, no baseline method is proposed for weighting (ILCD Handbook, 2010).

3.1. Goal and Scope Definition

Goal and scope phase defines the overall frame of the study by pointing out the purpose of the study, functional unit, system boundary, data sources, assumptions and limitations of the study such as time, place and life cycle stages, quality of necessary data, the required level of detail and determines the demands on the further phases.

The goal of this study is to evaluate and contrast the environmental performance of regular hair conditioner and oil spray formulations provided by a private company in Turkey. Oil spray is an alternative product which plays the same role as the regular hair conditioner. Yet, its physical structure and environmental performance are considerably different from the regular hair conditioner product. Oil spray is used after shower and need not to be rinsed off. The environmental impacts of regular hair conditioner and oil spray formulations throughout their entire life cycles are analyzed by the Life Cycle Assessment (LCA) methodology. The products are compared in terms of their potentials in global warming, acidification, eutrophication, ozone layer depletion and photochemical ozone creation. Plastic and cardboard packaging waste management and domestic wastewater treatment practices, as well as energy production conditions specific to Turkey are collected as a part of a country-specific data required for constructing this LCA study.

Table 3.1. Selected scenarios for regular hair conditioner and oil spray production.

Scenario 1	Alternative scenario for transportation: the maximum distance is considered as 500 km.
Scenario 2	Alternative scenario for raw materials: determination of harmful raw materials and replacing them with their substitutions.
Scenario 3	Refilling packs: bringing 30% of the bottles back to the stores and refilling the conditioner/spray bottles in the factory.

Three different scenarios are applied to both regular hair conditioner and oil spray products. Each result is compared with the conventional production system to determine the best option. Selected scenarios are shown in Table 3.1. These scenarios are investigated by the application of GaBi 6.0 Software.

3.1.1. Functional Unit

All relevant inputs and outputs in the Life Cycle Inventory (LCI), and final impact scores generated in Life Cycle Impact Assessment (LCIA) are expressed with a reference flow, named functional unit. It must be clearly defined and must be measurable. The functional unit of our LCA study will be expressed as “one bottle of hair conditioner (0.195 kg/bottle)” and “one bottle of oil spray (0.2077 kg/bottle)”.

Table 3.2. Product properties.

Function	**Hair Conditioner**	**Oil Spray**
Volume	200 mL/bottle	210 mL/bottle
Packed Product Weight	223 g/bottle	241 g/bottle
Dosage	14.5 g/use – 14.9 mL/use	0.00119 g/use – 1.2 mL/use
Number of use	14 use/bottle	175 use/bottle

3.1.1.1. Obligatory and Secondary Properties of Selected Products

Obligatory properties are the features that the product must have and are included in the functional unit. Products must met the criteria regarding Cosmetics Regulation (date: 23.05.2005, official gazette number: 25823), Cosmetics Law (date: 24.03.2005, official gazette number: 5324) and Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products. Additional properties have given in the following table (Table 3.3) indicating whether they are obligatory (O) or secondary (S) properties.

Table 3.3. Obligatory (O) and Secondary (S) properties.

		Hair Conditioner		Oil Spray	
		(O)/(S)	**Properties**	**(O)/(S)**	**Properties**
Primary Packaging Materials	**Bottle**	O	HDPE	O	PET
	Cap	O	PP	O	PP
	Pump	-	N/A	O	PP (48.07%), HDPE (36.89%), LDPE (0.61%), Steel (4.08%), Other Plastic (10.35%)
Use Phase	**Rinsing**	O	hair conditioner must be rinsed	O	oil spray doesn't need to be rinsed
Generated Solid Waste and Wastewater Pre-Treatment Sludge	**150102 coded PP and PE**	O	directed to licensed recovery plant	O	directed to licensed recovery plant
	160305 coded waste	O	directed to incineration plant	O	directed to incineration plant
	150110 and 150202 coded waste	O	directed to incineration plant	O	directed to incineration plant
	Sludge pre-treatment	S	directed to the cement plant for recovery	S	directed to the cement plant for recovery

3.1.2. System Boundaries

System boundary points out the burdens of the system under survey and interface of the environment. It also defines which unit processes are included in or excluded from the survey (ISO 2006a). The boundaries of this study include raw material acquisition of all the materials used in production of the conditioners including their transportation to the production site, manufacture of the products, transportation of the finished products to final consumer, the use of the products by consumers and disposal of the packaging waste. Included life cycle stages are illustrated in more detail in Figure 3.1 and Figure 3.2.

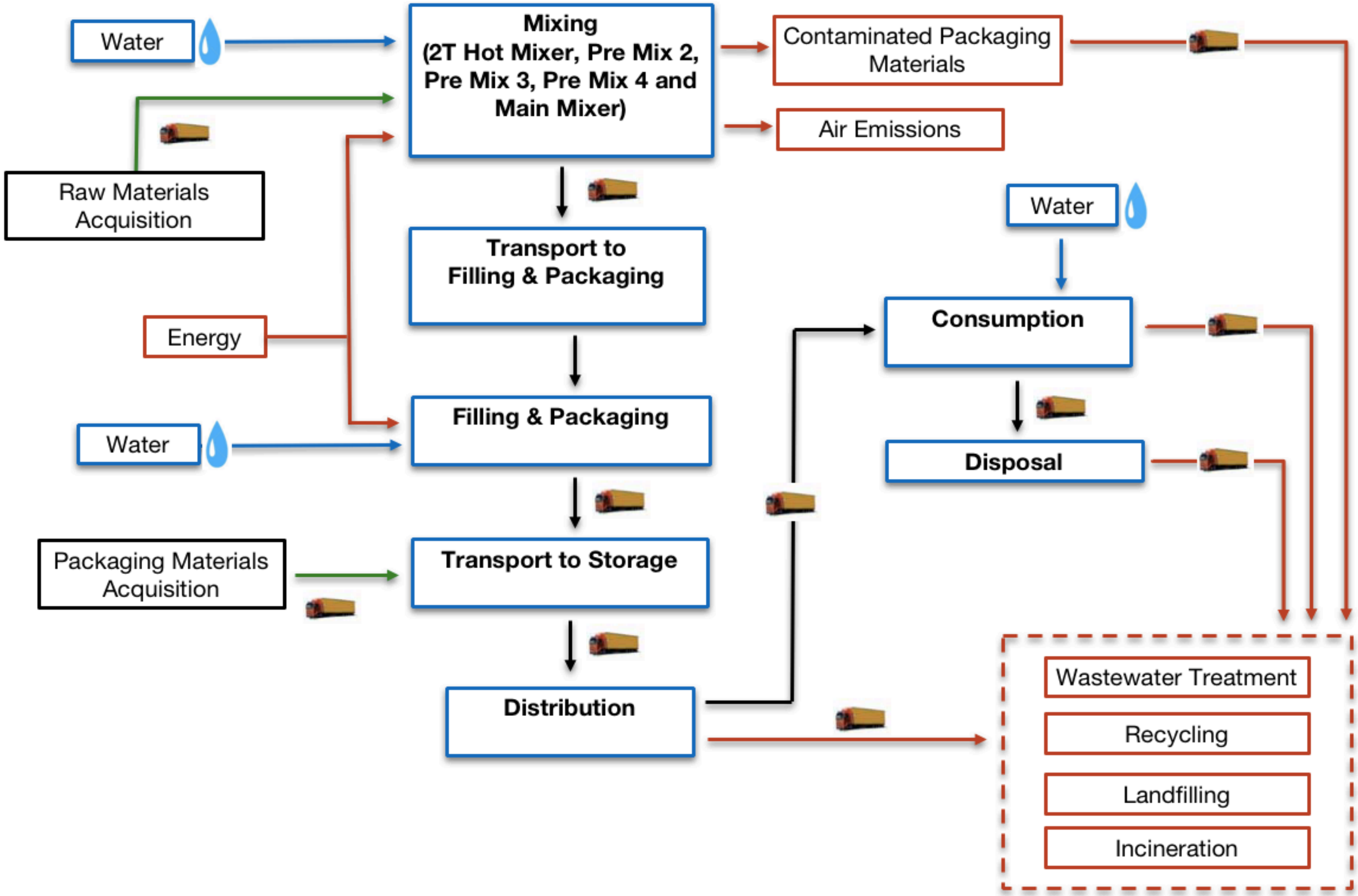


Figure 3.1. The hair conditioner production system boundaries developed for this study.

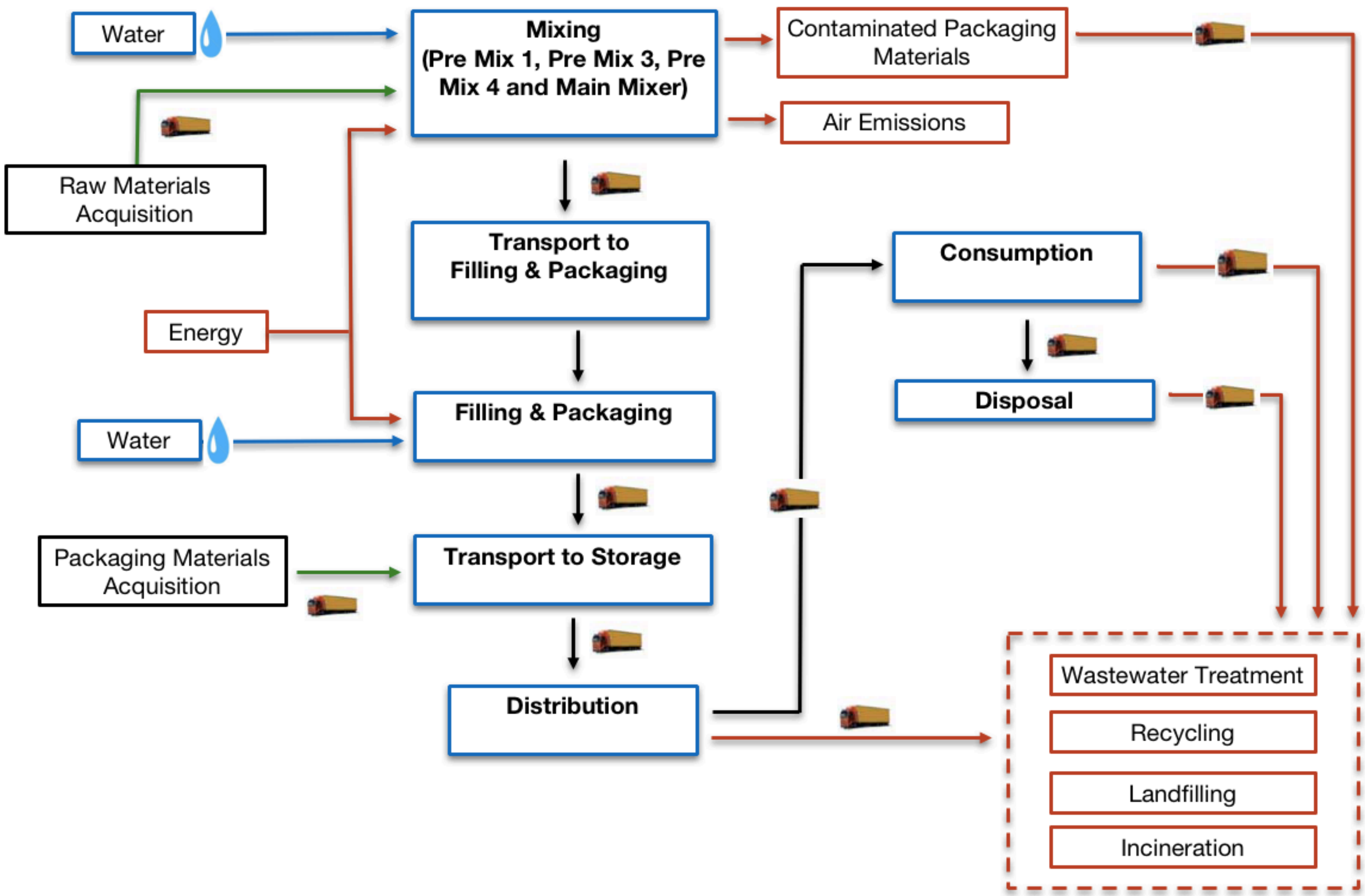


Figure 3.2. The oil spray production system boundaries developed for this study.

Regular hair conditioner life cycle consists of six main stages; raw materials acquisition, mixing, filling and packaging, distribution, consumer use and disposal. The raw material acquisition stage includes energy spending and emissions associated with production of the raw materials used in manufacturing of the products, as well as their transport to the factory. Production processes were considered for all ingredients.

Mixing stage includes four different side mixers, and one main mixer in which the mixture becomes ready for filling and packaging stage. In regular hair conditioner production, both cold and hot demineralized water is used to cool and warm up the walls of the side mixers. These stages cover all the energy spending, chemical and water consumption and emissions in the manufacture of the product. This study considers two types of packaging. Plastic bottles that contain the product, caps, front and back labels and shrink barcodes are considered as the primary packaging. On the other hand, secondary packaging is used for transportation of the finished products, and is made of either corrugated cardboard or LDPE stretch film. Filling and packaging process is conducted by a fason company for 200 mL of regular hair conditioner. For this reason, additional transport processes from the production facility to a fason company and from the fason company to the storage have to be assessed. Finished products are either delivered directly to supermarkets in case of large supermarket chains, or to regional distribution points for smaller supermarkets. The factory is located in the organized industrial site of Gebze, approximately 50 km away from Istanbul. Average transport distance from the factory was calculated as 602 km, based on the distance to main distributors, and volume of the transported products. However, this calculation does not take into consideration the transportation to large supermarket chains, majority of which are located in Istanbul, only 50 km away from the factory.

Calculation based on population density revealed a 545 km of average transport distance. Considering inevitable inaccuracies with regard to distance calculations, the average transport distance was rounded to 500 km for all products and formulation. Consumer use stage is basically the washing process in which the analyzed hair conditioner product is rinsed. The electricity and water inputs are calculated based on the water and energy expenditure of an average consumer in Turkey. Disposal stage of hair conditioner life cycle in this study includes disposal of primary and secondary packaging resulting from the consumer use stage of the product. The amount of the recycled material is subtracted from the total amount, and the remaining waste is landfilled. The waste disposal methods and the amounts of waste delivered to controlled landfill site and/or dumping sites were obtained from the “Municipal Waste Disposal Methods Statistics” document published by the Turkish Statistical Institute in 2014. In this report, it is indicated that 63.6% of municipal solid waste is sent to the controlled landfill sites and 35.5% of municipal solid waste is sent to municipality’s dumped site. Remaining are disposed to lakes and rivers (0.06%), buried (0.02%), delivered to composting plants (0.4%) and treated with other methods (0.41%) (TUIK, 2014). Further, disposal stage includes the wastewater, which is generated from consumption stage and fason company’s CIP activities, separately. These two are discharged to municipal wastewater treatment systems.

Oil spray life cycle differs from the life cycle of the regular hair conditioner in two main stages. The first one is the mixing stage; it includes three different side mixers and one main mixer in which the mixture becomes ready to filling and packaging process. In oil spray production there isn’t an application to cool and/or warm up the wall of the mixers. The second one is the consumer use stage. Water is not consumed while using oil spray, as the product would not have to be rinsed. Raw material acquisition, filling and packaging, distribution and disposal stages are the same as regular hair conditioner life cycle.

Additionally, there is a wastewater pre-treatment plant in the facility, in which the generated wastewater from production (reverse osmosis process and clean in place (CIP) applications) is pre-treated and discharged to organized industrial zone’s combined system. The sludge originating from the wastewater pre-treatment plant is directed to the cement plant and recovered.

The information regarding the COD removal rate at wastewater treatment plants in Turkey are based on the current “Municipal Wastewater Treatment Regulation” of Turkey published in the Official Gazette of Turkey (no: 26047) on 08.01.2006;

- Average COD removal during pre-treatment – **30%**
- Minimal COD removal requirement of the secondary wastewater treatment – **75%**

Since, no limitations are imposed on the primary wastewater treatment efficiency in the regulation, a literature survey was conducted to find an approximate COD removal efficiency of the primary treatment. The percentage of the wastewater treated at the wastewater treatment plants as well as the ratio of the secondary and advanced treatments were obtained from the "Municipality Wastewater Statistics" document published by the Turkish Statistical Institute in April, 2008 (TUIK, 2008). Data in the document is based on the comprehensive survey study that encompassed all 3225 municipalities of Turkey. The document also provides information about the ratio of wastewater discharged to sea and fresh water basins. In this way, COD emissions are examined separately in GaBi;

- The percentage of treated wastewater **– 64%**
- The percentage of physical (primary) treatment **– 33.4%**
- The percentage of biological (secondary) treatment **– 43.3%**
- The percentage of tertiary (advanced) treatment **– 23.3%**

COD influent of the generated wastewater is 24.29 kg and with 30% efficient pre-treatment system, COD effluent is considered as 17.003 kg for one batch (5000 kg) of product. Organized industrial zone treated the collected wastewater according to the discharge standards mentioned in "Water Pollution Control Regulation" published in the Official Gazette of Turkey (no: 25687) on 31.12.2004.

3.2. Life Cycle Inventory Analysis and the Key Assumptions

Life Cycle Inventory (LCI) is the list of resources, outputs and emissions to air, water and land associated with the product. Therefore, LCI stage involves data collection and calculation procedures to quantify relevant inputs and outputs. The stage includes development of a flow diagram of the processes being evaluated, data collection and evaluation, and reporting of results (ISO 2006a). Detailed information for the hair conditioner and oil spray production is collected from the production plant. The collected data set is on energy consumption, raw materials and additives used, and generated emissions at the facility for each stage of hair conditioner and oil spray production. The inventories for both regular hair conditioner and oil spray production are calculated compatibly with functional units. Table 3.4 illustrates the key assumptions for the production for LCA calculations.

Table 3.4. Key assumptions for the input data.

Input Data	**Selected Process from GaBi 6.0**				
Transportation	Truck, RM (Inland)	Truck, Waste	Truck, RM (Outland)	Tanker	Cargo Plane
	Euro 4, 11.4 ton	Euro 3, 9.4 ton	Euro 4, 27 ton	1500 ton	113 ton
Fuel	Diesel, at refinery				
Electricity	Electricity, medium voltage, production				
Water	Tap water, at user				
Incineration	Waste incineration of plastics (PE, PP, PS, PB) ELCD/CEWEP				
Landfilling	Landfill (Municipal household waste; AT, DE, IT, LU, NL, SE, CH) PE				
Natural Gas	Natural gas, production mix, at service station				

3.2.1. Selected Hair Conditioner Product

In order to select correct data within the system, the composition of the raw materials for the product was listed, and in doing that different ways were followed. Chemicals which are included in EcoInvent database were counted for directly. For the ones which are not in the database; approximations were applied according to chemical structures and production technologies. The selected data from EcoInvent database is presented in the table below (Table 3.5).

Table 3.5. The selected data from EcoInvent.

Raw Materials	**Data Selected**
Cetearyl Alcohol	Fatty alcohol production, from coconut oil
Stearamidopropyl Dimethylamine	Dimethylamine, at plant
Behentrimonium Chloride, Dipropylene Glycol	Trimethylamine, at plant
PEG 6000 Disterate	Ethylene glycol, at plant
Perfume	Benzyl alcohol, production
L-Panthenol	Fatty alcohol, production, from coconut oil
Ethylhexyl Methoxycinnamate	Toluene, liquid, at plant
Lysine HCl	Fatty acids, from vegetarian oil, at plant
Disodium EDTA	EDTA, ethylenediaminetetraacetic acid
Sodium Chloride	Sodium Chloride, powder, at plant
Lactic Acid	Fatty acids, from vegetarian oil, at plant
Silicone	Silicone product, at plant
DMDM Hydantoin	Formaldehyde, production mix, at plant
Methylchloroisothiazolinone, Methylisothiazolinone	Biocides, for paper production, unspecified, at plant

In Scenario 2, instead of harmful chemicals, alternative ones were selected to decrease the environmental footprint of a regular hair conditioner. In Table 3.6 the substitutions are presented.

Table 3.6. Alternative chemicals used for Scenario 2 (S2).

Raw Materials	**Data Selected for Scenario 2**
Behentrimonium Chloride	Dimethyl sulphate, at plant
Perfume	Crude coconut oil, at plant
Methylchloroisothiazolinone, Methylisothiazolinone	Phenoxy-compounds, at regional storehouse

The chemicals used in the production of the selected hair conditioner are listed in Table 3.7 with their physical, chemical and biological properties, environmental hazards and roles in formulation. CAS numbers of the raw materials are given in Appendix B, Table B.1.

The energy and emission inventory elements for the regular hair conditioner manufacturing scenario generated for LCA through input and output balances is shown in the following figure (Figure 3.3).

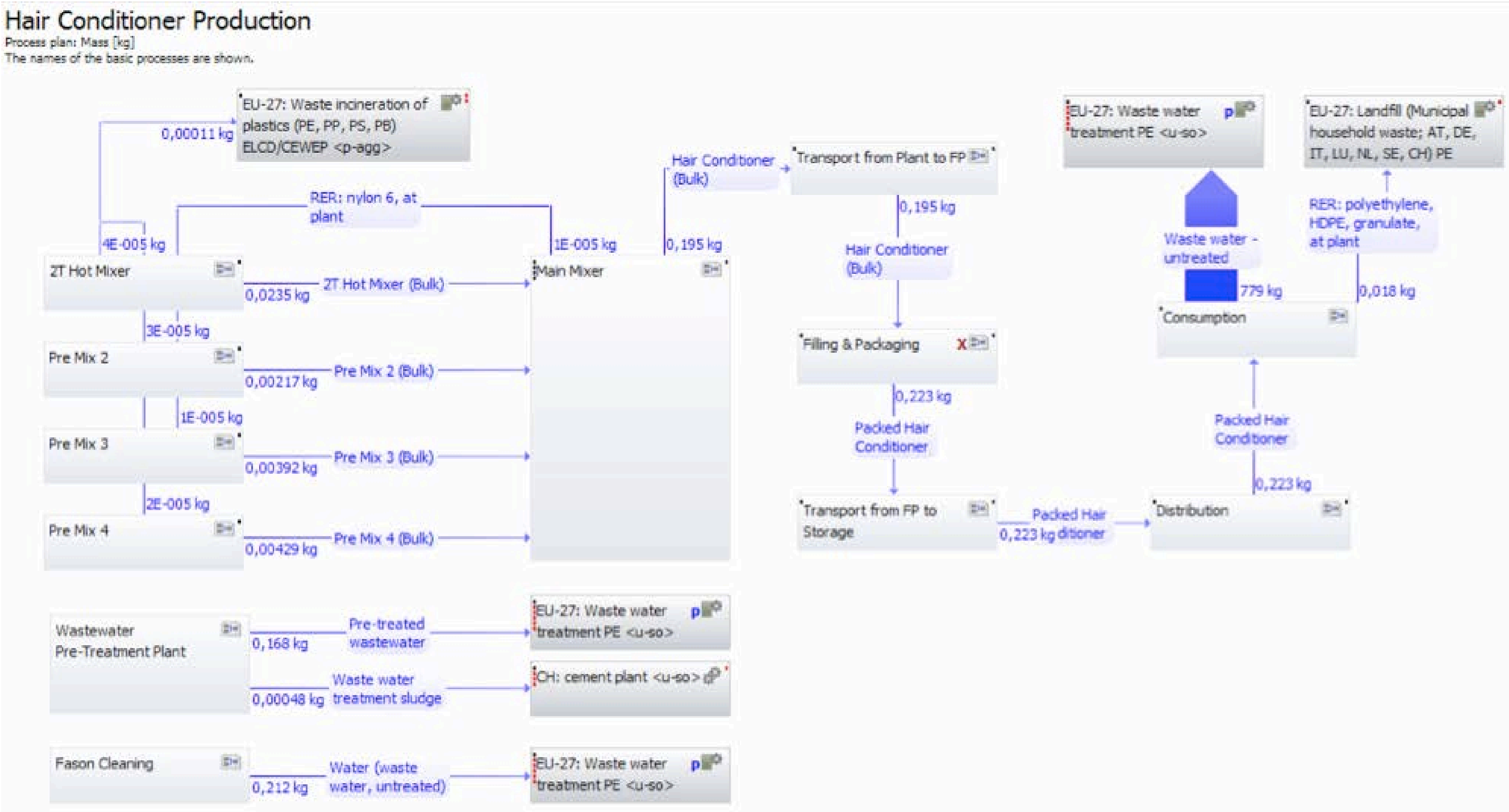


Figure 3.3. Production flow for one bottle (0.195 kg/bottle) of regular hair conditioner.

Table 3.7. The chemicals used in selected hair conditioner production.

Raw Materials	Physical & Chemical Properties	Biological Properties	Role
Cetearyl Alcohol	Waxy, odorless, white, insoluble in water. Flash point > 157 °C Solidification temp: 46-49 °C Density (50 °C): 0.81-0.83 g/cm^3	Good but not readily biodegradable. Acute oral toxicity LD_{50} >5000 mg/kg body weight Acute fish toxicity LC_{50} >100 mg product/L Acute bacterial toxicity EC_{50} >100 mg product/L	Fat phase, consistency agent
Stearamidopropyl Dimethylamine	Solid, amine odor, cream-light tan, insoluble in water. Boiling point > 300 °C Melting point: 69-70 °C Density (60°C): 0.94-0.95 g/cm^3 pH: 8.0-9.0 @ 10% Aq.	No special hazards for environment.	Quaternary Surfactants
Behentrimonium Chloride, Dipropylene Glycol*	Pellets, yellowish-white, characteristic odor, hygroscopic, partially soluble in water. Melting point: 70-80 °C Boiling point > 200 °C Flash point: 145 °C Density (20 °C): 0.9 g/cm^3 pH: 5.0-7.0	Good but not readily biodegradable, 60% ≈ 28 days Acute oral toxicity LD_{50} >2000 mg/kg (mouse) Acute fish toxicity LC_{50} >0.5 mg product/L Acute bacterial toxicity EC_{50} >53.8 mg product/L DOC: 696 mg/g COD: 2495 mg/g	Quaternary Surfactants

PEG 6000 Disterate	Solid, off-white flake, mild odor, partially soluble in water. Melting/Freezing point: 56 °C Boiling point: 150 °C Flash point: 249 °C pH: 4.0-6.0	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.	Viscosity Adjustor
Lactic Acid	Aqueous solution, colorless-yellow-white brown, characteristic odor, completely soluble in water. Boiling point/range: 110 °C (40% solution) – 125 °C (90% solution) Decomposition temperature > 200 °C Density: 1.19-1.25 g/cm^3 pH < 2 @ 25 °C	Readily biodegradable, not bioaccumulative. Acute oral toxicity LD_{50}: 3730 mg/kg (rat) Acute oral toxicity LD_{50}: 4875 mg/kg (mouse) Acute dermal toxicity LD_{50} > 2000 mg/kg (rabbit) Acute fish toxicity LC_{50}: 320 mg/L (48 h) Acute bacterial toxicity EC_{50}: 240 mg/L (48 h) Acute bacterial toxicity EC_{50}: 3500 mg/L (algae) BOD_5: 0.45 mg O_2/mg, BOD_{20}: 0.60 mg O_2/mg COD: 0.90 mg O_2/mg	pH Adjuster
Lysine HCl	Powder, white, soluble in water. Melting point: 263-264 °C Solubility (20 °C): 63 g/100 g water pH: 5.0-6.0	Acute oral toxicity LD_{50}: 10.6 g/kg (rat) BOD: 1.041 g/g 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.	Emotive

Perfume*	Liquid, colorless, characteristic odor. Flash point: 80 ^{o}C Density: 0.964-0.974 g/cm^3	Potential for bioaccumulation: N/A Toxic to aquatic life, may cause long-term adverse effects in the aquatic environment.	Perfume
L-Panthenol	Liquid, slightly yellowish, odorless, fully soluble in water. Density (25 ^{o}C): 1.16 g/cm^3 pH: 5.5-7	Not easily biodegradable. Accumulation in organisms is not to be expected. Acute oral toxicity LD_{50} > 10000 mg/kg (rat) Acute fish toxicity LC_{50} > 10000 mg/L (96 h) Acute bacterial toxicity EC_{50} > 100 mg/L (48 h)	Emotive
Ethylhexyl Methoxycinna-mate	Liquid, slightly yellow, almost odorless, soluble in water. Flash point: 114 ^{o}C Boiling range: 198-200 ^{o}C Density (20 ^{o}C): 1.008-1.014 g/cm^3 Solubility (24 ^{o}C): 0.041 mg/L pH ≈ 7	Readily biodegradable and bioaccumulative. Acute oral toxicity LD_{50} > 5000 mg/kg (rat) Acute dermal toxicity LD_{50} > 5000 mg/kg (rat) Acute bacterial toxicity EC_{50} > 0.0271 mg/L (48 h)	UV Absorber
Silicone	Liquid, white, slight odor, solubility in water is not determined. Boiling point > 100 ^{o}C Flash point > 101 ^{o}C pH: 10	N/A No special hazards for environment	Silicones

DMDM Hydantoin	Granule, white, odorless, soluble in water. Melting point = 90-97 ^oC Flash point = 152 ^oC Solubility (20 ^oC): 700 kg/m^3 water	Acute fish toxicity LC_{50}: 1.0-2.0 mg/L (96 h) Acute bacterial toxicity EC_{50}: 8 mg/L (48 h) Toxic to aquatic life, may cause long-term adverse effects in the aquatic environment.	Preservative
Methylchloroiso-thiazolinone, Methylisothiazol-inone*	Liquid, colorless to slightly yellowish, mild odor, fully miscible in water. Boiling point: 100 ^oC Flash point: N/A Density (20 ^oC): 1.027 ± 0.01 g/cm^3 pH (20 ^oC): 3.5 ± 0.3	Readily biodegradable, not bioaccumulative. Acute oral toxicity LD_{50} > 67 mg/kg (rat) Acute dermal toxicity LD_{50} > 140 mg/kg (rat) Acute bacterial toxicity EC_{50} > 0.043 mg/L (120 h) Acute bacterial toxicity EC_{50} > 0.12 mg/L (48 h) Acute fish toxicity LC_{50} > 0.32 mg/L (96 h)	Preservative
Disodium EDTA	Powder, white, odorless, soluble in water. Ignition temperature > 200 ^oC Density: 0.7 g/cm^3 Solubility: 100 g/L pH: 4.0-5.0	Not easily biodegradable, accumulation in organisms is not to be expected. Acute oral toxicity LD_{50} > 2000 mg/kg (rat) Acute fish toxicity LC_{50}: 320 mg/L (96 h) Acute bacterial toxicity EC_{50}: 140 mg/L (48 h)	Buffer
Sodium Chloride	Crystal, white, odorless, soluble in water. Melting point: 801 ^oC Boiling point: 1485 ^oC Density: 2.16 g/cm^3 Solubility (25 ^oC): 356 g/L	N/A The product itself and its products of degradation are not toxic.	Viscosity Adjustor

*: Harmful raw materials for the environment.

3.2.2. Selected Oil Spray Product

In order to select correct data within the system, the composition of the raw materials for the product was listed, and different ways were followed. Chemicals which are included in EcoInvent database were counted for directly. For the ones which were not in the database; approximations were applied according to chemical structures and production technologies. The selected data from EcoInvent database is presented in the table below (Table 3.8).

Table 3.8. The selected data from EcoInvent.

Raw Materials	**Data Selected**
Glydant Plus, Iodopropynyl Butylcarbamate	Formaldehyde, production mix, at plant
Glycerin	Glycerine, from rape oil, at esterification plant
Cetrimonium Chloride	Ammonium chloride, at plant
PEG/PPG-18/18 Dimethicone, Cyclopentasiloxane	Silicone product, at plant
Cyclomethicone	Silicone product, at plant
Dimethicone	Silicone product, at plant
Phenyl Trimethicone	Silicone product, at plant
Benzophenone-4	Benzoic-compounds, at regional storehouse
Lysine HCl	Fatty acids, from vegetarian oil, at plant
Disodium EDTA	EDTA, ethylenediaminetetraacetic acid
Polyquaternium-16	N-methyl-2-pyrrolidone, at plant
Perfume	Benzyl alcohol production
Babassu Oil	Chemicals organic, at plant
Argan Oil	Chemicals organic, at plant
Panthenol	Fatty alcohol,production, from coconut oil
Hydrolised Keratin	Chemicals organic, at plant

In Scenario 2, instead of the harmful chemicals, alternative ones were selected to decrease the environmental footprint of oil spray. In Table 3.9 the substitutions are presented.

Table 3.9. Alternative chemicals used for Scenario 2 (S2).

Raw Materials	**Data Selected for Scenario 2**
Glydant Plus, Iodopropynyl Butylcarbamate	Carbamate-compounds, at regional storehouse
Cetrimonium Chloride	2-Hydroxy-3-(trimethylammonio) Propyl Ether Chloride, at plant
Hydrolised Keratin	Crude coconut oil, at plant

The chemicals used in selected oil spray production are listed in Table 3.10 with their physical, chemical and biological properties, environmental hazards, roles in formulation and percentages in formulation. CAS numbers of the raw materials are presented in Appendix B, Table B.2.

The energy and emission inventory elements for the regular hair conditioner manufacturing scenario generated for LCA through input and output balances is shown in the following figure (Figure 3.4).

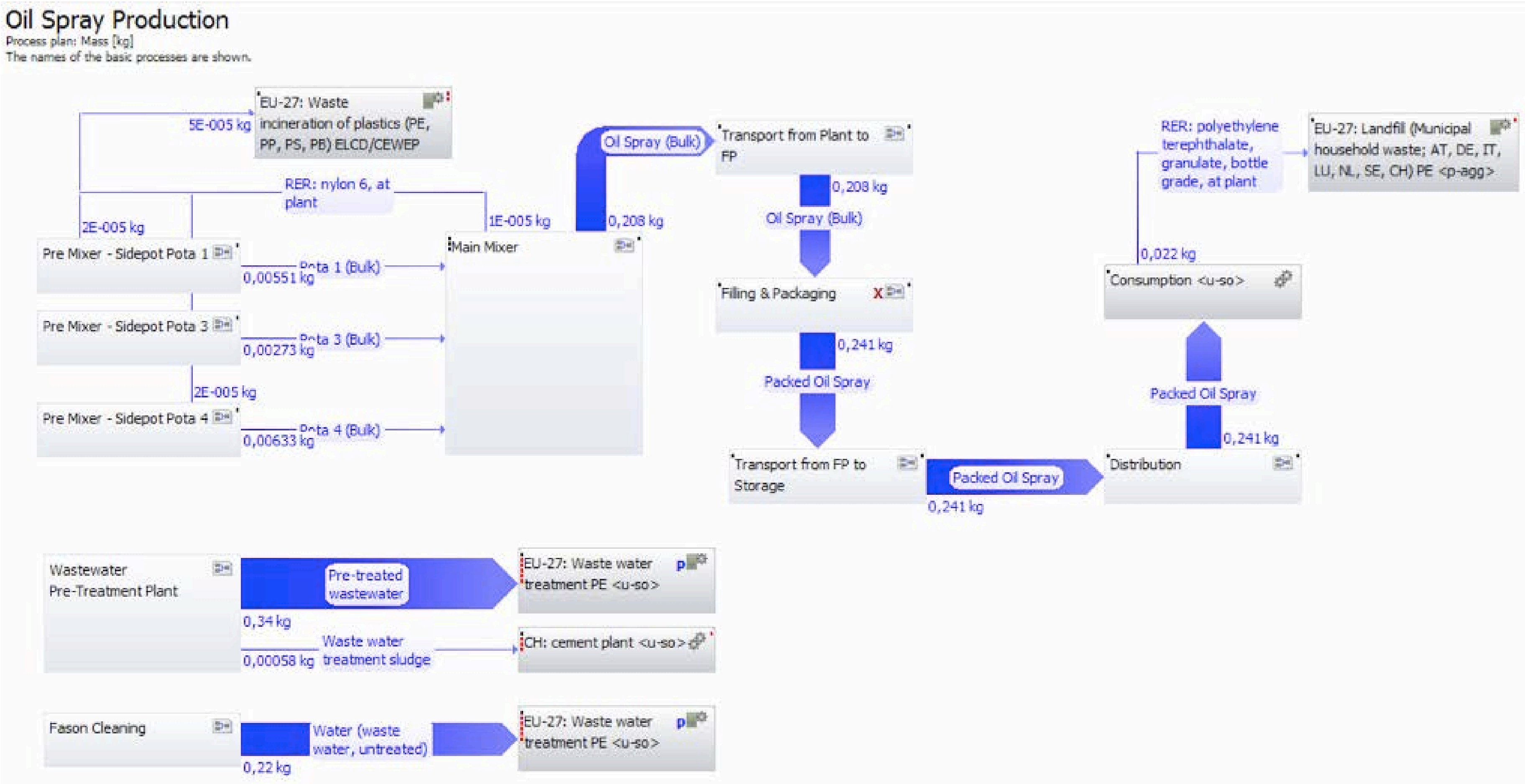


Figure 3.4. Production flow for one bottle (0.2077kg/bottle) of oil spray production.

Table 3.10. The chemicals used in selected oil spray production.

Raw Materials	**Physical & Chemical Properties**	**Biological Properties**	**Role**
Glydant Plus, Iodopropynyl Butylcarbamate*	Granule, white, odorless, soluble in water. Melting point = 90-97 ^{o}C Flash point = 152 ^{o}C Solubility (20 ^{o}C): 700 kg/m^3 water	Acute fish toxicity LC_{50}: 1.0-2.0 mg/L (96 h) Acute bacterial toxicity EC_{50}: 8 mg/L (48 h) Toxic to aquatic life, may cause long-term adverse effects in the aquatic environment.	Preservative
Benzophenone-4	Powder, white to yellow, characteristic odor, soluble in water. Flash point > 100 ^{o}C Melting point > 120 ^{o}C 1.2 < pH < 2.2	Not readily biodegradable. Acute oral toxicity LD_{50}: 3530 mg/kg Acute dermal toxicity LD_{50}: N/A	Emotive
Lysine HCl	Powder, white, soluble in water. Melting point: 263-264 ^{o}C Solubility (20 ^{o}C): 63 g/100 g water pH: 5.0-6.0	Potential for bioaccumulation: N/A Acute oral toxicity LD_{50}: 10.6 g/kg (rat) BOD: 1.041 g/g No special hazards for environment.	Emotive
Glycerin	Liquid, colorless, odorless, soluble in water. Boiling point: 290 ^{o}C Flash point: 177 ^{o}C Density (20 ^{o}C): 1.26 g/cm^3, pH: 5.0	Completely biodegradable. Acute oral toxicity LD_{50}: 9200 mg/kg (rat)	Water phase

Cetrimonium Chloride*	Liquid, slightly yellowish, characteristic odor, soluble in water. Boiling point: 100 ^{o}C Flash point > 100 ^{o}C Density (20 ^{o}C): 0.97 g/cm^3 pH: 5.0-7.0	Readily biodegradable, low potential for bioaccumulation. Acute oral toxicity LD_{50}: 1550 mg/kg (rat) Acute dermal toxicity LD_{50}: 528 mg/kg (rat) Acute fish toxicity LC_{50}: 0.7-1.0 mg/L (96 h) Acute bacterial toxicity EC_{50}: 3.2 mg/l	Conditioning
PEG/PPG-18/18 Dimethicone, Cyclopentasilox-ane	Liquid, translucent gray, characteristic odor, solubility in water is not determined. Boiling point > 65 ^{o}C Flash point: 77 ^{o}C	N/A No special hazards for environment.	Emulsifiers
Cyclomethicone	Liquid, colorless, odorless, partially soluble in water. Melting point: -44.15 ^{o}C Boiling point: 211 ^{o}C Flash point: 77.2 ^{o}C pH: 7.0	N/A They do not persist in water or soil. May bioaccumulate in closed test systems.	Lubricants
Dimethicone	Liquid, colorless, odorless, solubility in water is not determined. Boiling point > 35 ^{o}C Flash point > 101.1 ^{o}C, Density: 0.934 g/cm^3	N/A No special hazards for environment.	Lubricant

Phenyl Trimethicone	Liquid, colorless, odorless, solubility in water is not determined. Boiling point > 65 ^oC Flash point > 101 ^oC	No special hazards for environment. Acute dermal toxicity LD_{50} >2000 mg/kg (rabbit)	Lubricant
Disodium EDTA	Powder, white, odorless, soluble in water. Ignition temperature > 200 ^oC Density: 0.7 g/cm^3 Solubility: 100 g/L pH: 4.0-5.0	Not easily biodegradable, accumulation in organisms is not to be expected. Acute oral toxicity LD_{50} > 2000 mg/kg (rat) Acute fish toxicity LC_{50}: 320 mg/L (96 h) Acute bacterial toxicity EC_{50}: 140 mg/L (48 h)	Preservative
Polyquaternium-16*	Liquid, clear yellowish, faint specific odor, miscible in water. Boiling point: 100 ^oC Flash point > 100 ^oC Density (20 ^oC): 1.1 g/cm^3 pH: 7.0	Not readily biodegradable, accumulation in organisms is not be expected. Acute oral toxicity LD_{50} > 5000 mg/kg (rat) Acute dermal toxicity LD_{50} > 2000 mg/kg (rat) Acute bacterial toxicity EC_{50}: 17.7 mg/L (48 h) Acute fish toxicity LC_{50}: 0.7 mg/L (96 h)	Styling Aid
Perfume	Liquid, yellowish, flowery, fruity and woody odor, solubility in water is not determined. Flash point: 94 ^oC Density (20 ^oC): 0.975 g/cm^3	N/A No special hazards for environment. Prevent contamination of ground and surface water.	Fragrance

Babassu Oil	Oily liquid to fatty solid, yellowish white to yellow, characteristic odor, insoluble in water. Melting/Freezing point: 24.0-35.0 ^oC	Acute oral toxicity LD_{50} > 2000 mg/kg No special hazards for environment.	Emotive
Argan Oil	Liquid, yellow, characteristic odor, solubility in water is not determined. Flash point > 300 ^oC	Acute oral toxicity LD_{50} > 2000 mg/kg body weight No special hazards for environment.	Emotive
Panthenol	Liquid, slightly yellowish, odorless, fully soluble in water. Density (25 ^oC): 1.16 g/cm^3 pH: 5.5-7	Not easily biodegradable. Accumulation in organisms is not to be expected. Acute oral toxicity LD_{50} > 10000 mg/kg (rat) Acute fish toxicity LC_{50} > 10000 mg/L (96 h) Acute bacterial toxicity EC_{50} > 100 mg/L (48 h)	Emotive
Hydrolysed Keratin*	Liquid, amber, almost odorless, miscible in water. Density: 1.04-1.06 g/cm^3 pH: 5.0-5.8	Readily biodegradable. Acute oral toxicity LD_{50} > 5000 mg/kg body weight Acute fish toxicity LC_{50} > 100 mg product/l Acute bacterial toxicity EC_{50} > 100 mg product/l	Emotive

*: Harmful raw materials for the environment.

4. RESULTS AND DISCUSSION

Life Cycle Impact Assessment (LCIA) phase is evaluation of potential environmental impacts of the resources and releases of the surveyed system. This phase delivers essential information for the evaluation by associating the inflows and outflows resulting from the inventory analysis with specific environmental impact categories.

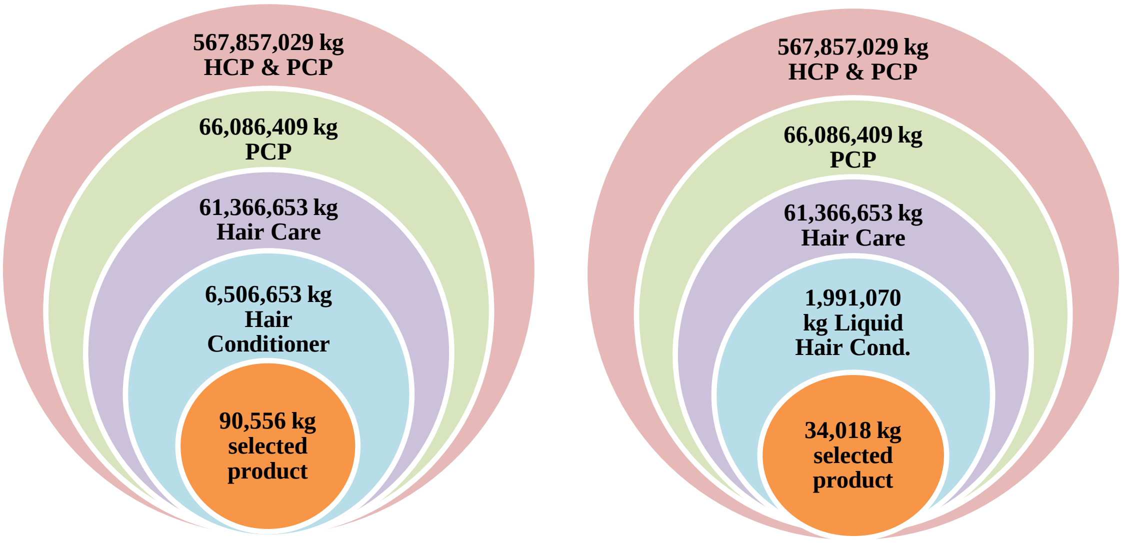


Figure 4.1. Hair conditioner (left) and oil spray (right) production amounts (2015).

The private company collaborated in this research manufactures some of the best known brands in the world, and those brands are present in 98% of households across the world. Their products are used by 2 billion people every day (USLP Report, 2014). In Figure 4.1 the annual amounts of production for both home and personal care products for 2015 are illustrated. Based on those amounts, the selected regular hair conditioner receives a share of 0.14% and the selected oil spray receives a share of 0.052% in general production of personal care products. The environmental impacts of products' whole life cycle that includes all life cycle stages are presented in this section.

4.1. Life Cycle Impact Assessment for Hair Conditioner Production

This part has been performed by using GaBi 6.0 Software program and EcoInvent database. All raw materials necessary for production and packaging stages have been determined. Flow diagrams 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, to assess the environmental impact; characterization, classification, normalization and weighting procedures are considered.

4.1.1. Classification

Inventory results are assigned to different impact categories, based on the expected types of impacts on the environment. Selected LCI data and the impact categories are shown in Table 4.1 below.

Table 4.1. Selected LCI data and impact categories in this study.

Impact Categories	Selected LCI Data	Unit
Global Warming Potential (GWP)	CO_2, N_2O, SF_6, NMVOC, CH_4	kg CO_2 eq.
Acidification Potential (AP)	NH_3, NO_x, SO_2, H_2SO_4	kg SO_2 eq.
Eutrophication Potential (EP)	NH_3, NO_x, N_2O, PO_4^{3-}, P	kg PO_4 eq.
Photochemical Ozone Creation Potential (POCP)	CO, NO_x, SO_2, NMVOC, CH_4, VOC (unspecified)	kg Ethane eq.
Ozone Layer Depletion Potential (ODP)	CH_4, Halon 1211, Halon 1301, R11, R114, R12	kg R11 eq.

4.1.2. Characterization

Direct comparison of LCI results within the impact categories is made possible by the characterization step. GaBi 6.0 Software calculates the contribution of the emissions to each impact category and classifies the emissions into relevant categories for regular hair conditioner life cycle scenarios. Table 4.2 illustrates the quantified LCA characterization results for the life cycle of conventional hair conditioner both for a single bottle and an annual scale.

Table 4.2. Characterization results for conventional hair conditioner production.

Impact Category	Unit	One bottle	Annual
Global Warming Potential (GWP)	[kg CO_2-eq.]	3.36027	1560476.2
Acidification Potential (AP)	[kg SO_2-eq.]	0.01629	7566.98
Eutrophication Potential (EP)	[kg Phosphate-eq.]	0.12962	60195.96
Ozone Layer Depletion Potential (ODP)	[kg Ethene-eq.]	0.0000004	0.1856
Photochemical Ozone Creation Potential (POCP)	[kg R11 eq.]	-0.003432	-1593.54

One bottle of regular hair conditioner life cycle with the conventional scenario is the worst option for GWP (Global Warming Potential). If S1 is applied and both raw materials and packaging materials are provided from inland, the GWP decreases by 0.043%/FU, which corresponds to 675.45 kg CO_2 equivalent for one-year period. If S2 is utilized and harmful chemicals for environment are exchanged with alternative ones, the GWP decreases by 0.192%/FU, which stands for 3002.07 kg CO_2 equivalent for one-year period. If S3 is implemented and refill system is adopted, the GWP decreases by 0.327%/FU, which equates 5101.58 kg CO_2 equivalent for one-year period. Thus, S3 is the best option to reduce the GWP.

The second impact category is AP (Acidification Potential), which demonstrates one bottle of regular hair conditioner life cycle with the conventional scenario is not the worst option to implement. If S1 is applied, and raw materials as well as packaging materials are provided from inland, the AP decreases by 0.055%/FU, which corresponds to 4.1437 kg SO_2 equivalent for one-year period. If S2 is utilized and harmful chemicals for environment are switched with alternative ones, the AP increases by 0.023%/FU, which stands for 1.73 kg SO_2 equivalent for one-year period. If S3 is implemented and refill system enters in force, the AP decreases by 0.009%/FU, which equates 0.6527 kg SO_2 equivalent for one-year period. These results show that S1 is the best option to reduce the AP.

Although there is a little difference between the scenarios compared with the GWP, another impact category is EP (Eutrophication Potential) . If S1 is applied, EP decreases by 0.019%/FU, which corresponds to 1.167 kg PO_4 equivalent for one-year period. If S2 is utilized, the EP decreases by 0.044%/FU, which stands for 2.65 kg PO_4 equivalent for one-year period. If S3 is implemented, EP decreases by 0.026%/FU, which equates 15.72 kg SO_2 equivalent for one-year period. S3 is the best option to reduce the EP.

There are no major changes between the scenarios in ODP (Ozone Layer Depletion Potential) category. If S1 is applied, ODP decreases by %0.0455 per bottle, which implies a miniscule impact for one-year period. If S2 is utilized, ODP decreases by %0.485/FU, which stands for 20.0009 kg R11 equivalent for one-year period. If S3 is implemented, the EP increases by %0.0016/FU, which again equates to a miniscule impact for one-year period.

Lastly, for POCP, the best scenario to reduce the impact is S2. If S1 is applied, the POCP decreases by 0.052%/FU, which corresponds to 0.8226 kg C_2H_4 equivalent for one-year period. If S2 is utilized, the POCP decreases by 0.106%/FU, which stands for 1.6855 kg C_2H_4 equivalent for one-year period. If S3 is implemented, the POCP decreases by 0.043%/FU, which equates 0.692 kg C_2H_4 equivalent for one-year period.

Table 4.3. Annual impacts of hair conditioner life cycle by each category and scenario.

Impact Categories	**Scenarios**			
	CS	**S1**	**S2**	**S3**
GWP, kg CO_2 eq	1,560,476.2	1,559,800.8	1,557,474.1	1555374.6
AP, kg SO_2 eq.	7,566.98	7,562.83	7,568.71	7566.3231
EP, kg PO_4 eq.	60,195.96	60,194.79	60193.3127	60180.2424
ODP, kg R11 eq.	0.186	0.186	0.1847	0.1856
POCP, kg C_2H_4 eq.	-1,593.54	-1,594.36	-1595.2272	-1594.2336

The water footprint of an individual consumer refers to the sum of direct and indirect freshwater use by the consumer. The direct water use is the water usage at home. The indirect water use relates to the total volume of freshwater used to produce the goods and services consumed by the consumer. The global average water footprint is 1240 m^3 water per person/year (Water Footprint Network, 2016). The water consumption of the hair conditioner life cycle scenarios are presented in Figure 4.2.

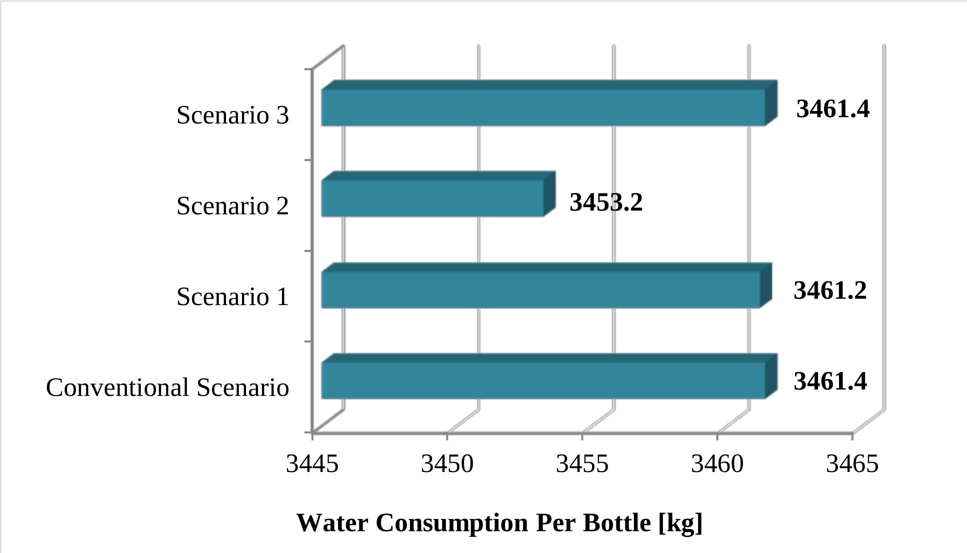
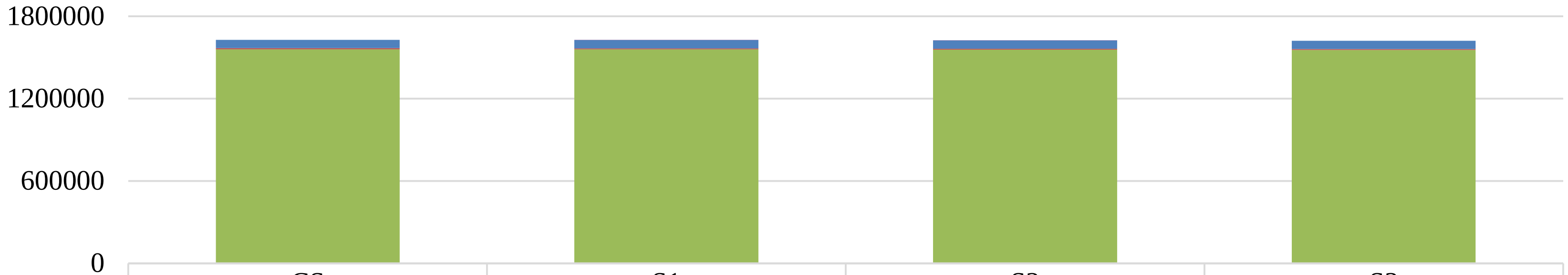


Figure 4.2. Water consumption of hair conditioner life cycle scenarios per bottle.

All impact categories and the variations between scenarios are shown in Table 4.3, Table 4.4 and Figure 4.3 both for FU and annual scale.

Table 4.4. One bottle (FU) hair conditioner's impact on each category and the % rate of change by each scenario.

	Conventional Scenario (CS)		**Scenario 1 (S1)**		**Scenario 2 (S2)**		**Scenario 3 (S3)**	
	FU Impact	**%of change**	**FU Impact**	**% of change**	**FU Impact**	**%of change**	**FU Impact**	**%of change**
GWP	3.36027275	-	3.35881827	0.0432846 ↓	3.3538082	0.1923817 ↓	3.34928717	0.326925 ↓
AP	0.01629445	-	0.01628553	0.0547609 ↓	0.01629818	0.0229039 ↑	0.01629305	0.0086259 ↓
EP	0.12962379	-	0.12962128	0.0019394 ↓	0.12961809	0.0043985 ↓	0.12958995	0.0261114 ↓
ODP	0.0000004	-	0.0000004	0.045523 ↓	0.0000004	0.4853085 ↓	0.0000004	0.0016132 ↑
POCP	-0.00343147	-	-0.00343325	0.051622 ↓	-0.0034351	0.1057704 ↓	-0.00343296	0.0434225 ↓



	CS	S1	S2	S3
POCP	-1593.5417	-1594.3643	-1595.2272	-1594.2336
ODP	0.1856	0.1856	0.1847	0.1856
EP	60195.9604	60194.7930	60193.3127	60180.2424
AP	7566.9758	7562.8321	7568.7090	7566.3231
GWP	1560476.1993	1559800.7537	1557474.1281	1555374.6123

Figure 4.3. Annual impacts of hair conditioner life cycle by each impact category and scenario.

4.1.2.1. Global Warming Potential (GWP)

Global warming potential (GWP) deals with all GHGs that may cause the earth's temperature to rise, or that may have an adverse effect on the ecosystem, human health and material welfare. Global warming is measured using the equivalent carbon dioxide emission over a 100-year time horizon.

Concerning the conventional scenario of a regular hair conditioner life cycle, consumption is the main source of environmental impact regarding GWP and the dominant gas is CO_2 in each stage. The reason is, in the consumption stage consumers use hot water (35 ^{o}C) to rinse the hair conditioner and this application lasts around 278 seconds which corresponds to 55.6 L of water usage. Raw materials acquisition and disposal stages contribute to GWP after consumption stage, respectively. In Figure 4.4 annual amount of GWP is shown by each life cycle stage.

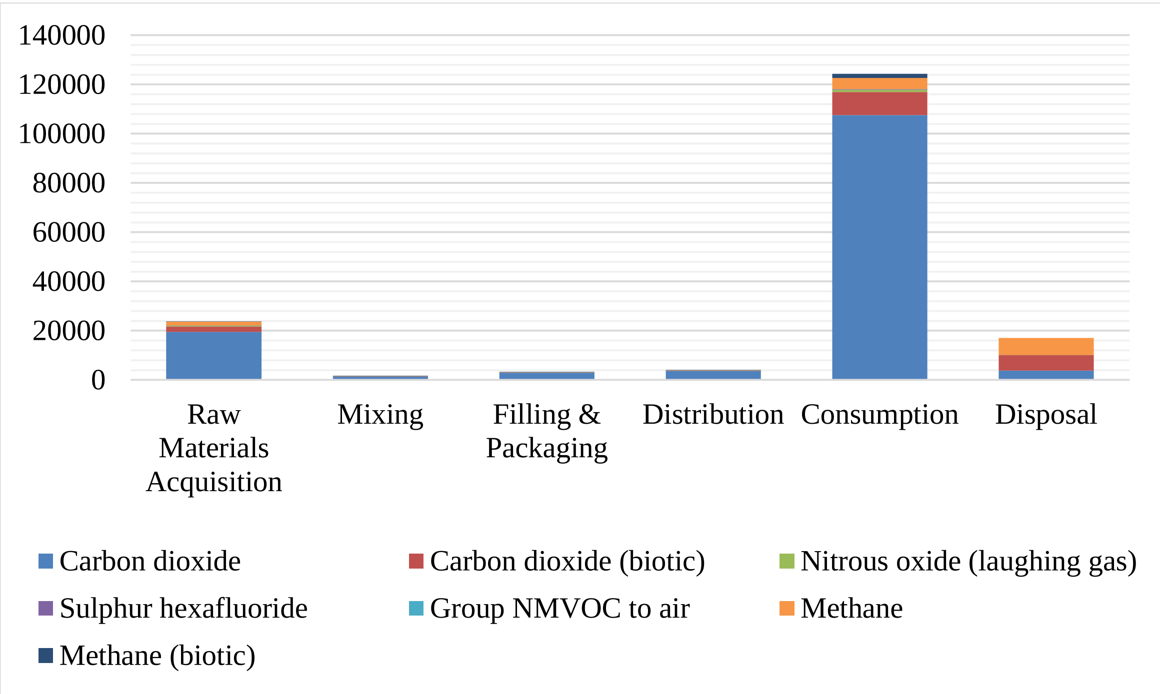


Figure 4.4. Annual global warming potential (GWP 100 years) (kg CO_2-Eq).

In Appendix C, Table C.1 the main process emissions by each scenario for GWP are expressed as kg CO_2 equivalents.

4.1.2.2. Acidification Potential (AP)

Acidification Potential (AP) covers all impacts on soil, water, organisms, ecosystems and materials by acidifying pollutants (e.g., SO_2, NOx, NHx), measured in 1kg of sulphur dioxide equivalent.

Pertaining to the conventional scenario of a regular hair conditioner life cycle, the consumption stage is the main source of environmental impact regarding AP. Raw materials acquisition and filling and packaging stages contribute to AP after consumption stage, respectively. Dominant gases enhancing this impact are mostly SO_2 and NO_x. In Figure 4.5 annual amount of AP is shown by each life cycle stage.

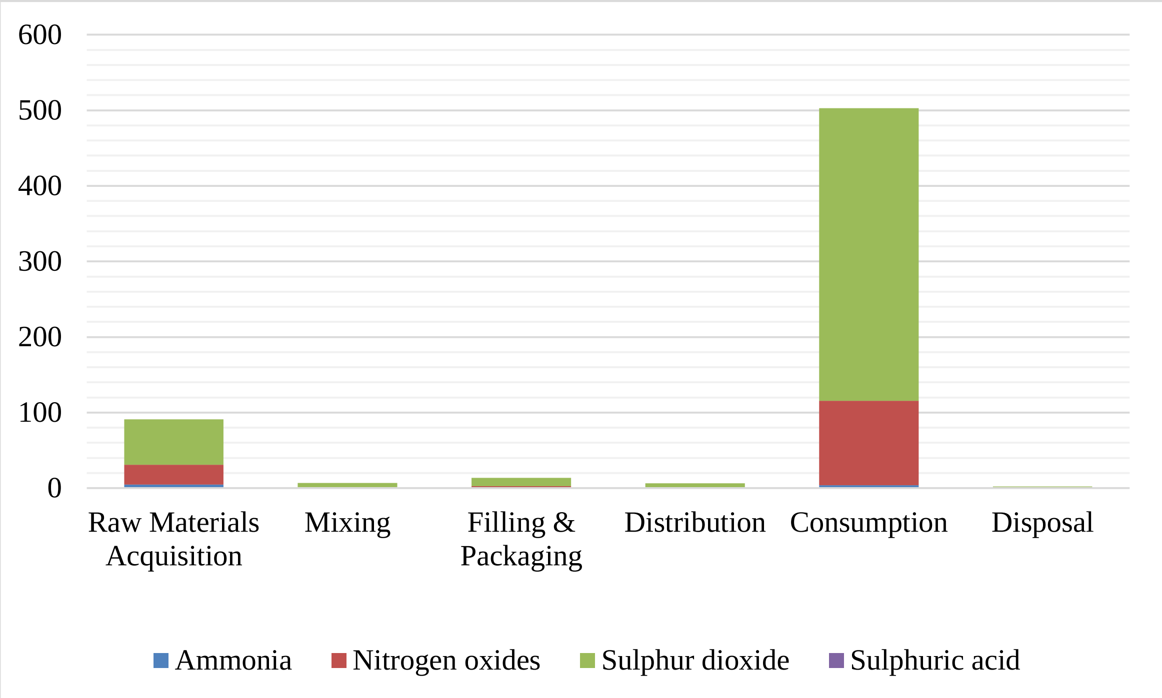


Figure 4.5. Annual acidification potential (AP) (kg SO_2-Eq).

In Appendix C, Table C.2 the main process emissions by each scenario for AP are expressed as kg SO_2 equivalents.

4.1.2.3. Eutrophication Potential (EP)

Eutrophication Potential (EP) covers all impacts of excessively high environmental levels of macronutrients (N, P); which generally cause a shift in species composition and an elevated biomass production in aquatic and terrestrial ecosystems, disturbing the balance between species. It is measured in kg phosphate equivalent.

Respecting the conventional scenario of a regular hair conditioner life cycle, the consumption stage is the main source of environmental impact regarding EP, and phosphate is the main gas causing EP as expressed below. Raw materials acquisition, filling and packaging stages contribute to EP after consumption stage, respectively. In Figure 4.6 annual amount of EP is shown by each life cycle stage.

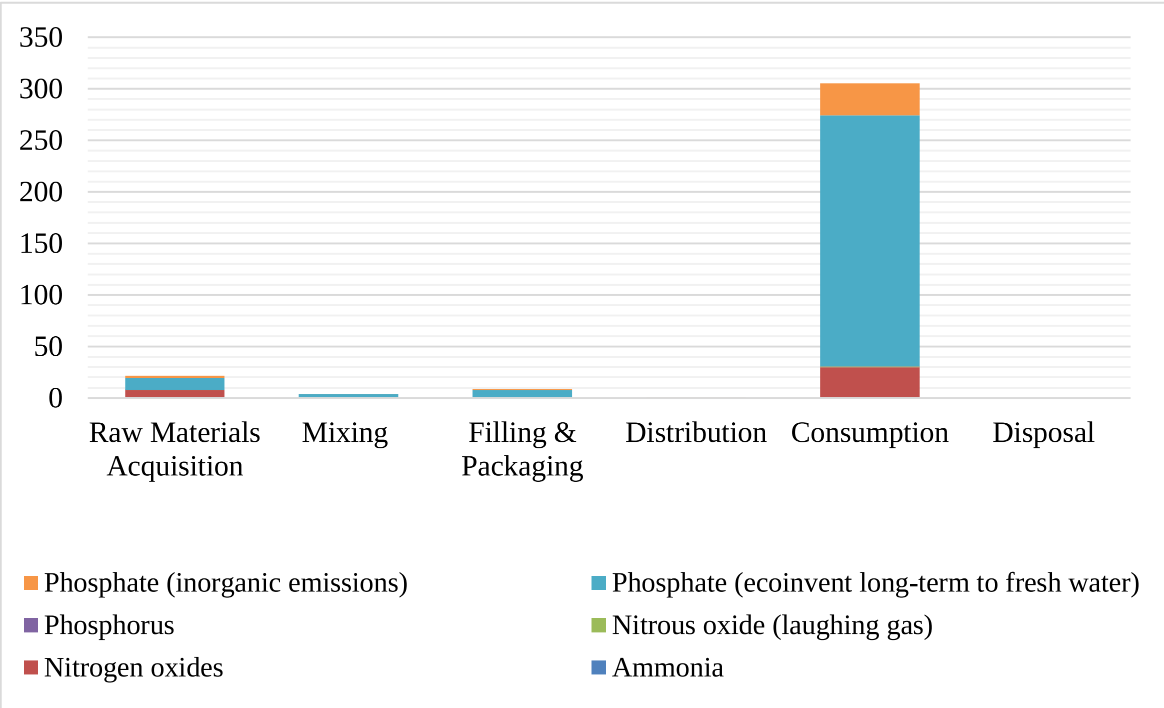


Figure 4.6. Annual eutrophication potential (EP) (kg PO_4-Eq).

In Appendix C, Table C.3, the main process emissions by each scenario for EP are expressed as kg PO_4 equivalents.

4.1.2.4. Ozone Layer Depletion Potential (ODP)

Ozone Layer Depletion Potential (ODP) of a chemical compound is the relative amount of degradation to the ozone layer it can cause. Concerning the conventional scenario of a regular hair conditioner life cycle, consumption and raw materials acquisition stages are the main sources of environmental impact regarding ODP. In Figure 4.7 annual amount of ODP is shown by each life cycle stage.

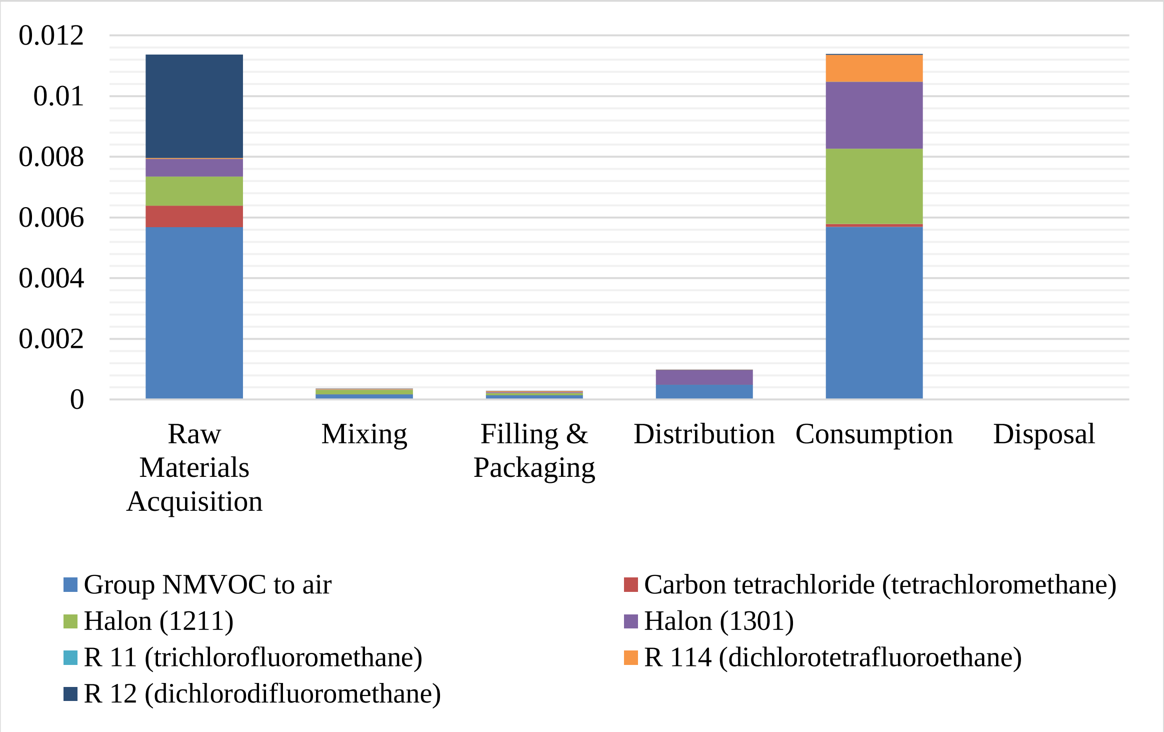


Figure 4.7. Annual ozone layer depletion potential (ODP) (kg R11-Eq).

In Appendix C, Table C.4 the main process emissions by each scenario for ODP are expressed as kg R11 equivalents.

4.1.2.5. Photochemical Ozone Creation Potential (POCP)

Photochemical Ozone Creation Potential (POCP), known as summer smog, indicates the potential capacity of an oxidizing photochemical substance, (such as volatile organic compounds (VOCs) and carbon monoxide (CO) to produce ozone in the presence of nitrogen oxides (NOx) which frees ozone in the low atmosphere), measured relative to

Ethane (C_2H_4). The effect of solar radiation on oxidizing photochemical substances gives rise to reactions between the oxidizing photochemical compounds and hydroxyl radicals (OH^-). With reference to the conventional scenario of a regular hair conditioner life cycle, consumption stage is the main source of environmental impact regarding POCP. This is followed by raw materials acquisition and disposal stages. In Figure 4.8 annual amount of POCP is shown by each life cycle stage.

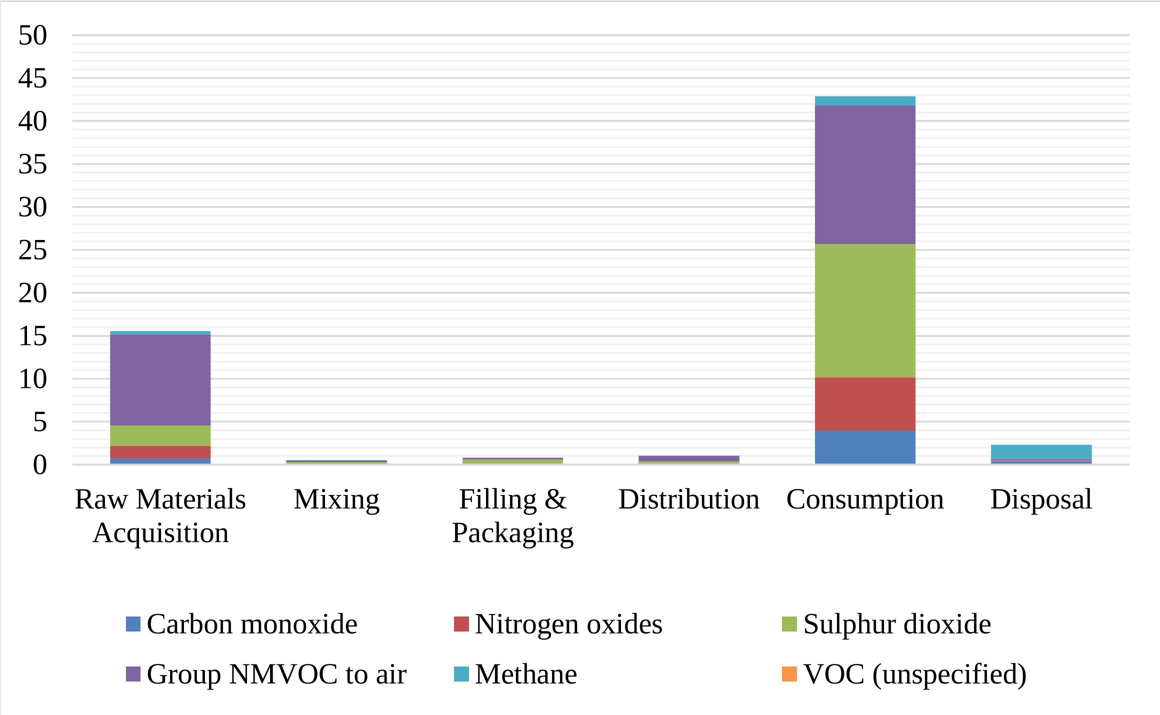


Figure 4.8. Annual photochemical ozone creation potential (POCP) (kg Ethene-Eq).

In Appendix C, Table C.5 the main process emissions by each scenario for POCP are expressed as kg Ethene equivalents.

4.1.3. Normalization

The goal of normalization is to refer the impact scores to a common reference to help us to compare different environmental impacts of the analyzed product system. Therefore, calculation is made by dividing the LCIA results of each impact category by the reference value. This reference value reflects the total impact from the emissions, extractions, radiations and land use, per impact category for EU25+3, over a year (Monteiro and Freire, 2012). The results have no unit that allows comparison of impact potentials. Normalization results present a suitable form for the final weighting in the decision-making process as well. In this study, CML2001 - April 2015, EU25+3, year 2000, excluding the biogenic carbon (region equivalents) option has been used for normalization step. Normalization results for regular hair conditioner production scenarios are demonstrated in Figure 4.9.

The normalization results indicate that the potential impact of eutrophication is the major impact among the other categories. AP, EP, GWP and ODP decreased by 0.055%, 0.002%, 0.043% and 0.046% respectively in the case of rearranging the raw materials' transportation system. Further, owing to the use of environmentally friendly raw materials rather than conventional ones; EP, GWP and ODP decreased by 0.0044%, 0.207% and 0.485%, respectively. Lastly, with alternative refill system AP, EP and GWP decreased by 0.0086%, 0.026% and 0.211% respectively.

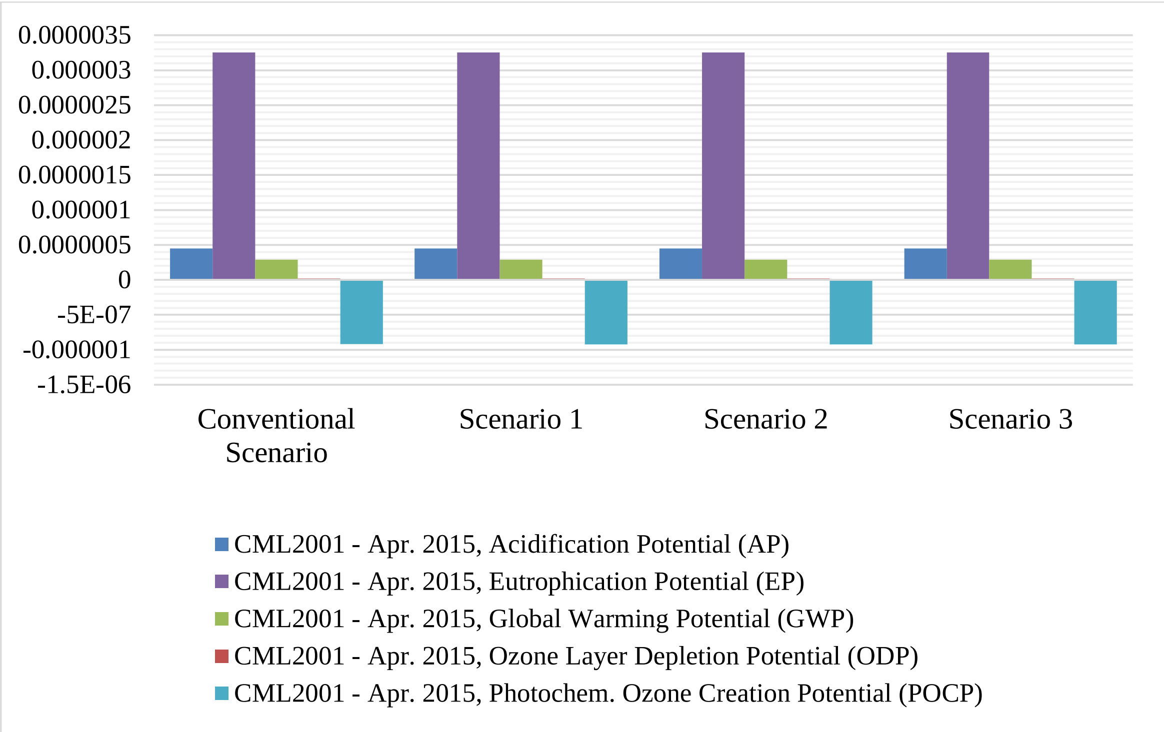


Figure 4.9. Normalization results for different production scenarios.

4.1.4. Weighting

The goal of the weighting step is to assign the relative amounts of normalization results to the different impact categories, based on their perceived importance or relevance. CML2001 - Dec. 07, Experts IKP (Southern Europe) option has been used for weighting step. The weighting results of different production scenarios resembled the normalization results in this study. However, GWP has dominated EP due to the relative importance of climate change. Figure 4.10 illustrates the weighting results.

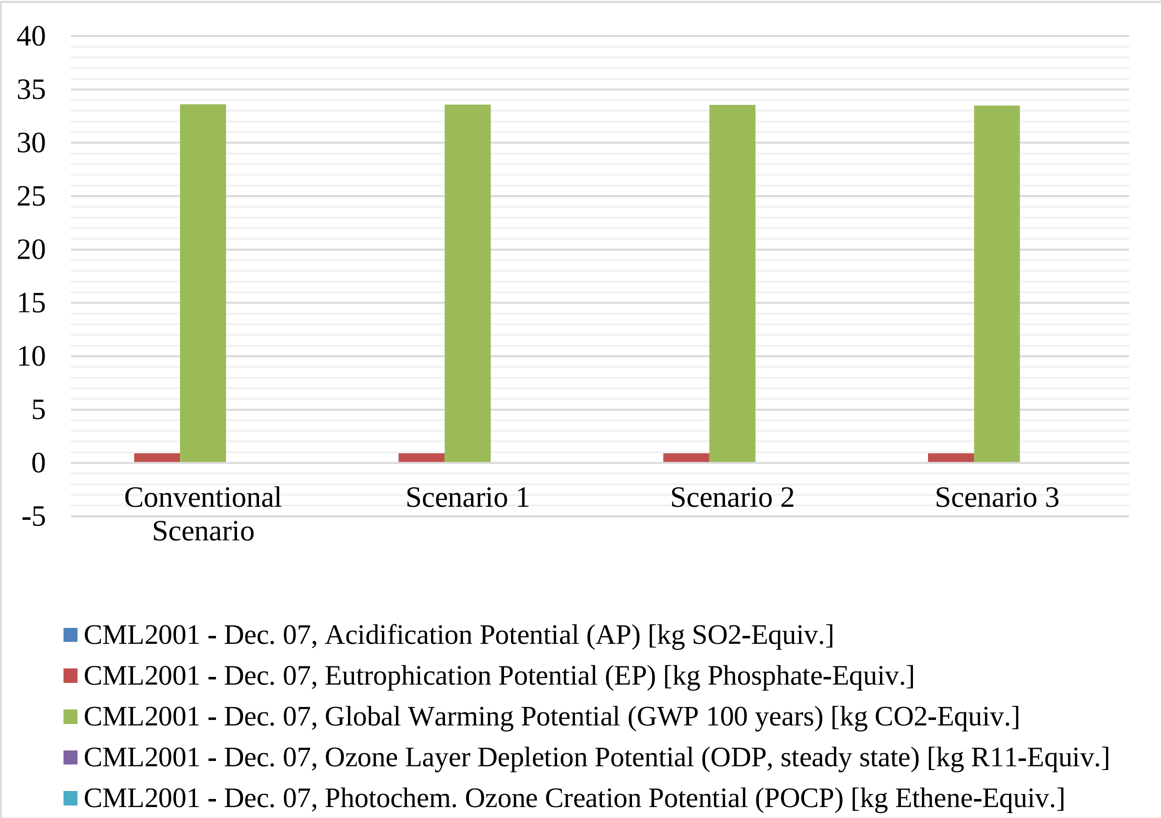


Figure 4.10. Weighting results for different production scenarios.

4.2. Life Cycle Impact Assessment for Oil Spray Production

This part has been performed by using GaBi 6.0 Software program and EcoInvent database. All raw materials necessary for production and packaging stages were determined. Flow diagram of production processes, transportation of raw materials and packaging materials were created in program. Environmental impacts were evaluated by considering results of product inventories. Within the scope of this study; characterization, classification, normalization and weighting procedures were done for environmental impact assessment.

4.2.1. Classification

In this step, LCI results are organized and combined with the related impact categories. As an initial step, prior to characterization, impact categories of global warming, acidification, eutrophication, photochemical ozone creation, and ozone layer depletion are determined by considering the emissions from a cradle-to-grave life-cycle of oil spray production. Selected LCI data and the impact categories are the same as hair conditioner life cycle analysis.

4.2.2. Characterization

Generated emissions and material use among the life cycle of one bottle of oil spray production is calculated for all the selected impact categories in the characterization step. GaBi 6.0 Software calculates the contribution of the emissions to each impact category and classifies the emissions into relevant categories. Table 4.5 summarizes the quantified LCA characterization results for conventional oil spray production scenario both for a single bottle and an annual scale.

Table 4.5. Characterization results for conventional oil spray production.

Impact Category	Unit	One bottle	Annual
Global Warming Potential (GWP)	[kg CO_2-eq.]	0.4653	76205.16
Acidification Potential (AP)	[kg SO_2-eq.]	0.00181	296.985
Eutrophication Potential (EP)	[kg Phosphate-eq.]	0.000983	160.9411
Photochemical Ozone Creation Potential (POCP)	[kg Ethene-eq.]	0.0002355	38.573
Ozone Layer Depletion Potential (ODP)	[kg R11 eq.]	1.35E-07	0.02204

Life cycle of one bottle of spray within Scenario 2, has presented the worst GWP results. If S1 is applied, and both raw materials and packaging materials are provided from inland, the GWP decreases by 21%/FU, which corresponds to 16185.5 kg CO_2 equivalent for one-year period. If S2 is utilized, and chemicals are replaced with alternative ones, the GWP increases by 2.41%/FU, which stands for 1836.31 kg CO_2 equivalent for one-year period. If S3 is implemented, and refill system enters in force, the GWP decreases by 2.36%/FU, which equates 1795.12 kg CO_2 equivalent for one-year period. S1 is the best option to reduce GWP.

The second impact category is AP, in which one bottle of regular oil spray life cycle with the Scenario 2 is the worst option to implement. If S1 is applied and both raw materials and packaging materials are provided from inland, the AP decreases by 14.021%/FU, which corresponds to 41.641 kg SO_2 equivalent for one-year period. If S2 is utilized, the AP increases by 3.24%/FU, which stands for 9.613 kg SO_2 equivalent for one-year period. If S3 is implemented and refill system enters in force, the AP increases by 0.424%/FU, which equates 1.258 kg SO_2 equivalent for one-year period. S1 is the best option to reduce AP.

Another impact category is EP, in which the best option is Scenario 1. If S1 is applied, the EP decreases by 8.178%/FU, which corresponds to 13.162 kg PO_4 equivalent for one-year period. If S2 is utilized, the EP increases by 5.007 %/FU, which stands for 8.058 kg PO_4 equivalent for one-year period. If S3 is implemented, the EP increases by 2.99%/FU, which equates 4.82 kg SO_2 equivalent for one-year period.

There aren't any major changes between the scenarios in ODP category. Lastly, for POCP, the best scenario is S3. If S1 and S2 is applied, the POCP increases 9.64% and 3.57%, respectively. If S3 is implemented, the POCP decreases by 0.318%/FU, which stands for 0.123 kg C_2H_4 equivalent for one-year period.

Table 4.6. Annual impacts of oil spray life cycle by each category and scenario.

Impact Categories	Scenarios			
	CS	S1	S2	S3
GWP, kg CO_2 eq.	76,205.16	60,019.66	78,041.47	74,410.04
AP, kg SO_2 eq.	296.99	255.34	306.6	298.24
EP, kg PO_4 eq.	160.94	147.78	169	165.76
ODP, kg R11 eq.	0.022	0.02	0.023	0.022
POCP, kg C_2H_4 eq.	38.57	42.29	39.95	38.45

Both direct (water used at home) and indirect (water used for production) water consumption of the oil spray life cycle scenarios are given in Figure 4.11.

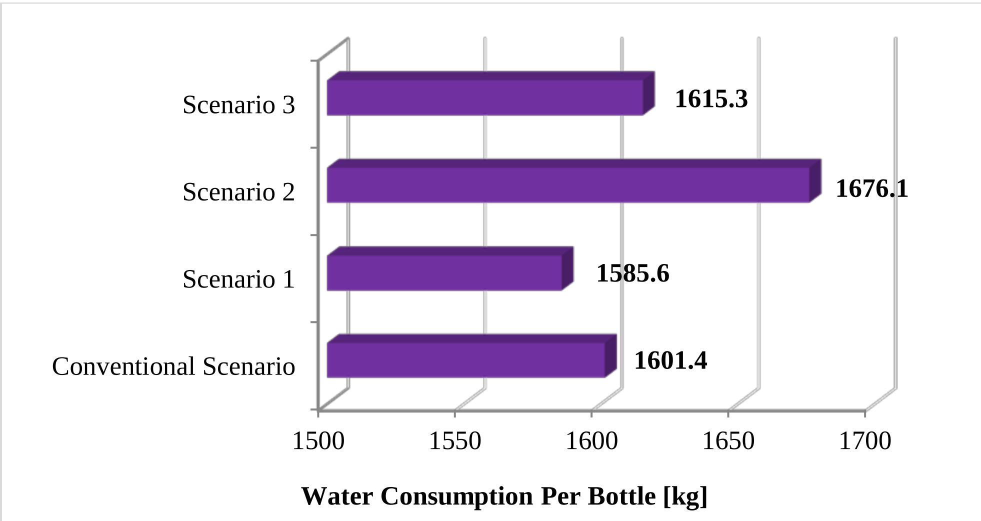
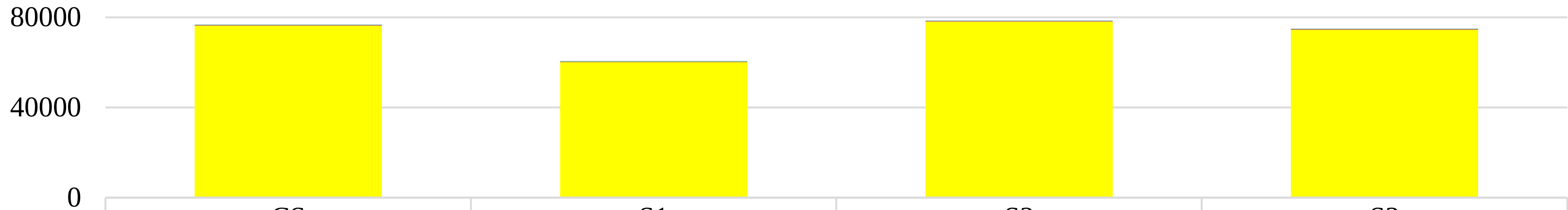


Figure 4.11. Water consumption of oil spray life cycle scenarios per bottle.

All impact categories and the variations between scenarios are shown in Table 4.6, Table 4.7 and Figure 4.12 both for FU and annual scale.

Table 4.7. One bottle (FU) oil spray's impact on each category and the % rate of change by each scenario.

	Conventional Scenario (CS)		**Scenario 1 (S1)**		**Scenario 2 (S2)**		**Scenario 3 (S3)**	
	FU Impact	**%of change**	**FU Impact**	**% of change**	**FU Impact**	**%of change**	**FU Impact**	**%of change**
GWP	0.46527753	-	0.36645549	21.23937 ↓	0.47648931	2.409698 ↑	0.45431726	2.3556404 ↓
AP	0.00181326	-	0.00155903	14.02110 ↓	0.00187196	3.236897 ↑	0.00182095	0.4237039 ↑
EP	0.00098264	-	0.00090228	8.177876 ↓	0.00103184	5.007034 ↑	0.00101205	2.9931196 ↑
ODP	1.35E-07	-	1.22E-07	9.205469 ↓	1.39E-07	2.929834 ↑	1.35E-07	0.4790930 ↑
POCP	0.00023551	-	0.00025822	9.641867 ↑	0.00024392	3.569570 ↑	0.00023476	0.3176489 ↓



	CS	S1	S2	S3
POCP	38.57292382	42.29207383	39.94981139	38.45039734
ODP	0.022043757	0.020014526	0.022689603	0.022149367
EP	160.9411167	147.7795514	168.9994932	165.7582768
AP	296.9845808	255.344087	306.5976658	298.2429161
GWP	76205.15633	60019.65815	78041.47044	74410.03691

Figure 4.12. Annual impacts of oil spray LC by each impact category and scenario.

4.2.2.1. Global Warming Potential (GWP)

Global warming is the increase in the average temperature of Earth's near-surface air and oceans since the mid-20th century, and its projected continuation. Most of the observed temperature increase since the middle of the 20th century is caused by increasing concentrations of greenhouse gases, which result from human activity such as burning fossil fuel, as well as deforestation. Global dimming, a result of increasing concentrations of atmospheric aerosols that block sunlight from reaching the surface, has partially countered the effects of warming induced by greenhouse gases.

In the conventional manufacturing system of the selected oil product, the raw materials acquisition stage is the main source of environmental impact regarding GWP. The reason for this result is that 16 out of 27 raw and packaging materials are imported from long distance suppliers. Disposal stage contributes to GWP after raw materials acquisition. In Figure 4.13 annual amount of GWP is shown by each life cycle stage.

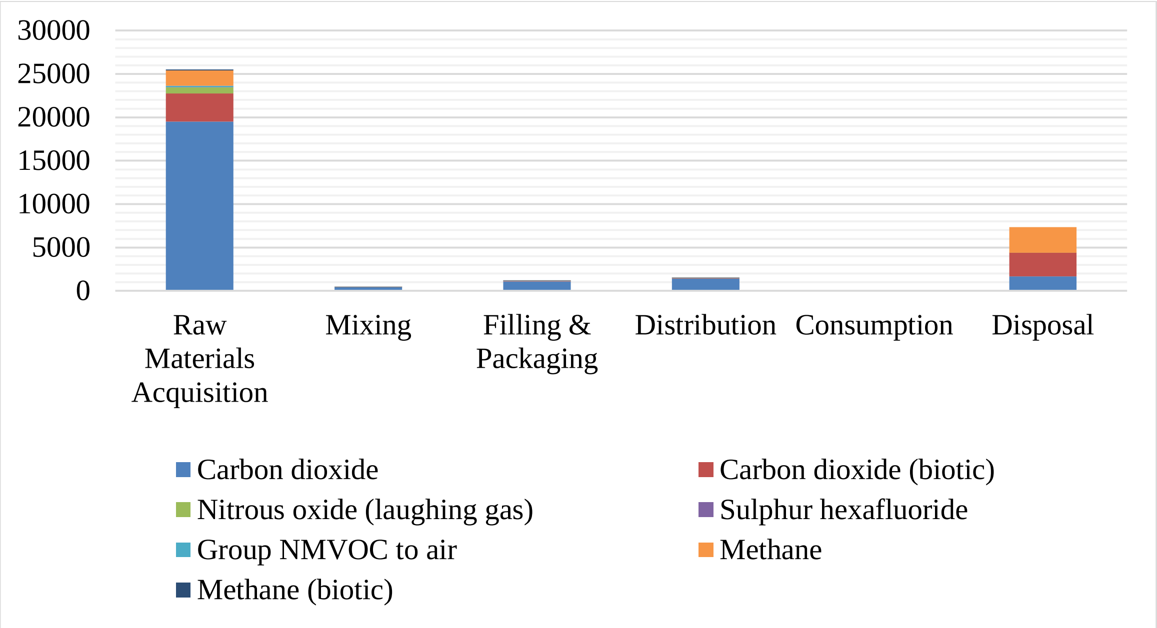


Figure 4.13. Annual global warming potential (GWP 100 years) (kg CO_2-Eq).

In Appendix D, Table D.1 the main process emissions by each scenario for GWP are expressed as kg CO_2 equivalents.

4.2.2.2. Acidification Potential (AP)

Considering the conventional scenario of an oil spray life cycle, raw materials acquisition stage is found as the main source of environmental impact regarding AP. Thus, high levels of SO_2 and NO_x are released. In Figure 4.14 annual amount of AP is shown by each life cycle stage.

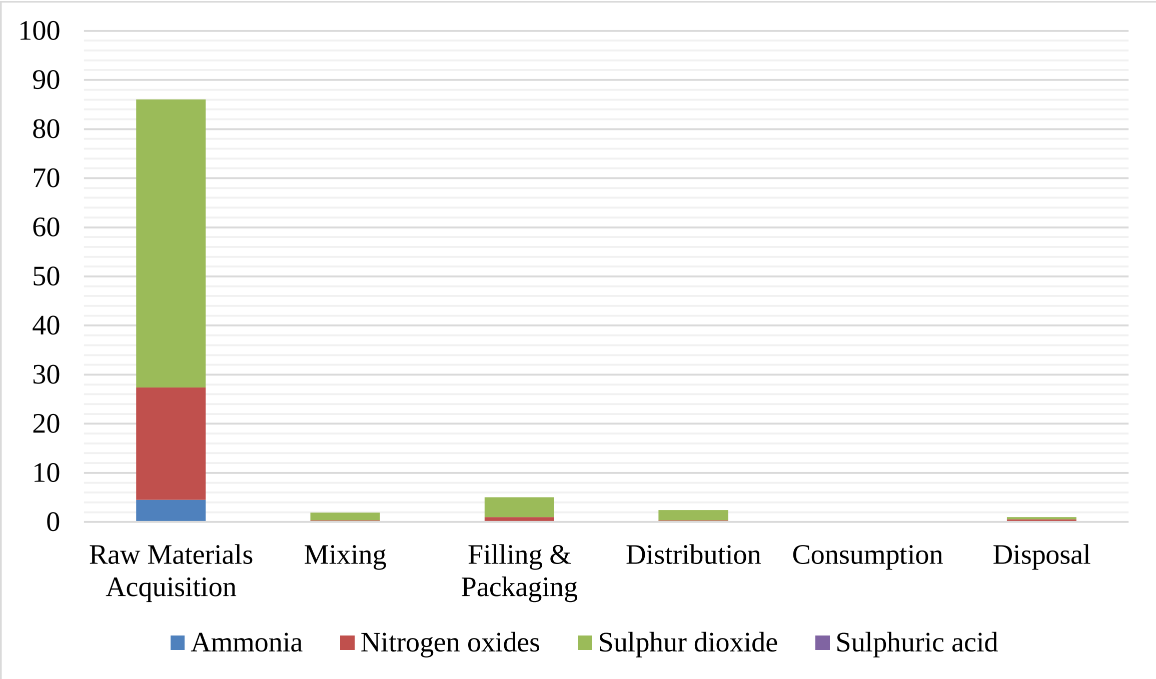


Figure 4.14. Annual acidification potential (AP) (kg SO_2-Eq).

In Appendix D, Table D.2 the main process emissions by each scenario for AP are expressed as kg SO_2 equivalents.

4.2.2.3. Eutrophication Potential (EP)

In the conventional scenario for an oil spray life cycle, raw materials acquisition stage is the one that contributes most to EP. Phosphate and NO_x are the main gases released in this impact category. Filling and packaging stage plays a part in enhancing EP, following raw materials acquisition. In Figure 4.15 annual amount of EP is shown by each life cycle stage.

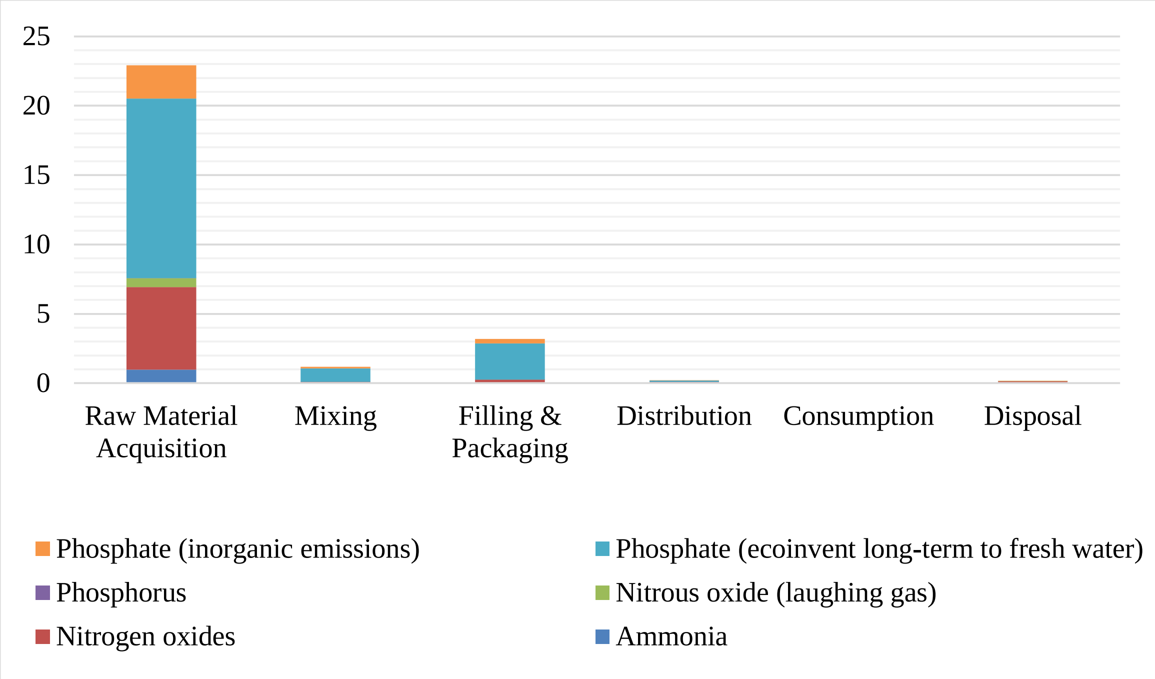


Figure 4.15. Annual eutrophication potential (EP) (kg PO_4-Eq).

In Appendix D, Table D.3 the main process emissions by each scenario for EP are expressed as kg PO_4 equivalents.

4.2.2.4. Ozone Layer Depletion Potential (ODP)

Raw materials acquisition stage is the main contributor to ODP in the life cycle of conventional oil spray production. The environmental impact in other processes is almost negligible for this category. The dominant emission R12, which is known as dichlorodifluoromethane, was universally banned in 1996 due to concerns about its damaging impact to the ozone layer. In Figure 4.16 annual amount of ODP is shown by each life cycle stage.

In Appendix D, Table D.4 the main process emissions by each scenario for ODP are expressed as kg R11 equivalents.

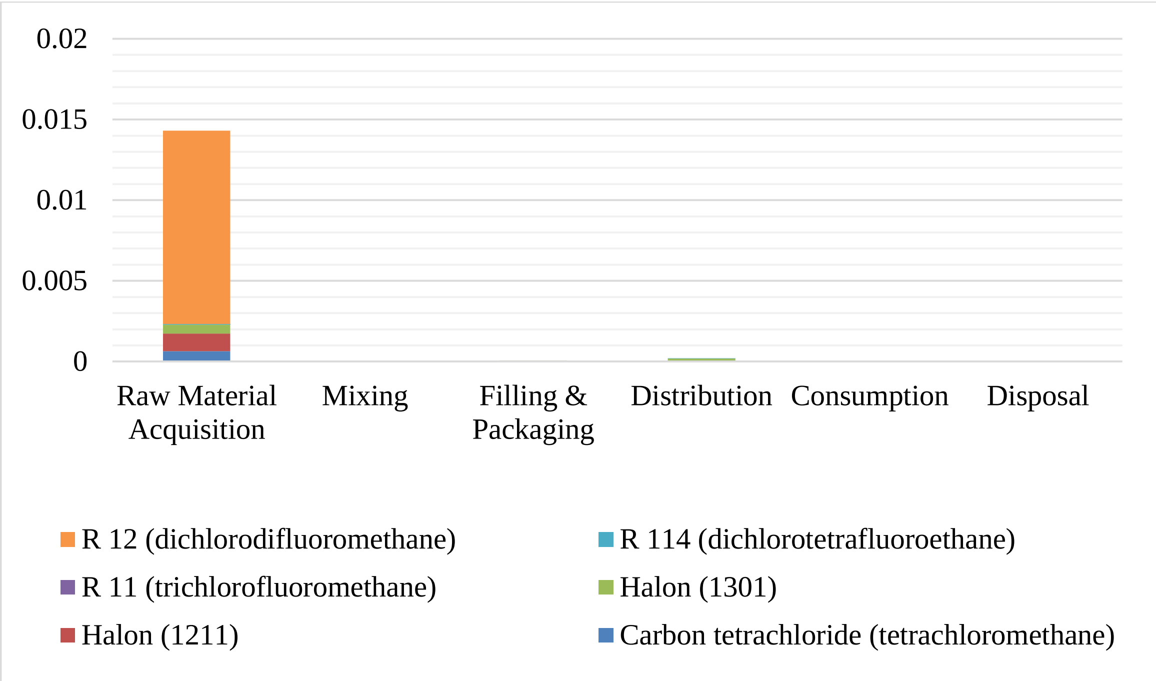


Figure 4.16. Annual ozone layer depletion potential (ODP) (kg R11-Eq).

4.2.2.5. Photochemical Ozone Creation Potential (POCP)

The majority of tropospheric ozone formation occurs when nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) such as xylene react in the atmosphere in the presence of sunlight. NO_x, CO, and VOCs are called ozone precursors. Motor vehicle exhaust, industrial emissions, and chemical solvents are the major anthropogenic sources of these chemicals. Although these precursors often originate in urban areas, winds have the possibility of carrying NO_x hundreds of kilometers, causing ozone formation to occur in less populated regions as well (EPA, 2010).

Pertaining to the conventional scenario of an oil spray life cycle, the raw materials acquisition stage is the main source of environmental impact regarding POCP. The dominant emissions are Group NMVOC, SO_2 and NO_x, respectively. In Figure 4.17 annual amount of POCP is shown by each life cycle stage.

Figure 4.17. Annual photochemical ozone creation potential (POCP) (kg Ethene-Eq).

In Appendix D, Table D.5 the main process emissions by each scenario for POCP are expressed as kg Ethene equivalents.

4.2.3. Normalization

As mentioned before; normalization is a way to compare how much different environmental impact categories contribute to the overall environmental problem. In this study, the normalization results indicate that POCP, GWP and AP are the main contributors of environmental concerns. Scenario 1 represents the best performance considering the overall environmental impact of oil spray production. The normalization results were calculated with CML2001- April 2015, EU25+3, year 2000, excluding biogenic carbon (region equivalents) methodology and are illustrated in Figure 4.18.

In comparison to conventional scenario, S1 provided 8.1%, 14.26% and 18.4% savings in EP, AP and GWP respectively. POCP increased 9.56% and ODP stood at approximately the same. Despite the fact that POCP increased in S1, it is the best scenario considering the annual impacts of the product to the environment.

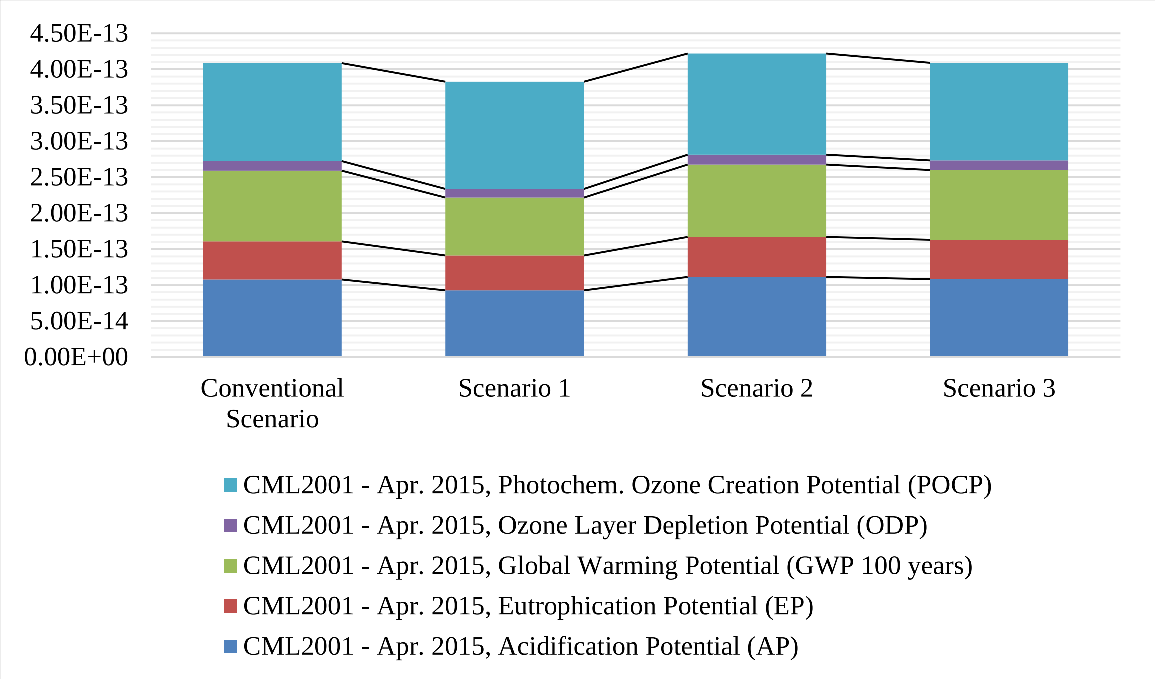


Figure 4.18. Normalization results for different production scenarios.

4.2.4. 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. For the weighting step, CML2001 – Dec. 07, Experts IKP (Southern Europe) option was used. The weighting results of different production scenarios have appeared like normalization results in this study. However, as illustrated in the Figure 4.19, GWP is the most dominant impact category due to the relative importance of climate change.

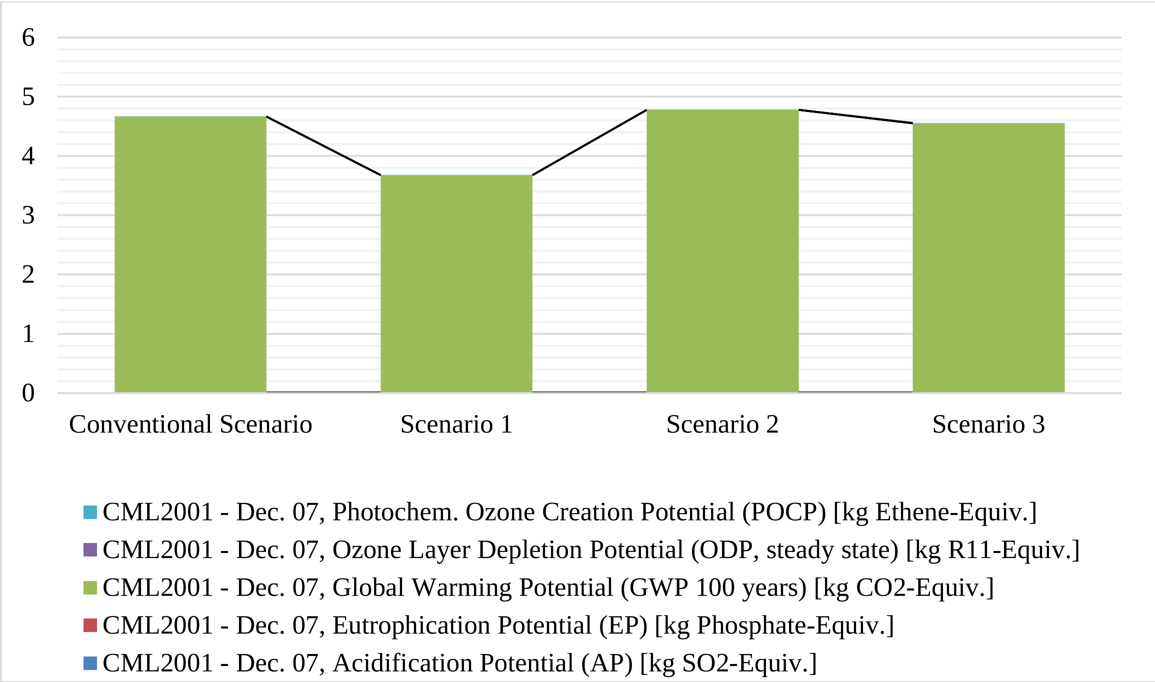


Figure 4.19. Weighting results for different production scenarios.

4.3. Comparison of Life Cycle Impact Assessments of Hair Conditioner and Oil Spray Productions

Hair conditioner is a hair care product that changes the texture and appearance of hair. It has often a creamy structure applied to the hair. It is usually used after washing the hair with shampoo and rinsing it off. Use of this product in Turkey has been assessed by a private company and technical observation report has been published (Trueman, 2009). In this report, it is indicated that time spent for rinsing the hair conditioner is approximately 4 minutes and 38 seconds, and the amount of regular hair conditioner is 14.5 g/per use for an average consumer.

Oil spray hair conditioner is an alternative product which takes on exactly the same role as the regular hair conditioner. The physical structure and the environmental performance are substantially different from regular hair conditioner product. Oil spray is used after shower and need not to be rinsed off. Leave-in spray conditioners can stay on the hair until the next shower, and thus propose a more beneficial effect in comparison to the regular hair conditioner. The amount of oil spray used is 1.44 mL/per use for an average consumer which equals to 1.404 g/per use (Trueman, 2009). In this section; GWP, AP, EP, ODP and POCP are evaluated and compared for the conventional scenarios of regular hair conditioner and oil spray products.

4.3.1. Classification

As stated in the previous chapters, inventory results are assigned to different impact categories. The selected categories are the same as before. Global warming, acidification, eutrophication, photochemical ozone creation and ozone layer depletion potentials are considered while comparing the environmental performance of these two products.

4.3.2. Characterization

Potential environmental impacts of emissions are calculated by using science-based conversion factors for each impact category, called characterization factors or equivalency factors. Table 4.8 summarizes the quantified LCA characterization results for regular hair conditioner production and oil spray production for a single bottle, and indicates the variations in percentage between two products.

Table 4.8. Comparison of characterization results for both products.

Impact Category	**Unit**	**Regular Hair Conditioner**	**Oil Spray**	**% of Change**
Global Warming Potential (GWP)	[kg CO_2-eq.]	3.519	0.6755	80.8% ↓
Acidification Potential (AP)	[kg SO_2-eq.]	0.00668	0.001739	73.99% ↓
Eutrophication Potential (EP)	[kg Phosphate-eq.]	0.0154	0.000606	96.06% ↓
Photochemical Ozone Creation Potential (POCP)	[kg Ethene-eq.]	0.001015	0.000253	75.06% ↓
Ozone Layer Depletion Potential (ODP)	[kg R11 eq.]	3.97E-07	1.14E-07	71.20% ↓

As indicated above, with oil spray production a significant improvement is achieved compared to the regular hair conditioner, when selected LCI data is taken into consideration.

A relative decrease in the global warming potential of oil spray production is observed compared to regular hair conditioner, due to the absence of water consumption. In 2015; 464,388 bottles of hair conditioner and 163,782 bottles of oil spray were produced. If oil spray is produced and consumed instead of regular hair conditioner, 2015 production data shows that 1,149,128.11 kg of CO_2 may be saved for one-year period. In Figure 4.21, GWP comparison for one bottle of hair conditioner and one bottle of oil spray product is expressed.

Characterization results demonstrate that producing oil spray is more efficient than producing regular hair conditioner in terms of acidification potential. If oil spray is produced and consumed instead of regular hair conditioner; 2,294.541 kg of SO_2 will be saved for one-year period. In Figure 4.22, AP comparison for one bottle of hair conditioner and one bottle of oil spray product has been stated.

The highest amount of decrease has been noted in EP. Although phosphate is the main contributor of EP in hair conditioner life cycle, oil spray does not have any significant emissions to be concerned about. If a shift to the new product is realized, 6870.16 kg of PO_4 will be saved for one-year period. In Figure 4.22 EP comparison for one bottle of hair conditioner and one bottle of oil spray product has been indicated.

The lowest amount of decrease achieved is in the ODP category. The main contributor for hair conditioner's life cycle, Halon 1301, is approximately zero in the life cycle of oil spray. This generates a 0.131 kg R11 worth of savings for one-year period. In Figure 4.24, ODP comparison for one bottle of hair conditioner and one bottle of oil spray product has been expressed.

On behalf of POCP, 75.06% reduction is calculated for the case the transition to oil spray is realized. The dominant POCP emissions are Group NMVOC, SO_2 and CO in hair conditioner life cycle. Those emissions are relatively small in oil spray production and consumption. If the new technology is applied, and production and consumption of oil spray is preferred rather than those of hair conditioner, 353.86 kg C_2H_4 will be saved for one-year period. In Figure 4.25 POCP comparison for one bottle of hair conditioner and oil spray product has been illustrated.

As mentioned before, the water footprint is an indicator of water use which considers both direct and indirect water usage of a consumer or producer. In Figure 4.20 direct and indirect water consumption comparison for one bottle of hair conditioner and one bottle of oil spray product is illustrated, and 53.74% water saving is calculated in case a transition to oil spray formulation occurred.

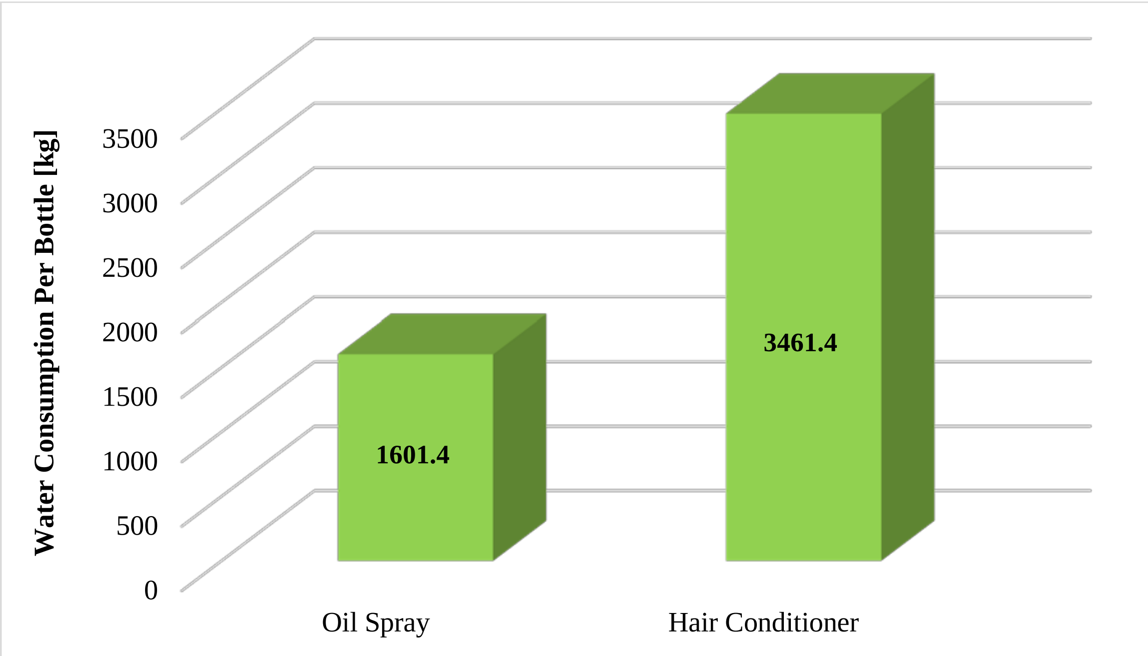
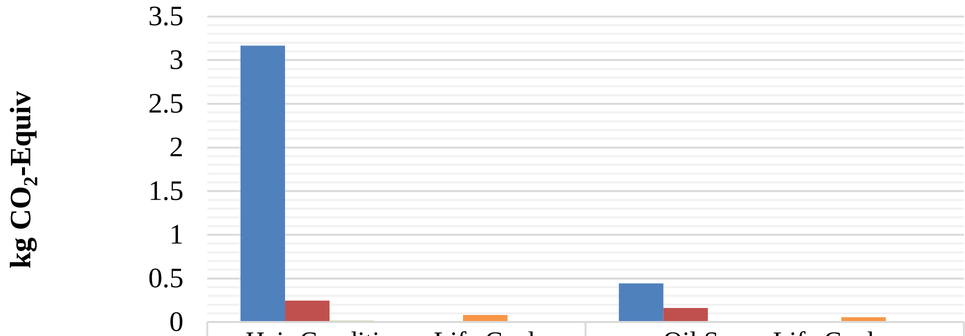
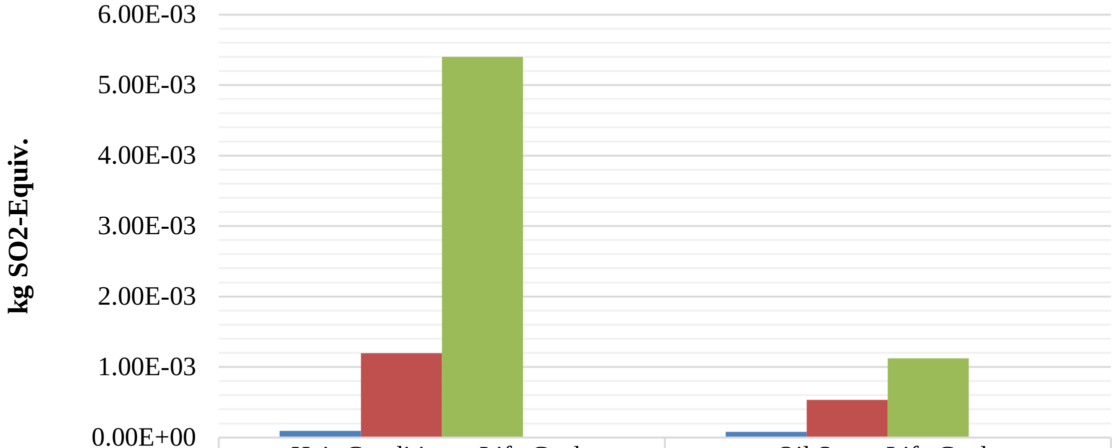


Figure 4.20. Direct and indirect water consumption comparison for one bottle of hair conditioner and one bottle of oil spray products.



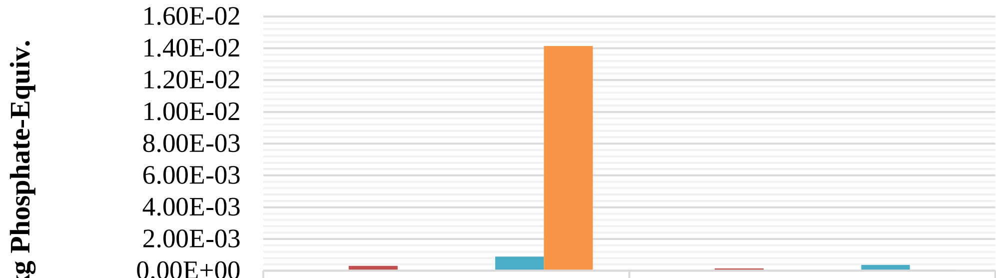
	Hair Conditioner Life Cycle	Oil Spray Life Cycle
Carbon dioxide	3.165845464	0.445526085
Carbon dioxide (biotic)	0.248302949	0.162507792
Nitrous oxide (laughing gas)	0.014667668	0.008665884
Sulphur hexafluoride	0.00094501	0.000364465
Group NMVOC to air	0.000642896	0.001196802
Methane	0.083515152	0.055116663
Methane (biotic)	0.004591985	0.002123217

Figure 4.21. Global warming potential (GWP 100 years) comparison for one bottle of hair conditioner and oil spray products.



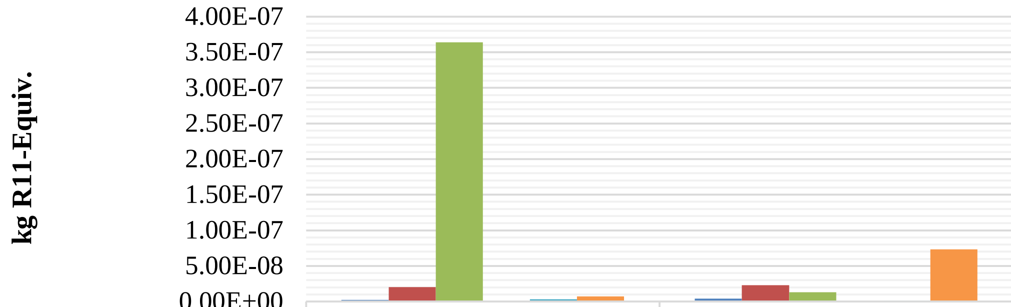
	Hair Conditioner Life Cycle	Oil Spray Life Cycle
Ammonia	9.16E-05	8.07E-05
Nitrogen oxides	0.001195686	0.000534864
Sulphur dioxide	0.005400663	0.001123586
Sulphuric acid	1.44E-12	9.55E-14

Figure 4.22. Acidification potential (AP) comparison for one bottle of hair conditioner and oil spray products.



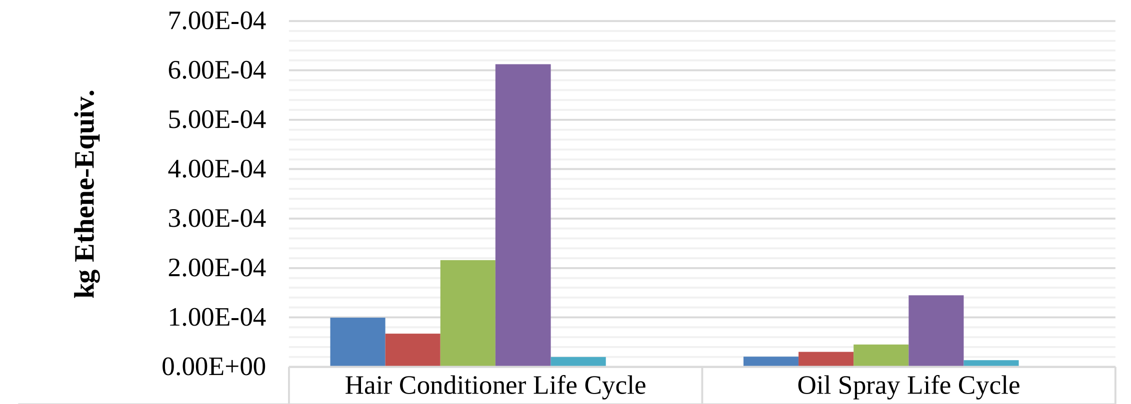
	Hair Conditioner Life Cycle	Oil Spray Life Cycle
Ammonia	2.00E-05	1.77E-05
Nitrogen oxides	0.000310878	0.000139065
Nitrous oxide (laughing gas)	1.33E-05	7.85E-06
Phosphorus	2.07E-07	2.06E-07
Phosphate (ecoinvent to fresh water)	0.00088829	0.000375224
Phosphate (inorganic emissions to fresh water)	0.014136469	6.60E-05

Figure 4.23. Eutrophication potential (EP) comparison for one bottle of hair conditioner and oil spray products.



	Hair Conditioner Life Cycle	Oil Spray Life Cycle
Carbon tetrachloride (tetrachloromethane)	2.14E-09	4.11E-09
Halon (1211)	2.05E-08	2.29E-08
Halon (1301)	3.64E-07	1.29E-08
R 11 (trichlorofluoromethane)	6.61E-13	3.18E-13
R 114 (dichlorotetrafluoroethane)	3.07E-09	1.14E-09
R 12 (dichlorodifluoromethane)	7.43E-09	7.32E-08

Figure 4.24. Ozone layer depletion potential (ODP) comparison for one bottle of hair conditioner and oil spray products.



	Hair Conditioner Life Cycle	Oil Spray Life Cycle
Carbon monoxide	9.98E-05	2.03E-05
Nitrogen oxides	6.70E-05	3.00E-05
Sulphur dioxide	0.000216027	4.49E-05
Group NMVOC to air	0.00061233	0.0001447
Methane	2.00E-05	1.32E-05
VOC (unspecified)	3.12E-11	1.42E-11

Figure 4.25. Photochemical ozone creation potential (POCP) comparison for one bottle of hair conditioner and oil spray products.

4.3.3. 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. In this part of the work, the normalization results indicate that EP, AP and GWP are the main contributors of environmental concerns, especially when the hair conditioner life cycle is concerned. Oil spray represents the best performance considering the overall environmental impact. The normalization results have been calculated with CML2001-April 2015, EU25+3, year 2000, excluding the biogenic carbon (region equivalents) methodology and the results are illustrated in Figure 4.26 below.

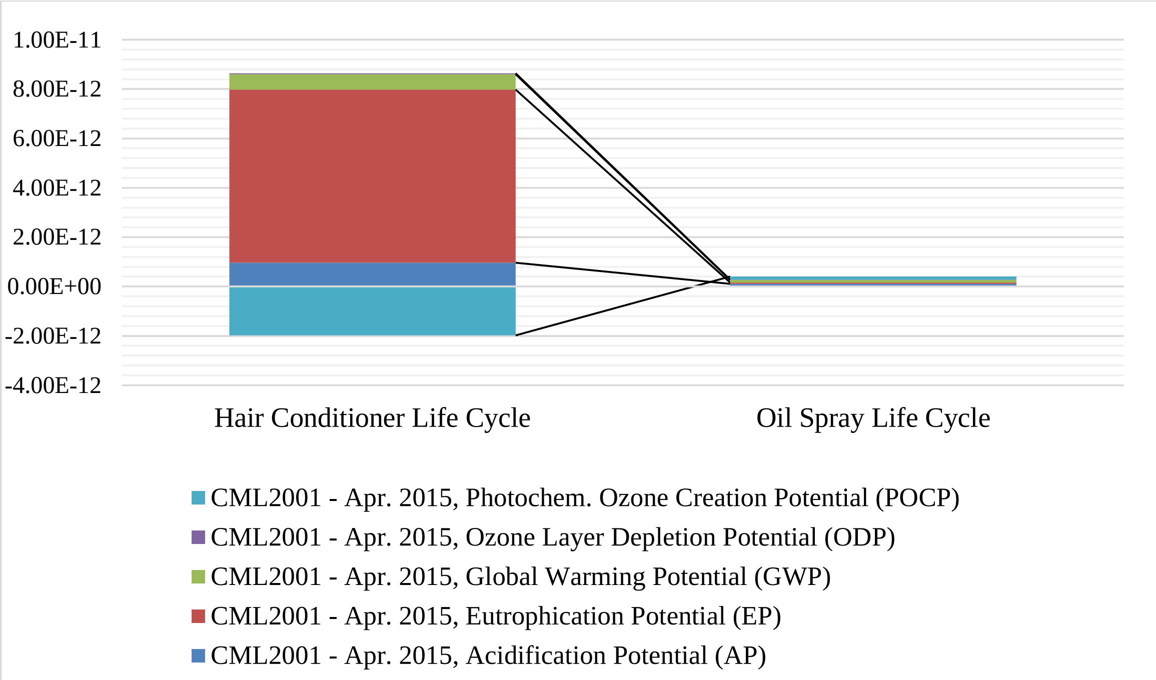


Figure 4.26. Normalization results for hair conditioner and oil spray production.

4.3.4. Weighting

In general, weighting includes two crucial activities: determining weights to place on impacts and applying weights to impact indicators (US EPA, 2006). In this study, CML2001 - Dec. 07, Experts IKP (Southern Europe) option has been used for weighting step.

In this study, the results from weighting of two different types of hair conditioner production are similar to normalization results. The positive influence of the oil spray production is observed in terms of GWP, AP, EP, POCP and ODP. GWP is the highest environmental impact category for the regular hair conditioner, decreased significantly in oil spray life cycle according to the weighting results. However, GWP has dominated EP due to the relative importance of climate change. Figure 4.27 illustrates the weighting results for the life cycle of these two products.

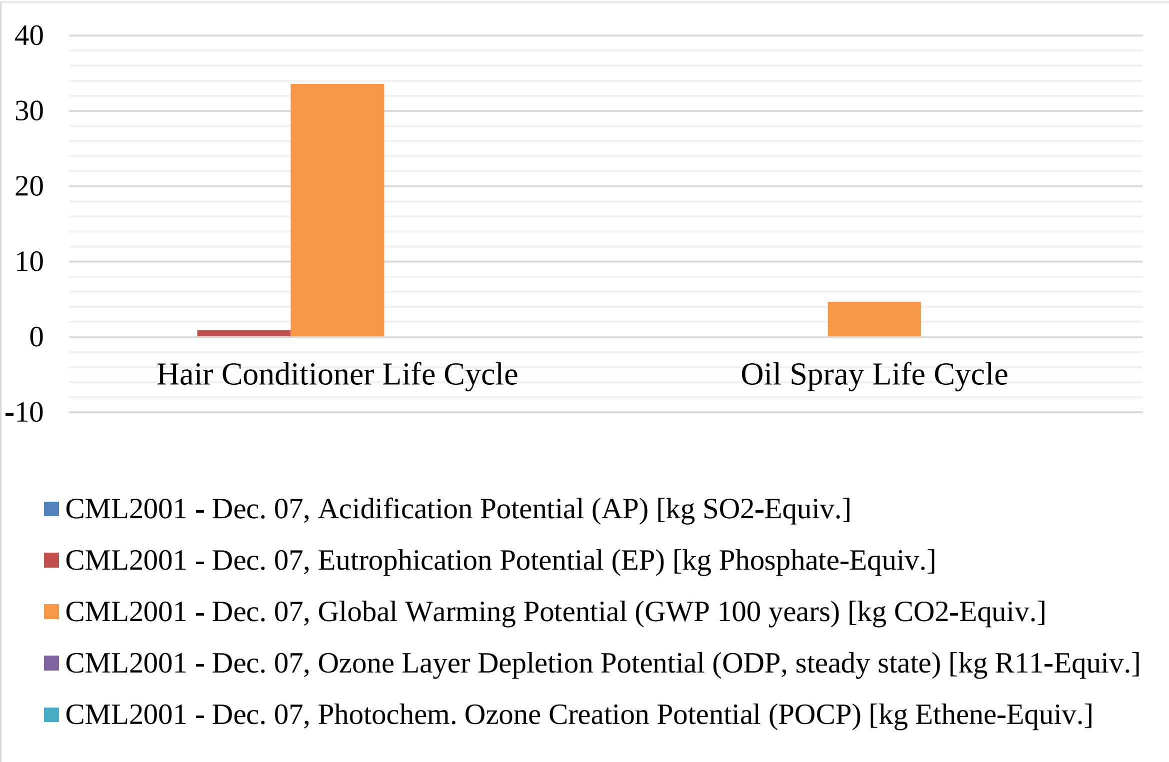


Figure 4.27. Weighting results for hair conditioner and oil spray production.

4.4. The Impact of Different Scenarios on EU Eco Label Certification

Some chemicals used in formulations of products are limited, and some are forbidden by the EU Eco Label, due to their adverse effects on environment and human health. The product compositions analyzed in this study are both for regular hair conditioner and oil spray products. Odorizing agents like perfumes, preservatives like methylchloroisothiazoline and methylisothiazoline, which cause an increase in Critical Dilution Volume (CDVtox) of products, are strictly prohibited. CDVtox shows minimum toxicity limits on aquatic environment and is limited (≤ 30 000 L/g active content) according to the EU Eco Label Criteria. Another criterion is about biodegradability: each ingredient used in the product must be readily biodegradable. For the regular hair conditioner 6 of 14 raw materials, and for the oil spray 5 of 16 raw materials meet this criterion. The European Union goes even further to limit the use of the preservatives in cosmetics to a maximum concentration of 0.02% for rinse-off products, and to 0.01% for leave-on products, except for deodorant/antiperspirant products. In Table 4.9 the criteria and the performance of hair conditioner and oil spray are illustrated.

Table 4.9. The pass criteria and the performance of products.

EU Eco Label Criteria	**Hair Conditioner**	**Oil Spray**
Critical Dilution Volume ≤ 30 000 L/g active content	**X**	**X**
Each surfactant used in the product shall be readily biodegradable	**X** (6/14)	**X** (5/16)
The ingredients comply with the requirements described in the criterion on fragrances. Product does not contain fragrances.	✓	✓
The ingredients comply with the requirements described in the criterion on dyes or coloring agents. Product does not contain dyes or coloring agents.	✓	✓
Biocides (or preservatives) in the product comply with the requirements described in the criterion on biocides. Product does not contain biocides.	**X**	**X**
The product and the ingredients comply with the requirements described in the criterion on hazardous substances.	**X**	**X**

There is a rapid increase in awareness by sensitive consumers about environmental and health related issues leading to a shift towards a more responsible consumption. The role and success of ecolabels in today's market is important for the promotion of sustainable production and consumption. Scenario 2 is designed to improve the raw materials' effect by replacing the old chemicals with the environmentally friendly ones. This scenario may fulfill the requirements about biodegradability, preservability and disposability of non-hazardous chemicals. Additionally, scenario 3 is designed to modernize the consumption habits of consumers by encouraging the use of refillable packs. A 30% turnabout of conditioner bottles is envisaged, and calculations are done regarding this option. This scenario may contribute the requirements in the use and end of life stages.

In the EU Eco Label checklist, the main criterion for the manufacture (formulation) stage is the safety of the product, for which the characteristics of raw materials are deeply examined. In terms of consumption stage, performance and durability criteria must be surveyed either through laboratory tests or a consumer test. Simply enough, the packaging must be designed to obtain the correct dosage easily, and this requirement is met by the oil spray product. For the disposal/end of life stage, limitations on the use of substances harmful for the aquatic environment and limitations of packaging waste are listed. Applicability of those criteria must be done by additional laboratory experiments.

5. CONCLUSIONS

This study analyzes and compares the environmental impacts of Regular (creamy) and Oil Spray (two-phase) hair conditioner formulations using LCA with CML 2001 -Dec.07 assessment methodology. The environmental parameters considered in this study are global warming, acidification, eutrophication, ozone layer depletion and photochemical ozone creation potentials. Overall normalized and weighted environmental impacts are also obtained and presented. Life cycle stages of hair conditioners included in the analysis are raw material acquisition (including transport of materials), manufacture, distribution, consumer use and disposal. All impacts are analyzed and presented on both “one bottle of product” and “annual” bases. Products are evaluated on stage-by-stage and overall basis.

The results of the analysis revealed major reductions across all environmental impact categories when shifting from regular to two-phase formulations. Decrease in the harmful environmental impacts is hand in hand with improvements in formulation, decrease in dose of product used per use, and different water consumption needs for the selected products. Producers are now responsible for not only production steps, but also for use and disposal stages which means the whole life cycle. Consumer habits are very important; consequently, companies should be in direct communication with the end customer and adopt an attitude that ensures awareness about resource consumption during use.

Raw material acquisition and consumer use stages are two main life cycle stages that affect the overall environmental impact of the regular hair conditioner product. Alternatively, in oil spray production, the main life cycle stage that contributes to the overall environmental impact is the raw material acquisition. The reason why consumption stage does not contribute to the overall impact is the usage habits of the end consumer. Oil spray is an alternative product which plays the same role as the hair conditioner. Oil spray does not need to be rinsed off. This way, saving is enhanced, at approximately 56 L of 35^{o}C tap water. An example of this is clearly evident in the decrease in the share of consumption stage in terms of global warming potential (GHG emissions), from 71% in regular formulations to 3% in oil spray formulations, while the share of the raw materials acquisition stage in the same category is reduced, granting it presents a rather moderate decline from 14% to 13.44%.

Switching from regular to two-phase formulation manifests itself most clearly in the significant reduction in eutrophication potential of the consumer use stage. This reduction is 96.06% and equals to 0.015 kg PO_4 equivalent for a single bottle life cycle. Moving from regular to two-phase formulation further improves the environmental performance of the hair conditioner products due to significant decrease in global warming potential, photochemical ozone creation potential, ozone layer depletion potential and acidification potential about 80.8%, 75.06%, 71.20% and 73.99% respectively.

In addition, this study focused on the possible improvements concerning the environmental impacts of both regular and two-phase hair conditioners while protecting the required performance properties. Three different scenarios are proposed and analyzed.

Firstly, considering the transportation impact on the product's life cycle, S1 is designed as an alternative transportation option, which aims supplying the raw materials from inland instead of outland. In regular hair conditioner product, this scenario provides 675.4 kg CO_2-equivalent decrease in GWP, 4.144 kg SO_2-equivalent decrease in AP, 1.17 kg PO_4-equivalent decrease in EP and 0.823 kg C_2H_4-equivalent decrease in POCP in an annual scale. In oil spray product, S1 provides 16185.5 kg CO_2-equivalent decrease in GWP, 41.641 kg SO_2-equivalent decrease in AP, 13.161 kg PO_4-equivalent decrease in EP, 0.002 kg R11-equivalent decrease in ODP and 3.719 kg C_2H_4-equivalent increase in POCP in an annual scale. Therefore, S1 is identified as the best scenario for oil spray production.

Secondly, considering the raw materials' impact on the life cycle of the product, S2 is envisaged to replace harmful chemicals with environmentally friendly ones. In regular hair conditioner product, this scenario is quite successful in terms of GWP, EP, ODP and POCP. Annual improvements are 3002.07 kg CO_2-equivalent, 2.65 kg PO_4-equivalent, 9E-04 kg R11-equivalent and 1.69 kg C_2H_4-equivalent decrease, respectively. Surprisingly, despite using more environmentally friendly raw materials, an increase is observed, again being rather minute, in each category. S2 derives 1836.31 kg CO_2-equivalent increase in GWP, 9.613 kg SO_2-equivalent increase in AP, 8.06 kg PO_4-equivalent increase in EP, 0.001 kg R11-equivalent increase in ODP and 1.4 kg C_2H_4-equivalent increase in POCP, annually.

Thirdly, considering the amount of packaging waste, Scenario 3 is proposed. In this scenario; the producers are encouraged to produce refillable bottles, and the consumers to use those packs. For the regular hair conditioner life cycle, the best results are observed in S3 in terms of GWP and EP. This scenario allows 5101.6 kg CO_2-equivalent decrease in GWP, 0.6527 kg SO_2-equivalent decrease in AP, 15.72 kg PO_4-equivalent decrease in EP and 0.692 kg C_2H_4-equivalent decrease in POCP in an annual scale. For oil spray life cycle, 1795.12 kg CO_2-equivalent decrease in GWP, 1.258 kg SO_2-equivalent increase in AP, 4.82 kg PO_4-equivalent increase in EP and 0.123 kg C_2H_4-equivalent decrease in POCP is observed in an annual scale.

In 2015 464,388 bottles of hair conditioner and 163,782 bottles of oil spray were produced. As mentioned before, if oil spray is produced and consumed instead of regular hair conditioner 1,150 ton of CO_2 may be saved for one-year period which indicates 1.95% reduction for just one type of oil spray product. In Turkey's Intended Nationally Determined Contribution (INDC) report, it is pointed that up to 21% reduction in GHG emissions from the Business as Usual (BAU) level by 2030 will enable Turkey to step on low-carbon development pathways compatible with the long-term objective of limiting the increase in global temperature below 2^oC (INDC, 2015). If environmentally friendly scenarios would have been adapted, this commitment may be materialized in 15-year period.

Mixed results were obtained for packaging of the products. The amount of packaging waste generated by formulations from highest to lowest for both the oil spray and the regular hair conditioner. Corrugated cardboard boxes have higher impact than LDPE stretch films as secondary packaging. Therefore, the cardboard boxes used for secondary packaging in oil spray have a higher packaging waste amount than the secondary packaging of the regular hair conditioner. Similarly, the bottle types and amounts differ between these two products. For regular hair conditioner, a HDPE bottle used with a PP cap; while in oil spray, distinctly a PET bottle is used with a pump that consists of different types of plastic and metal. The rest of the primary and secondary packaging such as front and back labels, shrink paper, barcode stickers, are the same in these two products.

The water footprint of an individual, a community or a business is defined as the total volume of freshwater used to produce the goods and services which are consumed by the individual or community, or which are produced by the business. Water usage is measured in water volume consumed and/or polluted per unit of time. Water footprint may be calculated for any well-defined group of consumers or producers. Regarding the regular hair conditioner formulation, 3461.434 kg/FU of water is consumed both directly and indirectly. Proposed scenarios slightly differ from each other (3461.201 kg/FU for S1, 3453.145 kg/FU for S2 and 3461.415 kg/FU for S3). Respecting the oil spray formulation, 1601.389 kg/FU of water is consumed both directly and indirectly. Just like the regular hair conditioner, scenarios slightly differ from each other as well (1585.537 kg/FU for S1, 1676.118 kg/FU for S2, 1615.258 kg/FU for S3). Consequently, 53.74% water saving is calculated regarding transition from hair conditioner to oil spray formulation.

The study was adjusted to reflect the conditions of Turkey as much as possible by including country-specific data where possible. These include the current recycling rates for various materials, emission limits imposed by Turkish environmental regulations, shower habits, and energy feedstock ratios for electric power production. It must be noted that electric power grid mix process is selected from the GaBi 6.0 Software based on values specific to Turkey and it represents the actual electricity production in the country. Other energy processes, such as natural gas production used in manufacturing process at factory and diesel fuel used by trucks distributing the product, for which no local data was available, were replaced with average EU-25 processes. The results of the study can be refined, as more country-specific data become available.

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APPENDIX A: ECOLABEL CRITERIA

A.1. EUROPE – EU ECOLABEL

Table A. 1. Checklist for the European ecolabel for soaps, shampoos and hair conditioners.

Life Cycle Step	Criterion	Expectations
Manufacturing (formulation)	Safety of the product	• The product shall not be classified with any of the following risk phases according to Directive 67/548/EEC: R50-53, R51-53 and R52-53. Rubbing/abrasive agents in hand cleaning agents are not included. • No constituent substance must be classified as carcinogenic, mutagenic or toxic to reproduction including rules for self-classification class III. • Fragrances must have been manufactured, handled and applied following the code of practice of the International Fragrance Association. • Preservatives must not release substances classified as carcinogenic, mutagenic or toxic to reproduction including rules for self-classification class III. • Additives contained in packaging must: o Not release substances classified as carcinogenic, mutagenic or toxic to reproduction including rules for self-classification class III. o Not be based on Cd or Hg or compounds with these elements.

Use	Performance and durability criteria	• The product's fitness for use must be demonstrated either through laboratory test(s) or a consumer test. • The packaging must be designed to make correct dosage easy.
End of life	Limitation of the use of substances harmful for the aquatic environment	• Critical Dilution Volume Toxicity (CDV_{tox}): o Shampoo, shower products and liquid soaps: CDV_{tox} < 20,000 l/FU o Conditioner: CDV_{tox} < 30,000 l/FU • Each surfactant shall be readily biodegradable • Content of ingredients exceeding 0.01% by weight of the product and not readily biodegradable o Shampoo, shower products and liquid soaps: < 30 mg/FU o Conditioner: < 50 mg/FU • Content of ingredients are not anaerobically biodegradable and having a lowest acute toxicity o Shampoo, shower products and liquid soaps: < 25 mg/FU o Conditioner: < 50 mg/FU • No APEOs and other alkyl phenol derivatives, NTA, boric acids, borates and perborates, nitromusks and polycyclic musks. • Some biocides to preserve the product are allowed, only in the appropriate dosage and if not potentially bio-accumulating. • Organic dyes or coloring agents must not be potentially bio-accumulating.
End of life	Limitation of packaging waste	• Weight/content relationship < 0.3 g of packaging/g of product. • Plastic parts in the primary packaging shall be marked according to DIN 6120, Part 2 or the equivalent. Caps and pumps are exempted.

Table A.2. Criteria on substances and ingredients for soaps, shampoos and hair conditioners.

Criterion	Product	Unit	Pass criterion
Toxicity to aquatic organisms Critical Dilution Volume (CDV)	Liquid soaps, shampoos, shower products and other liquid cleaning products	L/g AC	≤ 20 000
	Hair conditioners	L/g AC	≤ 30 000
	Mixed products	L/g AC	Arithmetic mean
Aerobic biodegradability of non-surfactants; aNBDO= milligrams of not aerobically degradable non-surfactants per gram active content	Liquid soaps, shampoos, shower products and other liquid cleaning products	mg/g AC	≤ 30
	Hair conditioners	mg/g AC	≤ 50
	Mixed products	mg/g AC	Arithmetic mean
Anaerobic biodegradability of toxic ingredients; anNBDO= milligrams of not anaerobically degradable toxic ingredients per gram active content. Toxic ingredient: Lowest acute toxicity is < 100 mg/l.	Liquid soaps, shampoos, shower products and other liquid cleaning products	mg/g AC	≤ 25
	Hair conditioners	mg/g AC	≤ 50
	Mixed products	mg/g AC	Arithmetic mean
Each surfactant used in the product shall be readily biodegradable		No Unit	Yes
The ingredients comply with the requirements described in the criterion on fragrances. Product does not contain fragrances.		No Unit	Yes
The ingredients comply with the requirements described in the criterion on dyes or coloring agents. Product does not contain dyes or coloring agents.		No Unit	Yes
Biocides (or preservatives) in the product comply with the requirements described in the criterion on biocides. Product does not contain biocides.		No Unit	Yes
The product and the ingredients comply with the requirements described in the criterion on hazardous substances.		No Unit	Yes

APPENDIX B: INVENTORIES

Table B.1. The CAS numbers of chemicals used in hair conditioner production.

Raw Materials	CAS number
Cetearyl Alcohol	67762-27-0
Stearamidopropyl Dimethylamine	7651-02-7
Behentrimonium Chloride, Dipropylene Glycol	68607-24-9
PEG 6000 Disterate	9005-08-7, 9004-99-3, 57-11-4, 25322-68-3
Lactic Acid	79-33-4
Lysine HCl	657-27-2
Perfume	54464-57-2, 60-12-8, 101-86-0, 80-54-6, 78-70-6, 138-86-3, 118-58-1, 106-22-9, 91-64-5, 5471-51-2, 88-41-5, 18479-58-8, 127-51-5, 142-92-7, 28219-61-6, 1335-46-2, 104-67-6, 65443-14-3
L-Panthenol	81-13-0, 599-04-2
Ethylhexyl Methoxycinnamate	5466-77-3
Silicone	63148-62-9, 106842-44-8, 112-02-7, 7732-18-5, 122-99-6, 57-55-6
DMDM Hydantoin	6440-58-0, 50-00-0, 7732-18-5
Methylchloroisothiazolinone, Methylisothiazolinone	26172-55-4, 2682-20-4
Disodium EDTA	139-33-3
Sodium Chloride	7647-14-5

Table B.2. The CAS numbers of chemicals used in oil spray production.

Raw Materials	CAS number
Glydant Plus, Iodopropynyl Butylcarbamate	6440-58-0, 55406-53-6
Benzophenone-4	4065-45-6
Lysine	657-27-2
Glycerin	56-81-5
Cetrimonium Chloride	112-02-7, 7732-18-5
PEG/PPG-18/18 Dimethicone, Cyclopentasilox-ane	541-02-6
Cyclomethicone	541-02-6
Dimethicone	63148-62-9
Phenyl Trimethicone	70131-69-0
Disodium EDTA	000139-33-3
Polyquaternium-16	95144-24-4
Perfume	101-86-0, 80-54-6, 78-70-6, 88-41-5, 118-58-1, 65113-99-7, 106-22-9, 68912-13-0, 8013-90-9, 142-19-8, 54464-57-2, 104-67-6, 10094-34-5, 5989-27-5, 6259-76-3, 1205-17-0, 477218-42-1, 65405-77-8, 68039-49-6, 1335-46-2, 144020-22-4
Babassu Oil	91078-92-1, 356065-49-1, 1948-33-0
Argan Oil	-
Panthenol	81-13-0, 599-04-2
Hydrolysed Keratin	-

APPENDIX C: LCIA Characterization for Hair Conditioner Production

Table C.1. Main process emissions by each scenario for GWP - kg CO_2-Equiv.

Global Warming Potential (GWP) - kg CO_2-Equiv. (Hair Conditioner)								
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Consumption**	**Disposal**
Conventional Scenario	Emissions to air	3.5185111	0.051235819	0.00347442	0.00683801	0.00839233	0.26765969	0.03673655
	Inorganic emissions to air	3.4297611	0.047629906	0.00324457	0.00654326	0.00828606	0.25430236	0.02195130
	Carbon dioxide	3.1658455	0.042057046	0.00305310	0.00614349	0.00788990	0.23171022	0.00831969
	Carbon dioxide (biotic)	0.2483029	0.004829454	0.00015036	0.00031405	0.00036820	0.02019528	0.01361561
	Nitrous oxide (laughing gas)	0.0146677	0.000719548	0.00002996	0.00006201	0.00002743	0.00181017	0.000016
	Sulphur hexafluoride	0.0009450	2.38572E-05	0.00001116	0.00002370	0.00000053	0.00058669	7.70E-13
	Organic emissions to air	0.0887500	0.003605913	0.00022985	0.00029475	0.00010627	0.01335734	0.01478524
	Group NMVOC to air	0.0006429	0.00012019	0.00000148	0.00000239	0.00000073	0.00011989	5.32E-09
	Methane	0.0835152	0.003395823	0.00022360	0.00028387	0.00010533	0.00974247	0.01478524
	Methane (biotic)	0.0045920	8.98998E-05	0.00000477	0.00000850	0.00000021	0.00349497	0
Scenario 1 (S1)	Emissions to air	**3.5170557**	**0.049780383**	0.00347442	0.00683801	0.00839233	0.26765969	0.03673655
	Inorganic emissions to air	**3.4283256**	**0.0461944**	0.00324457	0.00654326	0.00828606	0.25430236	0.02195130
	Carbon dioxide	**3.1644747**	**0.040686316**	0.00305310	0.00614349	0.00788990	0.23171022	0.00831969
	Carbon dioxide (biotic)	**0.2482390**	**0.004765464**	0.00015036	0.00031405	0.00036820	0.02019528	0.01361561
	Nitrous oxide (laughing gas)	**0.0146670**	**0.000718854**	0.00002996	0.00006201	0.00002743	0.00181017	0.000016
	Sulphur hexafluoride	**0.0009449**	**2.37657E-05**	0.00001116	0.00002370	0.00000053	0.00058669	7.70E-13
	Organic emissions to air	**0.0887301**	**0.003585983**	0.00022985	0.00029475	0.00010627	0.01335734	0.01478524
	Group NMVOC to air	**0.0006428**	**0.000120064**	0.00000148	0.00000239	0.00000073	0.00011989	5.32E-09

	Methane	**0.0834954**	**0.003376056**	0.00022360	0.00028387	0.00010533	0.00974247	0.01478524
	Methane (biotic)	**0.0045919**	**8.98629E-05**	0.00000477	0.00000850	0.00000021	0.00349497	0
Scenario 2 (S2)	Emissions to air	**3.5120077**	**0.044732426**	0.00347442	0.00683801	0.00839233	0.26765969	0.03673655
	Inorganic emissions to air	**3.4239861**	**0.041854906**	0.00324457	0.00654326	0.00828606	0.25430236	0.02195130
	Carbon dioxide	**3.1598220**	**0.036033581**	0.00305310	0.00614349	0.00788990	0.23171022	0.00831969
	Carbon dioxide (biotic)	**0.2485726**	**0.005099081**	0.00015036	0.00031405	0.00036820	0.02019528	0.01361561
	Nitrous oxide (laughing gas)	**0.0146491**	**0.000701**	0.00002996	0.00006201	0.00002743	0.00181017	0.000016
	Sulphur hexafluoride	**0.0009424**	**2.12445E-05**	0.00001116	0.00002370	0.00000053	0.00058669	7.70E-13
	Organic emissions to air	**0.0880216**	**0.00287752**	0.00022985	0.00029475	0.00010627	0.01335734	0.01478524
	Group NMVOC to air	**0.0006386**	**0.000115921**	0.00000148	0.00000239	0.00000073	0.00011989	5.32E-09
	Methane	**0.0827946**	**0.002675248**	0.00022360	0.00028387	0.00010533	0.00974247	0.01478524
	Methane (biotic)	**0.0045884**	**8.63511E-05**	0.00000477	0.00000850	0.00000021	0.00349497	0
Scenario 3 (S3)	Emissions to air	**3.5075127**	0.051243534	0.00346671	0.00683801	0.00839233	0.26765969	**0.02571558**
	Inorganic emissions to air	**3.4231954**	0.047637286	0.00323719	0.00654326	0.00828606	0.25430236	**0.01536591**
	Carbon dioxide	**3.1633682**	0.042063966	0.00304618	0.00614349	0.00788990	0.23171022	**0.00582378**
	Carbon dioxide (biotic)	**0.2442191**	0.004829819	0.00014999	0.00031405	0.00036820	0.02019528	**0.009530924**
	Nitrous oxide (laughing gas)	**0.0146630**	0.000719618	0.00002989	0.00006201	0.00002743	0.00181017	**0.0000112**
	Sulphur hexafluoride	**0.0009451**	2.38835E-05	0.00001113	0.00002370	0.00000053	0.00058669	**5.39E-13**
	Organic emissions to air	**0.0843173**	0.003606248	0.00022952	0.00029475	0.00010627	0.01335734	**0.01034967**
	Group NMVOC to air	**0.0006429**	0.000120193	0.00000148	0.00000239	0.00000073	0.00011989	**3.72E-09**
	Methane	**0.0790824**	0.003396142	0.00022328	0.00028387	0.00010533	0.00974247	**0.01035**
	Methane (biotic)	**0.0045920**	8.99134E-05	0.00000475	0.00000850	0.00000021	0.00349497	**0**

Table C.2. Main process emissions by each scenario for AP - kg SO_2-Equiv.

Acidification Potential (AP) - kg SO_2-Equiv. (Hair Conditioner)								
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Consumption**	**Disposal**
Conventional Scenario	Emissions to air	0.006688	1.96E-04	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Inorganic emissions to air	0.006688	1.96E-04	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Ammonia	9.16E-05	1.03E-05	7.866E-08	1.613E-07	1.13E-07	7.89E-06	2.80E-08
	Nitrogen oxides	1.20E-03	5.59E-05	2.818E-06	5.41E-06	1.89E-06	2.41E-04	2.66E-06
	Sulphur dioxide	0.005401	1.30E-04	1.173E-05	2.342E-05	1.16E-05	0.000834	2.17E-06
	Emissions to fresh water	1.44E-12	1.36E-12	0	0	0	0	7.46E-14
	Inorganic emissions to fresh water	1.44E-12	1.36E-12	0	0	0	0	7.46E-14
	Sulphuric acid	1.44E-12	1.36E-12	0	0	0	0	7.46E-14
Scenario 1 (S1)	Emissions to air	**0.006678**	**1.86E-04**	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Inorganic emissions to air	**0.006678**	**1.86E-04**	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Ammonia	**9.16E-05**	**1.03E-05**	7.866E-08	1.613E-07	1.13E-07	7.89E-06	2.80E-08
	Nitrogen oxides	**0.001188**	**4.81E-05**	2.818E-06	5.41E-06	1.89E-06	0.000241	2.66E-06
	Sulphur dioxide	**0.005399**	**1.28E-04**	1.173E-05	2.342E-05	1.16E-05	0.000834	2.17E-06
	Emissions to fresh water	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
	Inorganic emissions to fresh water	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
	Sulphuric acid	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
Scenario 2 (S2)	Emissions to air	**0.006692**	**2.00E-04**	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Inorganic emissions to air	**0.006692**	**2.00E-04**	1.46E-05	2.898E-05	1.36E-05	0.001083	4.86E-06
	Ammonia	**8.86E-05**	**7.27E-06**	7.866E-08	1.613E-07	1.13E-07	7.89E-06	2.80E-08
	Nitrogen oxides	**0.001191**	**5.16E-05**	2.818E-06	5.41E-06	1.89E-06	0.000241	2.66E-06
	Sulphur dioxide	**0.005412**	**1.41E-04**	1.173E-05	2.342E-05	1.16E-05	0.000834	2.17E-06

	Emissions to fresh water	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
	Inorganic emissions to fresh water	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
	Sulphuric acid	**1.44E-12**	**1.36E-12**	0	0	0	0	7.46E-14
Scenario 3 (S3)	Emissions to air	**0.006687**	1.96E-04	1.46E-05	2.898E-05	1.36E-05	0.001083	**3.40E-06**
	Inorganic emissions to air	**0.006687**	1.96E-04	1.46E-05	2.898E-05	1.36E-05	0.001083	**3.40E-06**
	Ammonia	**9.16E-05**	1.03E-05	7.866E-08	1.613E-07	1.13E-07	7.89E-06	**1.96E-08**
	Nitrogen oxides	**0.001195**	5.59E-05	2.818E-06	5.41E-06	1.89E-06	0.000241	**1.86E-06**
	Sulphur dioxide	**0.0054**	1.30E-04	1.173E-05	2.342E-05	1.16E-05	0.000834	**1.52E-06**
	Emissions to fresh water	**1.42E-12**	1.36E-12	0	0	0	0	**5.22E-14**
	Inorganic emissions to fresh water	**1.42E-12**	1.36E-12	0	0	0	0	**5.22E-14**
	Sulphuric acid	**1.42E-12**	1.36E-12	0	0	0	0	**5.22E-14**

Table C.3. Main process emissions by each scenario for EP - kg Phosphate-Equiv.

Eutrophication Potential (EP) - kg Phosphate-Equiv. (Hair Conditioner)									
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Consumption**	**Disposal**
Conventional Scenario	Emissions to air	0.000344	1.75E-05	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Inorganic emissions to air	0.000344	1.75E-05	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Ammonia	2.00E-05	2.26E-06	1.72E-08	3.529E-08	2.47E-08	1.73E-06	6.13E-09
	Nitrogen oxides	0.000311	1.45E-05	7.33E-07	1.407E-06	4.90E-07	6.26E-05	6.93E-07
	Nitrous oxide (laughing gas)	1.33E-05	6.52E-07	2.71E-08	5.619E-08	2.49E-08	1.64E-06	1.45E-08
	Phosphorus	2.07E-07	1.41E-08	1.43E-09	3.047E-09	5.54E-11	5.85E-08	0
	Emissions to fresh water	0.015025	2.92E-05	7.91E-06	1.677E-05	5.62E-07	0.000592	5.52E-10
	Ecoinvent long-term to fresh water	0.000888	2.43E-05	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Phosphate	0.000888	2.43E-05	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Inorganic emissions to fresh water	0.014136	4.84E-06	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10
	Phosphate	0.014136	4.84E-06	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10
Scenario 1 (S1)	Emissions to air	**0.000342**	**1.54E-05**	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Inorganic emissions to air	**0.000342**	**1.54E-05**	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Ammonia	**2.00E-05**	**2.26E-06**	1.72E-08	3.529E-08	2.47E-08	1.73E-06	6.13E-09
	Nitrogen oxides	**0.000309**	**1.25E-05**	7.33E-07	1.407E-06	4.90E-07	6.26E-05	6.93E-07
	Nitrous oxide (laughing gas)	**1.33E-05**	**6.51E-07**	2.71E-08	5.619E-08	2.49E-08	1.64E-06	1.45E-08
	Phosphorus	**2.07E-07**	**1.41E-08**	1.43E-09	3.047E-09	5.54E-11	5.85E-08	0
	Emissions to fresh water	**0.015025**	**2.91E-05**	7.91E-06	1.677E-05	5.62E-07	0.000592	5.52E-10
	Ecoinvent long-term to fresh water	**0.000888**	**2.42E-05**	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Phosphate	**0.000888**	**2.42E-05**	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Inorganic emissions to fresh water	**0.014136**	**4.83E-06**	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10

	Phosphate	**0.014136**	**4.83E-06**	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10
Scenario 2 (S2)	Emissions to air	**0.000343**	**1.57E-05**	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Inorganic emissions to air	**0.000343**	**1.57E-05**	7.78E-07	1.501E-06	5.40E-07	6.60E-05	7.13E-07
	Ammonia	**1.94E-05**	**1.59E-06**	1.72E-08	3.529E-08	2.47E-08	1.73E-06	6.13E-09
	Nitrogen oxides	**0.00031**	**1.34E-05**	7.33E-07	1.407E-06	4.90E-07	6.26E-05	6.93E-07
	Nitrous oxide (laughing gas)	**1.33E-05**	**6.35E-07**	2.71E-08	5.619E-08	2.49E-08	1.64E-06	1.45E-08
	Phosphorus	**2.06E-07**	**1.28E-08**	1.43E-09	3.047E-09	5.54E-11	5.85E-08	0
	Emissions to fresh water	**0.015021**	**2.59E-05**	7.91E-06	1.677E-05	5.62E-07	0.000592	5.52E-10
	Ecoinvent long-term to fresh water	**0.000885**	**2.15E-05**	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Phosphate	**0.000885**	**2.15E-05**	7.03E-06	1.491E-05	5.00E-07	0.000524	0
	Inorganic emissions to fresh water	**0.014136**	**4.39E-06**	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10
	Phosphate	**0.014136**	**4.39E-06**	8.75E-07	1.853E-06	6.23E-08	6.73E-05	5.52E-10
Scenario 3 (S3)	Emissions to air	0.000344	1.75E-05	7.78E-07	1.501E-06	5.40E-07	6.60E-05	**4.99E-07**
	Inorganic emissions to air	0.000344	1.75E-05	7.78E-07	1.501E-06	5.40E-07	6.60E-05	**4.99E-07**
	Ammonia	2.00E-05	2.26E-06	1.72E-08	3.529E-08	2.47E-08	1.73E-06	**4.29E-09**
	Nitrogen oxides	0.000311	1.45E-05	7.33E-07	1.407E-06	4.90E-07	6.26E-05	**4.85E-07**
	Nitrous oxide (laughing gas)	1.33E-05	6.52E-07	2.71E-08	5.619E-08	2.49E-08	1.64E-06	**1.02E-08**
	Phosphorus	2.07E-07	1.41E-08	1.43E-09	3.047E-09	5.54E-11	5.85E-08	**0**
	Emissions to fresh water	**0.015022**	2.92E-05	7.91E-06	1.677E-05	5.62E-07	0.000592	**3.87E-10**
	Ecoinvent long-term to fresh water	0.000888	2.43E-05	7.03E-06	1.491E-05	5.00E-07	0.000524	**0**
	Phosphate	0.000888	2.43E-05	7.03E-06	1.491E-05	5.00E-07	0.000524	**0**
	Inorganic emissions to fresh water	**0.014133**	4.84E-06	8.75E-07	1.853E-06	6.23E-08	6.73E-05	**3.87E-10**
	Phosphate	**0.014133**	4.84E-06	8.75E-07	1.853E-06	6.23E-08	6.73E-05	**3.87E-10**

Table C.4. Main process emissions by each scenario for ODP - kg R11-Equiv.

Ozone Layer Depletion Potential (ODP) - kg R11-Equiv. (Hair Conditioner)								
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Consumption**	**Disposal**
Conventional Scenario	Emissions to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Organic emissions to air (group VOC)	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Group NMVOC to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Halogenated organic emissions to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Carbon tetrachloride (tetrachloromethane)	2.14E-09	1.51E-09	6.05E-13	1.05E-12	8.82E-13	2.11E-10	0
	Halon (1211)	2.05E-08	2.08E-09	3.08E-10	1.66E-10	7.86E-12	5.34E-09	0
	Halon (1301)	3.64E-07	1.24E-09	3.43E-11	6.91E-11	1.04E-09	4.75E-09	1.17E-20
	R 11 (trichlorofluoromethane)	6.61E-13	2.84E-14	1.54E-16	9.67E-17	6.42E-18	4.75E-13	1.57E-18
	R 114 (dichlorotetrafluoroethane)	3.07E-09	7.18E-11	3.11E-11	6.40E-11	1.68E-12	1.91E-09	3.74E-14
	R 12 (dichlorodifluoromethane)	7.43E-09	7.34E-09	2.17E-13	1.48E-13	1.38E-14	5.34E-11	3.38E-19
Scenario 1 (S1)	Emissions to air	3.97E-07	**1.21E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Organic emissions to air (group VOC)	3.97E-07	**1.21E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Group NMVOC to air	3.97E-07	**1.21E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Halogenated organic emissions to air	3.97E-07	**1.21E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Carbon tetrachloride (tetrachloromethane)	2.14E-09	**1.51E-09**	6.05E-13	1.05E-12	8.82E-13	2.11E-10	0
	Halon (1211)	2.05E-08	**2.08E-09**	3.08E-10	1.66E-10	7.86E-12	5.34E-09	0
	Halon (1301)	3.64E-07	**1.06E-09**	3.43E-11	6.91E-11	1.04E-09	4.75E-09	1.17E-20
	R 11 (trichlorofluoromethane)	6.61E-13	**2.84E-14**	1.54E-16	9.67E-17	6.42E-18	4.75E-13	1.57E-18
	R 114 (dichlorotetrafluoroethane)	3.07E-09	**7.16E-11**	3.11E-11	6.40E-11	1.68E-12	1.91E-09	3.74E-14
	R 12 (dichlorodifluoromethane)	7.43E-09	**7.34E-09**	2.17E-13	1.48E-13	1.38E-14	5.34E-11	3.38E-19

Scenario 2 (S2)	Emissions to air	**3.95E-07**	**1.03E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Organic emissions to air (group VOC)	**3.95E-07**	**1.03E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Group NMVOC to air	**3.95E-07**	**1.03E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Halogenated organic emissions to air	**3.95E-07**	**1.03E-08**	3.74E-10	3.01E-10	1.05E-09	1.23E-08	3.74E-14
	Carbon tetrachloride (tetrachloromethane)	**8.92E-10**	**2.64E-10**	6.05E-13	1.05E-12	8.82E-13	2.11E-10	0
	Halon (1211)	**1.99E-08**	**1.54E-09**	3.08E-10	1.66E-10	7.86E-12	5.34E-09	0
	Halon (1301)	**3.64E-07**	**1.11E-09**	3.43E-11	6.91E-11	1.04E-09	4.75E-09	1.17E-20
	R 11 (trichlorofluoromethane)	**6.61E-13**	**2.83E-14**	1.54E-16	9.67E-17	6.42E-18	4.75E-13	1.57E-18
	R 114 (dichlorotetrafluoroethane)	**3.06E-09**	**6.26E-11**	3.11E-11	6.40E-11	1.68E-12	1.91E-09	3.74E-14
	R 12 (dichlorodifluoromethane)	**7.42E-09**	**7.34E-09**	2.17E-13	1.48E-13	1.38E-14	5.34E-11	3.38E-19
Scenario 3 (S3)	Emissions to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	**2.62E-14**
	Organic emissions to air (group VOC)	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	**2.62E-14**
	Group NMVOC to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	**2.62E-14**
	Halogenated organic emissions to air	3.97E-07	1.22E-08	3.74E-10	3.01E-10	1.05E-09	1.23E-08	**2.62E-14**
	Carbon tetrachloride (tetrachloromethane)	2.14E-09	1.51E-09	6.05E-13	1.05E-12	8.82E-13	2.11E-10	**0**
	Halon (1211)	2.05E-08	2.08E-09	3.08E-10	1.66E-10	7.86E-12	5.34E-09	**0**
	Halon (1301)	3.64E-07	1.24E-09	3.43E-11	6.91E-11	1.04E-09	4.75E-09	**8.20E-21**
	R 11 (trichlorofluoromethane)	6.61E-13	2.84E-14	1.54E-16	9.67E-17	6.42E-18	4.75E-13	**1.10E-18**
	R 114 (dichlorotetrafluoroethane)	3.07E-09	7.18E-11	3.11E-11	6.40E-11	1.68E-12	1.91E-09	**2.62E-14**
	R 12 (dichlorodifluoromethane)	7.43E-09	7.34E-09	2.17E-13	1.48E-13	1.38E-14	5.34E-11	**2.36E-19**

Table C.5. Main process emissions by each scenario for POCP - kg Ethene-Equiv.

Photochemical Ozone Creation Potential (POCP) - kg Ethene-Equiv. (Hair Conditioner)								
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Consumption**	**Disposal**
Conventional Scenario	Emissions to air	0.001015136	3.35E-05	1.10E-06	1.788E-06	2.19E-06	9.23E-05	5.02E-06
	Inorganic emissions to air	0.000382762	9.83E-06	6.62E-07	1.294E-06	7.87E-07	5.53E-05	1.03E-06
	Carbon monoxide	9.98E-05	1.51E-06	3.50E-08	5.426E-08	2.17E-07	8.45E-06	7.92E-07
	Nitrogen oxides	6.70E-05	3.13E-06	1.58E-07	3.029E-07	1.06E-07	1.35E-05	1.49E-07
	Sulphur dioxide	0.000216027	5.20E-06	4.69E-07	9.366E-07	4.64E-07	3.34E-05	8.67E-08
	Organic emissions to air (group VOC)	0.000632373	2.37E-05	4.37E-07	4.939E-07	1.41E-06	3.70E-05	3.99E-06
	Group NMVOC to air	0.00061233	2.28E-05	3.83E-07	4.257E-07	1.38E-06	3.47E-05	4.42E-07
	Methane	2.00E-05	8.15E-07	5.37E-08	6.813E-08	2.53E-08	2.34E-06	3.55E-06
	VOC (unspecified)	3.12E-11	0	0	0	0	0	0
Scenario 1 (S1)	Emissions to air	**0.001013681**	**3.20E-05**	1.10E-06	1.788E-06	2.19E-06	9.23E-05	5.02E-06
	Inorganic emissions to air	**0.00038212**	**9.19E-06**	6.62E-07	1.294E-06	7.87E-07	5.53E-05	1.03E-06
	Carbon monoxide	**9.96E-05**	**1.38E-06**	3.50E-08	5.426E-08	2.17E-07	8.45E-06	7.92E-07
	Nitrogen oxides	**6.65E-05**	**2.70E-06**	1.58E-07	3.029E-07	1.06E-07	1.35E-05	1.49E-07
	Sulphur dioxide	**0.000215945**	**5.12E-06**	4.69E-07	9.366E-07	4.64E-07	3.34E-05	8.67E-08
	Organic emissions to air (group VOC)	**0.000631561**	**2.28E-05**	4.37E-07	4.939E-07	1.41E-06	3.70E-05	3.99E-06
	Group NMVOC to air	**0.000611522**	**2.20E-05**	3.83E-07	4.257E-07	1.38E-06	3.47E-05	4.42E-07
	Methane	**2.00E-05**	**8.10E-07**	5.37E-08	6.813E-08	2.53E-08	2.34E-06	3.55E-06
	VOC (unspecified)	**3.12E-11**	**0**	0	0	0	0	0

Scenario 2 (S2)	Emissions to air	**0.001011509**	**2.99E-05**	1.10E-06	1.788E-06	2.19E-06	9.23E-05	5.02E-06
	Inorganic emissions to air	**0.000382854**	**9.92E-06**	6.62E-07	1.294E-06	7.87E-07	5.53E-05	1.03E-06
	Carbon monoxide	**9.97E-05**	**1.38E-06**	3.50E-08	5.426E-08	2.17E-07	8.45E-06	7.92E-07
	Nitrogen oxides	**6.67E-05**	**2.89E-06**	1.58E-07	3.029E-07	1.06E-07	1.35E-05	1.49E-07
	Sulphur dioxide	**0.000216479**	**5.65E-06**	4.69E-07	9.366E-07	4.64E-07	3.34E-05	8.67E-08
	Organic emissions to air (group VOC)	**0.000628655**	**1.99E-05**	4.37E-07	4.939E-07	1.41E-06	3.70E-05	3.99E-06
	Group NMVOC to air	**0.000608784**	**1.93E-05**	3.83E-07	4.257E-07	1.38E-06	3.47E-05	4.42E-07
	Methane	**1.99E-05**	**6.42E-07**	5.37E-08	6.813E-08	2.53E-08	2.34E-06	3.55E-06
	VOC (unspecified)	**3.12E-11**	**0**	0	0	0	0	0
Scenario 3 (S3)	Emissions to air	**0.001013641**	3.35E-05	1.10E-06	1.788E-06	2.19E-06	9.23E-05	**3.51E-06**
	Inorganic emissions to air	**0.000382459**	9.83E-06	6.62E-07	1.294E-06	7.87E-07	5.53E-05	**7.19E-07**
	Carbon monoxide	**9.95E-05**	1.51E-06	3.50E-08	5.426E-08	2.17E-07	8.45E-06	**5.54E-07**
	Nitrogen oxides	**6.69E-05**	3.13E-06	1.58E-07	3.029E-07	1.06E-07	1.35E-05	**1.04E-07**
	Sulphur dioxide	**0.000216003**	5.20E-06	4.69E-07	9.366E-07	4.64E-07	3.34E-05	**6.07E-08**
	Organic emissions to air (group VOC)	**0.000631182**	2.37E-05	4.37E-07	4.939E-07	1.41E-06	3.70E-05	**2.79E-06**
	Group NMVOC to air	**0.000612203**	2.28E-05	3.83E-07	4.257E-07	1.38E-06	3.47E-05	**3.09E-07**
	Methane	**1.90E-05**	8.15E-07	5.37E-08	6.813E-08	2.53E-08	2.34E-06	**2.48E-06**
	VOC (unspecified)	**3.12E-11**	0	0	0	0	0	**0**

APPENDIX D: LCIA Characterization for Oil Spray Production

Table D.1. Main process emissions by each scenario for GWP - kg CO_2-Equiv.

Global Warming Potential (GWP) - kg CO_2-Equiv. (Oil Spray)							
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Disposal**
Conventional Scenario	Emissions to air	0.675500908	1.56E-01	0.002745	0.007283	0.009095466	0.044900223
	Inorganic emissions to air	0.617064226	1.43E-01	0.002621	0.006969	0.008980288	0.02682937
	Carbon dioxide	0.445526085	1.19E-01	0.002460	0.006544	0.008550937	0.010168506
	Carbon dioxide (biotic)	0.162507792	1.98E-02	0.000127	0.000335	0.000399049	0.016641295
	Nitrous oxide (laughing gas)	0.008665884	4.29E-03	0.000025	0.000066	2.97E-05	1.96E-05
	Sulphur hexafluoride	0.000364465	1.01E-04	0.000009	0.000025	5.72E-07	9.41E-13
	Organic emissions to air	0.058436682	1.25E-02	0.000124	0.000314	0.000115178	0.018070853
	Group NMVOC to air	0.001196802	8.87E-04	0.000001	0.000003	7.90E-07	6.50E-09
	Methane	0.055116663	1.09E-02	0.000119	0.000302	0.000114157	0.018070846
	Methane (biotic)	0.002123217	7.72E-04	0.000004	0.000009	2.31E-07	0
Scenario 1 (S1)	Emissions to air	**0.576613747**	**5.82E-02**	0.002745	0.007283	0.009095466	0.044900223
	Inorganic emissions to air	**0.519431088**	**4.69E-02**	0.002621	0.006969	0.008980288	0.02682937
	Carbon dioxide	**0.352412778**	**2.72E-02**	0.002460	0.006544	0.008550937	0.010168506
	Carbon dioxide (biotic)	**0.158202194**	**1.55E-02**	0.000127	0.000335	0.000399049	0.016641295
	Nitrous oxide (laughing gas)	**0.00845788**	**4.08E-03**	0.000025	0.000066	2.97E-05	1.96E-05
	Sulphur hexafluoride	**0.000358236**	**9.45E-05**	0.000009	0.000025	5.72E-07	9.41E-13
	Organic emissions to air	**0.057182659**	**1.13E-02**	0.000124	0.000314	0.000115178	0.018070853
	Group NMVOC to air	**0.001188203**	**8.79E-04**	0.000001	0.000003	7.90E-07	6.50E-09
	Methane	**0.053873754**	**9.63E-03**	0.000119	0.000302	0.000114157	0.018070846

	Methane (biotic)	**0.002120702**	**7.69E-04**	0.000004	0.000009	2.31E-07	0
Scenario 2 (S2)	Emissions to air	**0.686940968**	**1.67E-01**	0.002745	0.007283	0.009095466	0.044900223
	Inorganic emissions to air	**0.627780837**	**1.67E-01**	0.002621	0.006969	0.008980288	0.02682937
	Carbon dioxide	**0.455509421**	**1.54E-01**	0.002460	0.006544	0.008550937	0.010168506
	Carbon dioxide (biotic)	**0.162726114**	**1.29E-01**	0.000127	0.000335	0.000399049	0.016641295
	Nitrous oxide (laughing gas)	**0.009162834**	**2.00E-02**	0.000025	0.000066	2.97E-05	1.96E-05
	Sulphur hexafluoride	**0.000382467**	**4.78E-03**	0.000009	0.000025	5.72E-07	9.41E-13
	Organic emissions to air	**0.059160131**	**1.19E-04**	0.000124	0.000314	0.000115178	0.018070853
	Group NMVOC to air	**0.001217031**	**1.32E-02**	0.000001	0.000003	7.90E-07	6.50E-09
	Methane	**0.055811235**	**9.07E-04**	0.000119	0.000302	0.000114157	0.018070846
	Methane (biotic)	**0.002131865**	**1.15E-02**	0.000004	0.000009	2.31E-07	0
Scenario 3 (S3)	Emissions to air	**0.664607779**	1.56E-01	0.002745	0.007283	0.009095466	**0.031759267**
	Inorganic emissions to air	**0.611172497**	1.43E-01	0.002621	0.006969	0.009095466	**0.018977214**
	Carbon dioxide	**0.44440885**	1.19E-01	0.002460	0.006544	0.008980288	**0.007192488**
	Carbon dioxide (biotic)	**0.157716394**	1.98E-02	0.000127	0.000335	0.008550937	**0.011770885**
	Nitrous oxide (laughing gas)	**0.008677012**	4.29E-03	0.000025	0.000066	0.000399049	**1.38E-05**
	Sulphur hexafluoride	**0.000370241**	1.01E-04	0.000009	0.000025	2.97E-05	**6.65E-13**
	Organic emissions to air	**0.053435282**	1.25E-02	0.000124	0.000314	5.72E-07	**0.012782053**
	Group NMVOC to air	**0.001198222**	8.87E-04	0.000001	0.000003	0.000115178	**4.60E-09**
	Methane	**0.050110875**	1.09E-02	0.000119	0.000302	7.90E-07	**0.012782049**
	Methane (biotic)	**0.002126184**	7.72E-04	0.000004	0.000009	0.000114157	**0**

Table D.2. Main process emissions by each scenario for AP - kg SO_2-Equiv.

Acidification Potential (AP) - kg SO_2-Equiv. (Oil Spray)							
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Disposal**
Conventional Scenario	Emissions to air	0.001739189	5.25E-04	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Inorganic emissions to air	0.001739189	5.25E-04	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Ammonia	8.07E-05	2.75E-05	6.49E-08	1.72E-07	1.23E-07	3.43E-08
	Nitrogen oxides	0.000534864	1.40E-04	2.18E-06	5.76E-06	2.04E-06	3.26E-06
	Sulphur dioxide	0.001123586	3.58E-04	9.37E-06	2.49E-05	1.26E-05	2.65E-06
	Emissions to fresh water	9.55E-14	0	0	0	0	9.12E-14
	Inorganic emissions to fresh water	9.55E-14	0	0	0	0	9.12E-14
	Sulphuric acid	9.55E-14	0	0	0	0	9.12E-14
Scenario 1 (S1)	Emissions to air	**0.001567012**	**3.65E-04**	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Inorganic emissions to air	**0.001567012**	**3.65E-04**	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Ammonia	**7.99E-05**	**2.67E-05**	6.49E-08	1.72E-07	1.23E-07	3.43E-08
	Nitrogen oxides	**0.000500753**	**1.16E-04**	2.18E-06	5.76E-06	2.04E-06	3.26E-06
	Sulphur dioxide	**0.000986327**	**2.22E-04**	9.37E-06	2.49E-05	1.26E-05	2.65E-06
	Emissions to fresh water	**9.55E-14**	**0**	0	0	0	9.12E-14
	Inorganic emissions to fresh water	**9.55E-14**	**0**	0	0	0	9.12E-14
	Sulphuric acid	**9.55E-14**	**0**	0	0	0	9.12E-14
Scenario 2 (S2)	Emissions to air	**0.001793301**	**5.79E-04**	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Inorganic emissions to air	**0.001793301**	**5.79E-04**	1.16E-05	3.09E-05	1.48E-05	5.94E-06
	Ammonia	**8.14E-05**	**2.82E-05**	6.49E-08	1.72E-07	1.23E-07	3.43E-08
	Nitrogen oxides	**0.000544502**	**1.49E-04**	2.18E-06	5.76E-06	2.04E-06	3.26E-06
	Sulphur dioxide	**0.001167428**	**4.02E-04**	9.37E-06	2.49E-05	1.26E-05	2.65E-06

	Emissions to fresh water	**9.55E-14**	**0**	0	0	0	9.12E-14
	Inorganic emissions to fresh water	**9.55E-14**	**0**	0	0	0	9.12E-14
	Sulphuric acid	**9.55E-14**	**0**	0	0	0	9.12E-14
Scenario 3 (S3)	Emissions to air	**0.001746738**	5.25E-04	1.16E-05	3.09E-05	1.48E-05	**1.82E-05**
	Inorganic emissions to air	**0.001746738**	5.25E-04	1.16E-05	3.09E-05	1.48E-05	**1.82E-05**
	Ammonia	**8.08E-05**	2.75E-05	6.49E-08	1.72E-07	1.23E-07	**1.34E-07**
	Nitrogen oxides	**0.000535846**	1.40E-04	2.18E-06	5.76E-06	2.04E-06	**2.96E-06**
	Sulphur dioxide	**0.001130119**	3.58E-04	9.37E-06	2.49E-05	1.26E-05	**1.51E-05**
	Emissions to fresh water	**6.88E-14**	0	0	0	0	**0**
	Inorganic emissions to fresh water	**6.88E-14**	0	0	0	0	**0**
	Sulphuric acid	**6.88E-14**	0	0	0	0	**0**

Table D.3. Main process emissions by each scenario for EP - kg Phosphate-Equiv.

Eutrophication Potential (EP) - kg Phosphate-Equiv. (Oil Spray)							
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Disposal**
Conventional Scenario	Emissions to air	0.000164784	4.63E-05	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Inorganic emissions to air	0.000164784	4.63E-05	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Ammonia	1.77E-05	6.02E-06	1.42E-08	3.76E-08	2.68E-08	7.50E-09
	Nitrogen oxides	0.000139065	3.63E-05	5.67E-07	1.50E-06	5.32E-07	8.47E-07
	Nitrous oxide (laughing gas)	7.85E-06	3.88E-06	2.24E-08	5.98E-08	2.69E-08	1.77E-08
	Phosphorus	2.06E-07	2.78E-08	1.20E-09	3.25E-09	6.01E-11	0
	Emissions to fresh water	0.000441215	9.37E-05	6.68E-06	1.79E-05	6.09E-07	6.75E-10
	Ecoinvent long-term to fresh water	0.000375224	7.90E-05	5.94E-06	1.59E-05	5.42E-07	0
	Phosphate	0.000375224	7.90E-05	5.94E-06	1.59E-05	5.42E-07	0
	Inorganic emissions to fresh water	6.60E-05	1.47E-05	7.39E-07	1.97E-06	6.75E-08	6.75E-10
	Phosphate	6.60E-05	1.47E-05	7.39E-07	1.97E-06	6.75E-08	6.75E-10
Scenario 1 (S1)	Emissions to air	**0.000155549**	**3.96E-05**	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Inorganic emissions to air	**0.000155549**	**3.96E-05**	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Ammonia	**1.75E-05**	**5.85E-06**	1.42E-08	3.76E-08	2.68E-08	7.50E-09
	Nitrogen oxides	**0.000130196**	**3.00E-05**	5.67E-07	1.50E-06	5.32E-07	8.47E-07
	Nitrous oxide (laughing gas)	**7.66E-06**	**3.69E-06**	2.24E-08	5.98E-08	2.69E-08	1.77E-08
	Phosphorus	**2.05E-07**	**2.72E-08**	1.20E-09	3.25E-09	6.01E-11	0
	Emissions to fresh water	**0.000434583**	**8.72E-05**	6.68E-06	1.79E-05	6.09E-07	6.75E-10
	Ecoinvent long-term to fresh water	**0.000369326**	**7.32E-05**	5.94E-06	1.59E-05	5.42E-07	0
	Phosphate	**0.000369326**	**7.32E-05**	5.94E-06	1.59E-05	5.42E-07	0
	Inorganic emissions to fresh water	**6.53E-05**	**1.39E-05**	7.39E-07	1.97E-06	6.75E-08	6.75E-10
	Phosphate	**6.53E-05**	**1.39E-05**	7.39E-07	1.97E-06	6.75E-08	6.75E-10

Scenario 2 (S2)	Emissions to air	**0.00016788**	**4.94E-05**	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Inorganic emissions to air	**0.00016788**	**4.94E-05**	6.05E-07	1.60E-06	5.85E-07	8.72E-07
	Ammonia	**1.78E-05**	**6.16E-06**	1.42E-08	3.76E-08	2.68E-08	7.50E-09
	Nitrogen oxides	**0.00014157**	**3.89E-05**	5.67E-07	1.50E-06	5.32E-07	8.47E-07
	Nitrous oxide (laughing gas)	**8.30E-06**	**4.33E-06**	2.24E-08	5.98E-08	2.69E-08	1.77E-08
	Phosphorus	**2.08E-07**	**3.03E-08**	1.20E-09	3.25E-09	6.01E-11	0
	Emissions to fresh water	**0.000473896**	**1.26E-04**	6.68E-06	1.79E-05	6.09E-07	6.75E-10
	Ecoinvent long-term to fresh water	**0.000392512**	**9.63E-05**	5.94E-06	1.59E-05	5.42E-07	0
	Phosphate	**0.000392512**	**9.63E-05**	5.94E-06	1.59E-05	5.42E-07	0
	Inorganic emissions to fresh water	**8.14E-05**	**3.01E-05**	7.39E-07	1.97E-06	6.75E-08	6.75E-10
	Phosphate	**8.14E-05**	**3.01E-05**	7.39E-07	1.97E-06	6.75E-08	6.75E-10
Scenario 3 (S3)	Emissions to air	**0.000165057**	4.63E-05	6.05E-07	1.60E-06	5.85E-07	**6.17E-07**
	Inorganic emissions to air	**0.000165057**	4.63E-05	6.05E-07	1.60E-06	5.85E-07	**6.17E-07**
	Ammonia	**1.77E-05**	6.02E-06	1.42E-08	3.76E-08	2.68E-08	**5.30E-09**
	Nitrogen oxides	**0.00013932**	3.63E-05	5.67E-07	1.50E-06	5.32E-07	**5.99E-07**
	Nitrous oxide (laughing gas)	**7.86E-06**	3.88E-06	2.24E-08	5.98E-08	2.69E-08	**1.25E-08**
	Phosphorus	**2.06E-07**	2.78E-08	1.20E-09	3.25E-09	6.01E-11	**0**
	Emissions to fresh water	**0.000448883**	9.37E-05	6.68E-06	1.79E-05	6.09E-07	**4.78E-10**
	Ecoinvent long-term to fresh water	**0.000378841**	7.90E-05	5.94E-06	1.59E-05	5.42E-07	**0**
	Phosphate	**0.000378841**	7.90E-05	5.94E-06	1.59E-05	5.42E-07	**0**
	Inorganic emissions to fresh water	**7.00E-05**	1.47E-05	7.39E-07	1.97E-06	6.75E-08	**4.78E-10**
	Phosphate	**7.00E-05**	1.47E-05	7.39E-07	1.97E-06	6.75E-08	**4.78E-10**

Table D.4. Main process emissions by each scenario for ODP - kg R11-Equiv.

Ozone Layer Depletion Potential (ODP) - kg R11-Equiv. (Oil Spray)							
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Disposal**
Conventional Scenario	Emissions to air	1.14E-07	8.74E-08	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Organic emissions to air (group VOC)	1.14E-07	8.74E-08	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Group NMVOC to air	1.14E-07	8.74E-08	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Halogenated organic emissions to air	1.14E-07	8.74E-08	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Carbon tetrachloride (tetrachloromethane)	4.11E-09	3.92E-09	4.57E-13	1.11E-12	9.56E-13	0
	Halon (1211)	2.29E-08	6.65E-09	8.03E-11	1.77E-10	8.52E-12	0
	Halon (1301)	1.29E-08	3.35E-09	2.81E-11	7.36E-11	1.13E-09	1.43E-20
	R 11 (trichlorofluoromethane)	3.18E-13	2.09E-13	1.36E-16	1.03E-16	6.96E-18	1.92E-18
	R 114 (dichlorotetrafluoroethane)	1.14E-09	2.48E-10	2.55E-11	6.81E-11	1.82E-12	4.57E-14
	R 12 (dichlorodifluoromethane)	7.32E-08	7.32E-08	7.73E-14	1.58E-13	1.49E-14	4.13E-19
Scenario 1 (S1)	Emissions to air	**1.02E-07**	**7.51E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Organic emissions to air (group VOC)	**1.02E-07**	**7.51E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Group NMVOC to air	**1.02E-07**	**7.51E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Halogenated organic emissions to air	**1.02E-07**	**7.51E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Carbon tetrachloride (tetrachloromethane)	**4.10E-09**	**3.91E-09**	4.57E-13	1.11E-12	9.56E-13	0
	Halon (1211)	**2.28E-08**	**6.56E-09**	8.03E-11	1.77E-10	8.52E-12	0
	Halon (1301)	**6.63E-10**	**-8.76E-09**	2.81E-11	7.36E-11	1.13E-09	1.43E-20
	R 11 (trichlorofluoromethane)	**3.18E-13**	**2.09E-13**	1.36E-16	1.03E-16	6.96E-18	1.92E-18
	R 114 (dichlorotetrafluoroethane)	**1.12E-09**	**2.29E-10**	2.55E-11	6.81E-11	1.82E-12	4.57E-14
	R 12 (dichlorodifluoromethane)	**7.32E-08**	**7.32E-08**	7.73E-14	1.58E-13	1.49E-14	4.13E-19

Scenario 2 (S2)	Emissions to air	**1.18E-07**	**9.13E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Organic emissions to air (group VOC)	**1.18E-07**	**9.13E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Group NMVOC to air	**1.18E-07**	**9.13E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Halogenated organic emissions to air	**1.18E-07**	**9.13E-08**	1.34E-10	3.20E-10	1.14E-09	4.57E-14
	Carbon tetrachloride (tetrachloromethane)	**7.49E-09**	**7.30E-09**	4.57E-13	1.11E-12	9.56E-13	0
	Halon (1211)	**2.32E-08**	**6.89E-09**	8.03E-11	1.77E-10	8.52E-12	0
	Halon (1301)	**1.32E-08**	**3.60E-09**	2.81E-11	7.36E-11	1.13E-09	1.43E-20
	R 11 (trichlorofluoromethane)	**3.21E-13**	**2.12E-13**	1.36E-16	1.03E-16	6.96E-18	1.92E-18
	R 114 (dichlorotetrafluoroethane)	**1.20E-09**	**3.07E-10**	2.55E-11	6.81E-11	1.82E-12	4.57E-14
	R 12 (dichlorodifluoromethane)	**7.32E-08**	**7.32E-08**	7.73E-14	1.58E-13	1.49E-14	4.13E-19
Scenario 3 (S3)	Emissions to air	**1.15E-07**	8.74E-08	1.34E-10	3.20E-10	1.14E-09	**3.23E-14**
	Organic emissions to air (group VOC)	**1.15E-07**	8.74E-08	1.34E-10	3.20E-10	1.14E-09	**3.23E-14**
	Group NMVOC to air	**1.15E-07**	8.74E-08	1.34E-10	3.20E-10	1.14E-09	**3.23E-14**
	Halogenated organic emissions to air	**1.15E-07**	8.74E-08	1.34E-10	3.20E-10	1.14E-09	**3.23E-14**
	Carbon tetrachloride (tetrachloromethane)	**4.11E-09**	3.92E-09	4.57E-13	1.11E-12	9.56E-13	**0**
	Halon (1211)	**2.35E-08**	6.65E-09	8.03E-11	1.77E-10	8.52E-12	**0**
	Halon (1301)	**1.29E-08**	3.35E-09	2.81E-11	7.36E-11	1.13E-09	**1.01E-20**
	R 11 (trichlorofluoromethane)	**3.18E-13**	2.09E-13	1.36E-16	1.03E-16	6.96E-18	**1.36E-18**
	R 114 (dichlorotetrafluoroethane)	**1.16E-09**	2.48E-10	2.55E-11	6.81E-11	1.82E-12	**3.23E-14**
	R 12 (dichlorodifluoromethane)	**7.32E-08**	7.32E-08	7.73E-14	1.58E-13	1.49E-14	**2.92E-19**

Table D.5. Main process emissions by each scenario for POCP - kg Ethene-Equiv.

Photochemical Ozone Creation Potential (POCP) - kg Ethene-Equiv. (Oil Spray)							
Scenarios	**Flows**	**Total**	**Raw Materials Acquisition**	**Mixing**	**Filling & Packaging**	**Distribution**	**Disposal**
Conventional Scenario	Emissions to air	0.000253141	6.57E-05	7.34E-07	1.90E-06	2.38E-06	6.13E-06
	Inorganic emissions to air	9.52E-05	2.50E-05	5.21E-07	1.38E-06	8.53E-07	1.26E-06
	Carbon monoxide	2.03E-05	2.81E-06	2.35E-08	5.78E-08	2.35E-07	9.68E-07
	Nitrogen oxides	3.00E-05	7.83E-06	1.22E-07	3.23E-07	1.14E-07	1.82E-07
	Sulphur dioxide	4.49E-05	1.43E-05	3.75E-07	9.98E-07	5.03E-07	1.06E-07
	Organic emissions to air (group VOC)	0.000157928	4.07E-05	2.13E-07	5.26E-07	1.52E-06	4.88E-06
	Group NMVOC to air	0.0001447	3.81E-05	1.85E-07	4.53E-07	1.50E-06	5.40E-07
	Methane	1.32E-05	2.61E-06	2.85E-08	7.26E-08	2.74E-08	4.34E-06
	VOC (unspecified)	1.42E-11	0	0	0	0	0
Scenario 1 (S1)	Emissions to air	**0.000224261**	**3.85E-05**	7.34E-07	1.90E-06	2.38E-06	6.13E-06
	Inorganic emissions to air	**8.25E-05**	**1.30E-05**	5.21E-07	1.38E-06	8.53E-07	1.26E-06
	Carbon monoxide	**1.50E-05**	**-2.33E-06**	2.35E-08	5.78E-08	2.35E-07	9.68E-07
	Nitrogen oxides	**2.80E-05**	**6.47E-06**	1.22E-07	3.23E-07	1.14E-07	1.82E-07
	Sulphur dioxide	**3.95E-05**	**8.90E-06**	3.75E-07	9.98E-07	5.03E-07	1.06E-07
	Organic emissions to air (group VOC)	**0.000141722**	**2.55E-05**	2.13E-07	5.26E-07	1.52E-06	4.88E-06
	Group NMVOC to air	**0.000128792**	**2.32E-05**	1.85E-07	4.53E-07	1.50E-06	5.40E-07
	Methane	**1.29E-05**	**2.31E-06**	2.85E-08	7.26E-08	2.74E-08	4.34E-06
	VOC (unspecified)	**1.42E-11**	**0**	0	0	0	0
Scenario 2 (S2)	Emissions to air	**0.000261541**	**7.41E-05**	7.34E-07	1.90E-06	2.38E-06	6.13E-06
	Inorganic emissions to air	**9.85E-05**	**2.82E-05**	5.21E-07	1.38E-06	8.53E-07	1.26E-06

	Carbon monoxide	**2.13E-05**	**3.80E-06**	2.35E-08	5.78E-08	2.35E-07	9.68E-07
	Nitrogen oxides	**3.05E-05**	**8.37E-06**	1.22E-07	3.23E-07	1.14E-07	1.82E-07
	Sulphur dioxide	**4.67E-05**	**1.61E-05**	3.75E-07	9.98E-07	5.03E-07	1.06E-07
	Organic emissions to air (group VOC)	**0.000163042**	**4.58E-05**	2.13E-07	5.26E-07	1.52E-06	4.88E-06
	Group NMVOC to air	**0.000149647**	**4.31E-05**	1.85E-07	4.53E-07	1.50E-06	5.40E-07
	Methane	**1.34E-05**	**2.77E-06**	2.85E-08	7.26E-08	2.74E-08	4.34E-06
	VOC (unspecified)	**1.42E-11**	**0**	0	0	0	0
Scenario 3 (S3)	Emissions to air	**0.000252382**	6.57E-05	7.34E-07	1.90E-06	2.38E-06	**4.34E-06**
	Inorganic emissions to air	**9.53E-05**	2.50E-05	5.21E-07	1.38E-06	8.53E-07	**8.88E-07**
	Carbon monoxide	**2.01E-05**	2.81E-06	2.35E-08	5.78E-08	2.35E-07	**6.84E-07**
	Nitrogen oxides	**3.00E-05**	7.83E-06	1.22E-07	3.23E-07	1.14E-07	**1.29E-07**
	Sulphur dioxide	**4.52E-05**	1.43E-05	3.75E-07	9.98E-07	5.03E-07	**7.50E-08**
	Organic emissions to air (group VOC)	**0.000157102**	4.07E-05	2.13E-07	5.26E-07	1.52E-06	**3.45E-06**
	Group NMVOC to air	**0.000145075**	3.81E-05	1.85E-07	4.53E-07	1.50E-06	**3.82E-07**
	Methane	**1.20E-05**	2.61E-06	2.85E-08	7.26E-08	2.74E-08	**3.07E-06**
	VOC (unspecified)	**1.42E-11**	0	0	0	0	**0**