RESOURCE AND ENVIRONMENTAL PROFILE EVALUATION OF PERSONAL CARE AND COSMETIC PRODUCTS WITH LIFE CYCLE ASSESSMENT METHODOLOGY

by

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ABSTRACT

RESOURCE AND ENVIRONMENTAL PROFILE EVALUATION OF PERSONAL CARE AND COSMETIC PRODUCTS WITH LIFE CYCLE ASSESSMENT METHODOLOGY

Resource and energy depletion have been limiting for many industries, including the personal care and cosmetic products (PCCPs) sector. Moreover, intense use of chemical ingredients has fastened emerging problems occurring in aquatic environments at the end of life of these chemicals. As they have an immense ecological footprint, their fate should be tracked for elimination of the adverse environmental impacts. The PCCPs sector has reached a large trade capacity due to accelerating demands of consumers. As the participation of companies/policymakers to the green initiatives affects the behavior intention of consumers, the sales rate of ecolabelled products have ascended. Correspondingly, manufacturers are required to choose ingredients considering potential improvements towards product formulations, to lessen the environmental impacts of their product chain, to promote their products as environmentally friendly, and to fulfil the consumers' expectations. Under the guidance of ecolabel standards, a selected group of PCCPs (liquid & bar soaps, shampoo, hair conditioner, body cleaning products) was analyzed with LCA methodology. Two products providing the same service in each product category were compared to determine environmental hotspots in their product chain. Although characterization results varied depending on the life cycle stage by composition, consumption, and end-of-life stages, Global Warming Potential (GWP) was the highest impact category for all the selected products. The highest contribution to GWP originated from wastewater treatment (WWT) and transportation processes in hand wash products while in shower products energy use in production & consumption, and the WWT process had the highest impact; 90.3 % and 7.4 %, respectively.

ÖZET

KİŞİSEL BAKIM VE KOZMETİK ÜRÜNLERİNİN YAŞAM DÖNGÜSÜ METODOLOJİSİ İLE KAYNAK VE ÇEVRESEL PROFİLİNİN ANALİZİ

Hammadde ve enerji kaynaklarındaki azalma kişisel bakım ve kozmetik ürünleri sektörü de dahil olmak üzere birçok endüstri için kısıtlayıcı unsur haline gelmiştir. Ayrıca, kimyasal bileşenlerin yoğun kullanımı, bu kimyasalların ömrünü tamamladığı noktada sucul ortamlarda öncelik gerektiren sorunların oluşumunu hızlandırmaktadır. Kimyasal bileşenler doğada ekolojik ayak izine sahip olduğundan, olumsuz etkilerin ortadan kaldırılması için bunların akıbeti takip edilmelidir. Kozmetik sektörü, tüketicilerin artan talepleri nedeniyle büyük bir ticaret kapasitesine ulaşmıştır. Şirketlerin/karar mercilerinin yeşil girişimlere katılımının, tüketicilerin davranış eğilimlerini de etkilediğinin kanıtlanması sebebiyle eko-etiketli ürünlerin satış oranı yükselmiştir. Buna paralel olarak, üreticilerden, ürün içeriğindeki bileşenleri ürün formülasyonlarını iyileştirmeye yönelik potansiyel gelişmeler doğrultusunda seçmeleri, ürün zincirlerinin çevresel etkilerini azaltmaları, ürünlerini çevre dostu olarak tanıtmaları ve tüketicilerin taleplerini karşılamaları beklenmektedir. Eko-etiket standartlarının rehberliğinde, seçilmiş bir grup kişisel bakım ve kozmetik ürün (sıvı sabun, katı sabun, şampuan, saç kremi ve vücut yıkama ürünleri) Yaşam Döngüsü Değerlendirmesi (YDD) metodolojisi ile analiz edilmiştir. Ürün zincirindeki çevresel sıcak noktaları belirlemek için her bir ürün kategorisinde aynı hizmeti veren iki ürün karşılaştırılmıştır. Karakterizasyon sonuçları, kimyasal içerik, tüketim ve yaşam sonu prosesleri gibi yaşam döngüsü aşamalarına bağlı olarak farklılık göstermesine rağmen küresel ısınma potansiyeli (GWP) incelenen tüm ürünler için en yüksek etki kategorisidir. El yıkama ürünlerinde küresel ısınma potansiyeline en yüksek katkı sağlayan prosesler kentsel atıksu arıtma ve lojistik prosesleri iken banyo ürünlerinde üretim & tüketim ile kentsel atıksu arıtma prosesleri sırasıyla % 90,3 ve % 7,4 ile en yüksek etkiye sahiptir.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	**Explanation**
Be	Beryllium
CH_4	Methane
Co	Cobalt
CO	Carbon monoxide
CO_2	Carbon dioxide
Cu	Copper
HCl	Hydrogen chloride
H_2O	Water
HNO_3	Nitric acid
H_2SO_4	Sulphuric acid
NH_3	Ammonia
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
P	Phosphorus
PO_4^{3-}	Phosphate
SF_6	Sulphur hexafluoride
SO_2	Sulphur dioxide

Abbreviation	**Explanation**
AP	Acidification Potential
BPA	Bisphenol-A
CA	Company A
CB	Company B
CC	Company C
CLP	Classification, Labelling, and Packaging
COSMOS	Cosmetic Organic and Natural Standard
DCB	Dichlorobenzene
DEP	Diethyl phthalate
EDCs	Endocrine disrupting chemicals

EDTA	Ethylenediaminetetraacetic acid
EP	Eutrophication Potential
FAETP	Freshwater Aquatic Ecotoxicity Potential
GHG	Greenhouse gas
GHS	Globally Harmonized System
GWP	Global Warming Potential
IFRA	International Fragrance Association
ISO	International Organization for Standardization
KTDS	Kozmetik ve Temizlik Ürünleri Sanayiciler Derneği
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MCI	Methylchloroisothiazolinone
MI	Methylisothiazolinone
OECD	Organization for Economic Co-operation and Development
OPP	Oriented Polypropylene
PCCPs	Personal Care and Cosmetic Products
PET	Polyethylene Terephthalate
PEPB	Pro-Environmental Planned Behavior
POCP	Photochemical Ozone Creation Potential
PPCPs	Pharmaceutical and Personal Care Products
SDG	Sustainable Development Goal
SETAC	Society of Environmental Toxicology and Chemistry
SCCS	Scientific Committee on Consumer Safety
SLES	Sodium Laureth Sulphate
SLS	Sodium Lauryl Sulphate
TCS	Triclosan
TPB	Theory of Planned Behavior
UNEP	United Nations Environment Programme
YDD	Yaşam Döngüsü Değerlendirmesi
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

Personal care and cosmetic products (PCCPs) have been used for centuries that their existence has become an indispensable part of human life in modern times for sanitation and improvement of attraction. As the global trends and consumption habits change over time, demand for cosmetics and personal care products has enhanced the number of earnings in both domestic and overseas markets. Enlargement of demands on these products has led the sector to expand, especially for the last decade.

The largest market of the cosmetic industry is known as European countries. When the total capacity of cosmetic products consumption in the world reached 390 billion euros according to the sales at retail prices as of 2017 (TOBB, 2018), the share of the EU market in the total was 77.6 billion euros. It was followed by the USA and China with 67.2 and 43.4 billion euros respectively (Ozden et al., 2019). The capacity of cosmetic products consumption in Europe was 79.8 billion euros in 2019 (Ridder, 2020); however, it regressed to 76.7 billion euros in 2020. In that year, Germany (14 billion euros) and France (11.5 billion euros) had the maximum share of retail sales among the European countries (Cosmetics Europe, 2020).

Turkey was in a position that the export rate was constantly declining between the years of 2014 and 2016. Nonetheless, it started to rise in 2017 despite the fact that most of the produced products were consumed domestically. For example, the total amount of skin cleansing products manufactured was 205,646 tons in 2017, and almost 97 % of this amount (199,394 tons) consumed in Turkey (TOBB, 2018). Make-up and skincare is the product category that generally constitutes the largest share in the world's cosmetic exports, and it was corresponding to 42.2 % of the total exported cosmetic products in the world (The Turkish Ministry of Trade, 2021).

Nowadays, the quality and safety of PCCPs have become a critical issue for customers' buying preferences as well as the ecological footprint of these products. People are concurrently exposed to certain chemical ingredients by applying more than one product involving those chemicals which are of great concern due to their tendency to accumulate in the human body (Sy et al., 2020). Scientific studies show that specific chemicals like phthalates and bisphenol-A (BPA) have a damaging impact on human body. Negative impacts of these chemicals might even have been observed on maternal and newborns' health, when the interaction of such chemicals with pregnant women occurs (Fisher et al., 2019). Certain synthetic chemicals are classified as environmentally persistent, bioaccumulative, bioactive, and endocrine disruptive (Chavoshani et al., 2020). Endocrine-disrupting

chemicals (EDCs) (phthalates, parabens, triclosan and benzophenone-3 (BP3) and so on), frequently used in personal care products, have resulted in malfunctioning of the endocrine system because of long-term exposure (Bellavia et al., 2019). In addition to chemical components existing in the formula of PCCPs, components in the packaging materials are also significant determinants throughout the life cycles of these products. Life cycle assessment (LCA) helps to detect the particular impacts of every stage along the lifetime of a product.

The production methods of PCCPs began to be questioned by consumers as the entire product chain became more transparent. For instance, supply of raw materials with an unsustainable approach or laboratory tests applied on animals are the factors taken into account by modern society. Besides chemical ingredients, even organic ingredients such as natural and plant-based oils and additives used in cosmetics formulations have become uncertain whether the plants are grown without exposing pesticides and synthetic fertilizers. Consumption patterns show that people have been more cautious about choosing organic and natural products over synthetic products. Customer expectations such as credibility of a brand, safe consumption for both human health and ecological health have raised its voice upon the producers to prefer organic and green cosmetics (Ghazali et al., 2017). The increasing awareness about the hazards of synthetic chemicals (parabens, sodium lauryl sulphate (SLS), sodium laureth sulphate (SLES), diethanolamine, etc.) have led to a green consumerism consciousness' growth and directed the consumption habits towards organically produced products (Li and Suh, 2019). This kind of alteration has also created great differences in the market share of green products. In addition to that, the major contribution of Ecolabels has accelerated the demand towards environmentally friendly products. In parallel with these developments, producers in the industry, organizations, and academics from various disciplinary fields have started to pay attention to sustainable production and consumption of PCCPs all around the world.

LCA was utilized in this study to determine the environmental hotspots in the production and consumption of selected personal care and cosmetic products by defining system boundaries with a cradle-to-grave approach starting from raw material supply to waste management processes after consumption of the products and to analyze the environmental impacts depending on the comparative analysis of two different products in each product group (bar soap, liquid soap, shampoo, hair conditioner, and body cleaning products).

2. LITERATURE REVIEW

2.1. Composition of Personal Care and Cosmetic Products

A cosmetic product is usually defined as a preparation applied to human body for cleansing, softening, moistening, and improving body attractiveness by pouring, rubbing, or spraying into skin. These products can also be determined as personal care products since the reason is not only to beautify the skin for attractiveness but to improve the derma for health. The cosmetic and personal care products divided into two types in general; one is rinse-off products that need to be washed off skin or hair with water after use (soaps, shampoos, oily hair creams, shower gels, some face cleansing products, and toothpastes), while the other is leave-on products that do not require to be removed from the body (hand/face creams, body lotions, and hair sprays). Besides the differences in the way of application of these products, there might be another type of distinguished features as in their compositions such as fragrances, colorants, and preservative agents, and these features cause the products to have specific health concerns and ecological footprints.

There are certain chemical components, called sensitizers, that are categorized into general groups as fragrances, preservatives (including antimicrobials and antioxidants), surfactants, emollients, and excipients (inactive ingredients) (Smith and Wilkinson, 2016). Most of these chemicals are bioactive, potentially bioaccumulative, persistent in the environment. For these reasons, they are considered a major risk to the health of people and ecosystems. Rinse-off care products are known not to generate serious effects on the skin often but some of the fragrance agents have allergic reactions even if they are washed off the skin. On the other hand, leave-on products might cause more often allergic reactions and dermatitis because of long-term exposure and/or accumulation effect in long-term. The United States Food and Drug Administration (FDA) has collected the list of allergen chemicals that are commonly used in personal care and cosmetic products (U.S. Food and Drug Administration, 2020). According to the FDA, there are 26 fragrance ingredients, which should be written by name on the cosmetic products' label if used in higher concentrations than 0.001 % in leave-on and 0.01 % in rinse-off, have been compiled to allergens list by European Union Cosmetics Directive in Annex III (European Parliament, 2009). Among the 26 fragrance agents, the most frequently seen in the formulations are hexyl cinnamal, cinnamyl alcohol, citronellol, geraniol, linalool, limonene, and coumarin. Furthermore, HICC (hydroxyisohexyl 3-cyclohexene carboxaldehyde), also known as lyral, is one of the allergen fragrances that was prohibited from August, 2019 for cosmetic products which shall be placed on the Union market by

European Commission (SCCS, 2011). In addition to that, use of another common fragrance, butylphenyl methylpropional (CAS no. 80-54-6), has also been revised by the International Fragrance Association (IFRA) in accordance with the 49th amendment released in 2019 (IFRA, 2020). Butylphenyl methylpropional, which is well-known with its trade name; lilial, was recently reconciled classification as CMR 1B substance according to a current amendment to the Classification, Labelling, and Packaging (CLP) Regulation (Commission Delegated Regulation (EU) 2020/1182) (European Commission, 2018). After the classification under CMR 1B which indicates the toxic substances for reproduction, the consumption of lilial in cosmetic products will possibly be banned from 1st March 2022.

The second skin sensitizing chemical group is preservatives that are usually known as parabens because the major part of the preservative ingredients take part in a cosmetic product formulation composed of parabens. Besides parabens, the most frequently observed preservatives are phenoxyethanol, sodium benzoate (Yazar et al., 2011), isothiazolinones (MI; methylisothiazolinone and MCI; methylchloroisothiazolinone), formaldehyde and formaldehyde releasing agents (DMDM hydantoin, and Quaternium-15, etc.) (U.S. Food and Drug Administration, 2020). Certain parabens are regarded harmful chemicals as they have adverse effect in the way that endocrine-disruptive (Nassan et al., 2017), and reproductive toxicity on human body as well as phthalates and bisphenol-A (BPA) (Genuis et al., 2012). However, diethyl phthalate (DEP), which is the form of phthalates largely used in personal care products, has been determined that does not pose a risk to human health according to studies conducted by the FDA and EU Scientific Committee on Consumer Safety (SCCS) (KTDS, 2021). Furthermore, BPA, which was defined as an emerging pollutant and banned to be added to products formula in 2006, has still the possibility to be passed from packaging materials to products in trace amounts. Since this amount would be quite small to exposure, it is regarded as innocuous for human body (McDougall, 2015). Although it is observed that the most common forms of parabens used in personal care products are methylparaben, propylparaben, and butylparaben (Ferguson et al., 2017; Błedzka et al., 2014; Braun et al., 2014), benzoic acid, sorbic acid, propionic acid, and esters of p-hydroxybenzoic acid ingredients, which can be seen usually on labels of cosmetic and personal care products, also refer to parabens (Kumar & Gowda, 2014; Guo et al., 2013).

Addition of preservatives into personal care and cosmetic products are preferred not only to extend the shelf life of products but also gain them additional specialties such as antimicrobials, which helps to inhibit bacterial growth, and antioxidants, which supports to restrain the breakdown of unsaturated fatty acids. Formaldehydes, which are mainly categorized into preservatives having antimicrobial effect, was discovered that they can cause finger dermatitis because of preservatives as

in wet wipes. Even antioxidants sometimes might cause allergic reactions (Smith and Wilkinson, 2016). Another preservative used for blocking bacterial growth is triclosan (TCS) which has the chemical name 5-chloro-2-(2,4-dichlorophenoxy)phenol. Even though a study conducted by FDA in 1997 revealed that triclosan used in the toothpaste of a well-known brand provided benefits to users by preventing gingivitis, it has not obtained any evidence for other care products (antibacterial soaps, etc.) that triclosan is beneficial (U.S. Food and Drug Administration, 2019). On the other hand, triclosan was detected in water bodies homogeneously at concentrations reaching up to 0.00018 mg per liter resulting from the consumption of cosmetic and care products that include TCS, according to a survey carried out in Japanese rivers (Kimura et al., 2014). Furthermore, in some instances TCS can turn into chlorinated compounds, which shows poisonous characteristics, and might be even more persistent than the original form of triclosan in wastewater treatment plants (Bilal et al., 2020). On top of that, TCS had also been detected in terrestrial environments since the sludge obtained from wastewater treatment plants was applied to cultivated lands as fertilizer (Chalew and Halden, 2009). The FDA banned the consumption of 19 antimicrobial chemicals on September 9 in 2016, including TCS due to inadequate data on their use safely (Cuffari, 2019).

Surfactants are active agents included mostly in skin and hair products providing several functions such as foaming, emulsifying, conditioning, thickening, and solubilizing (Brannon, 2020). In respect to the chemical function of surfactants, they stabilize mixtures by lowering the surface tension between two different phases as in oil and water molecules. In other words, they prevent layer forming as a result of oil and water insoluble in each other. Surfactants, frequently added in personal care and cosmetic products' formulation, are sodium lauryl sulphate (SLS), cocamidopropyl betaine, cocamide diethanolamine (DEA), cetyl-, oleyl-, and myristyl alcohols (Smith and Wilkinson, 2016). These types of synthetic surfactants can cause health damages such as irritation in both eye and respiratory organs as well as the environmental damages in variable natures (water, soil, etc.) due to their non-biodegradable structures. Pradhan and his colleague (2017) demonstrate the efficiency of saponins, a class of chemical compounds are found in the body of certain plants, as cleaning and foaming chemicals which are also biologically degradable, renewable and commercially easy to obtain (Pradhan and Bhattacharyya, 2017). Surfactants comprises three groups namely; synthetic, microbial, and bio-based. Although the most environmentally friendly type is microbial surfactants, they are not the most preferable ones since synthetic surfactants are much more economical. Yet, regarding with the eco-friendly options, there are promising findings that will pave the way for altering synthetic surfactants either with microbial surfactants which are biologically compatible and greener or with natural agents such as soapnut (Moldes et al., 2021; Panda et al., 2020).

2.2. Ecolabels and ISO Standards

2.2.1. Impact of Environmentally Friendly Products on Consumers' Perception

Plenty of research reveal the positive effect of applications regardless of voluntary or mandatory on the preferences of environmentally friendly products and green initiatives in accordance with both production and consumption, and further to that, pro-environmental activities and pro-environmental reasoned actions (Lin et al., 2015; Nadlifatin et al., 2016). On the other part, Lin and his colleagues surveyed the effects of the Pro-Environmental Planned Behavior (PEPB) model. PEPB, which refers to the action of people who consciously make choices to minimize their negative impact on the environment, is considered as an extended form of a well-known model named Theory of Planned Behaviour (TPB), which is a psychological theory that correlates attitude with beliefs. According to the results, the behavior intention of citizens, which is required for complete success to support green initiatives, is affected by the considerations of companies or policy makers in order to improve their formulations to reduce environmental impacts of products or services (Lin et al., 2017). In another research investigates the behavior intention of users to prefer labelled green products with the PEPB model in two different regions, results demonstrated that behavior intention of research groups has showed a tendency to use ecolabelled products in Taiwan and Indonesia cases, with almost 50 % and more than 70 %, respectively (Mufidah et al., 2018). In conclusion, consumers' perception and intention have been influenced by environmental soundness of manufacturers based on producing more environment friendly products and certifying the products in accordance with ecolabel standards as it is seen in the PEPB model results.

In addition to the utilitarian impacts of ecolabels on the market, the sphere of environmentalist business initiatives' influence has been expanding since the beginning of 21st century with the growing "corporate environmentalism" effect (Kirchhoff, 2000). As Kirchhoff's considerations (2000) emphasized the applications to reduce the environmental burdens, such as emissions and pollution, resulted in saving money in the last instance even though they are considered to be reducing profits of the companies in the short term. Although ecolabels, which enable people to choose environmental friendly products to decrease environmental impacts, were also planned to nudge corporates to be influenced by consumers who promote the green products, the average proportion of ecolabelled products in the market was relatively low in some industries (Rex and Baumann, 2007). However, as ecolabels have become credible schemes for the environment, efficiency of such environmental labels has been expected to ascend day after day (Iraldo et al., 2020).

There are several studies searching the impacts of natural and/or organic claimed personal care products on consumers' intentions to purchase. Current studies all emphasize the growing popularity of eco-friendly consumption, in other words green consumerism which emerged from environmental concerns about natural resource destruction, unsustainable raw material supply and production methods, irresponsible consumption and waste management challenges. These concerns can be assessed as the key factors to bring attention to environment friendly cosmetics and personal care products in the market. One of the studies which is attempting to understand consumers' intention on buying organically produced care products indicated that among the consumer behavior values, based on three pillars namely consciousness of health, environment, and appearance, environmental consciousness affects more than health consciousness of consumers' attitude on purchasing organic hair and skin care products in a positive side (Kim and Chung, 2011).

Besides environmental concerns, other perceived value constructs of consumers such as the trustworthiness of the brand, health concerns, safe consumption, and social value have a guiding influence on purchasing attitudes towards organic and green cosmetics, which may also turn into a repurchase intention afterward, as in the Theory of Planned Behavior (Ghazali et al., 2017). According to the results obtained by Ghazali and his colleagues; health promoting effects, safe product perception, and responsible way of manufacturing process were the options that reached the highest outer loading which reflects the reliability of organic personal care products in terms of health, safety, and environmental value, respectively. Although green marketing, green brand image, and greenwashing can be misused as deceptive statements to mislead consumers' buying intentions (Kahraman and Kazancoglu, 2019), the green brand equity of companies, that are strictly attentive for ecological footprints of their products, truly obey the environmental commitments, and fulfill their claims of being eco-friendly, have provided an attractive image to convince consumers about the curative effect of green business to economy and ecology (Bekk et al., 2016). Companies can built up a credible reputation to become distinguished brands among the competitors on the market and to be chosen by consumers by emphasizing their green, organic, or natural claims and efforts verified from independent organizations (ecolabels, recognized certification schemes, etc.) as long as they avoid boosting insincere claims with respect to green products and applications.

2.2.2. Ecolabels and the Requirements

Environmental labels have become popular and trustable for most organizations which have been ameliorating their procurement and production methods with a more sustainable economy approach. The United Nations has stringently promoted to reduce carbon footprint by supporting sustainability

and energy efficient policies, in addition to previous initiatives on promoting Sustainable Development Goals (SDGs) which call for taking urgent actions to alter current economic models to a more economic and social model depending upon sustainable consumption and production, especially in second half of the last decade. Environmental labels have started to be used as beneficial tools for the last four decades to close the gap between the current situation and the intentions for the future. Nevertheless, popularity of labels has been increasing specifically in recent years in relation to growing concern about climate change resulting from destruction of nature. An ecolabel, differently from environmental labels, emphasizes the preferability of environmentally friendly products based on life cycle evaluations (Global Ecolabelling Network, 2004).

As a beginning, ten different ecolabel standards (European Commission, COSMOS, Green Seal, Blue Angel, Korean Ecolabel, Nordic Swan, Good Environmental Choice (Bra Miljöval), ECOCERT, Environmental Choice of New Zealand, Green Choice Philippines) were analyzed with their requirements that should be accomplished to have an ecolabel award. When the existing national legislation is examined, it is seen that the Regulation on Environmental Label entered into force on 19th October 2018 in Turkey in compliance with the acquis communautaire, and the national Environmental Label criteria for personal care and cosmetic products sector was recently announced by the Turkish Ministry of Environment, Urbanization and Climate Change on 9th September 2021. The aim of the Regulation is to encourage businesses to use environmental labelling to support sustainable consumption and production practices by encouraging them to consider issues such as low carbon emissions, waste prevention, energy efficiency, water conservation, and reducing certain chemicals that have adverse effects on products/services that they provide to society. Apart from the national legislation, there are also several internationally-recognized ecolabel standards with the PCCPs selected within the scope of the respective study. EU Ecolabel, Blue Angel, Nordic Swan, and ECOCERT are some of the important ones because they have the most parameters that are in parallel with the developed national label criteria in terms of comprehensiveness and adaptedness. All the standards focused on are particular to "Type – I Environmental Label"

2.2.1.1. EU Ecolabel, European Countries. The EU Ecolabel was established in 1992 to meet higher environmental standards in entire life cycles of products/services. A product that carries the flower logo has built up a reputation in the market as it refers to high performance and quality with lower environmental impacts (European Commission, 2020). This is one of the most recognized environmental labels around Europe. It encourages manufacturers to decrease the amount of waste and carbon dioxide emissions generated throughout the production process. Furthermore, the EU ecolabel criteria urge businesses to design items to be more long-lasting, repairable and recyclable.

The commission decision on establishing the ecological criteria for rinse-off cosmetic products (notified under document C(2014) 9302) involves seven criteria (toxicity to aquatic organisms, biodegradability, excluded/limited substances and mixtures, packaging, sustainable sourcing of palm oil/palm kernel oil, and derivatives, fitness for use, and information appearing on the EU Ecolabel) (European Union, 2014) of which four criteria related to excluded/limited substances (production stage), wastewater and packaging waste management processes (end-of-life stage) in a life cycle, are considered as can be seen in Table 2.1 (European Commission, 2016).

Table 2.1. EU Ecolabel criteria set for rinse-off products (European Commission, 2016).

<table>
<tr><th>Criterion Name</th><th>Requirements</th></tr>
<tr><td>Excluded or limited substances and mixtures</td><td><u>Excluded ingoing substances are listed below:</u>
Alkylphenol ethoxylates (APEOs) and other alkyl phenol derivatives; nitrile-tri-acetate (NTA); nitromusks and polycyclic musks; octamethylcyclotetrasiloxane (D4); butylated hydroxytoluene (BHT); ethylenediaminetetraacetate (EDTA) and its salts; certain preservatives (triclosan, parabens, formaldehyde and formaldehyde releasers); certain fragrances (HICC, atranol, chloroatranol); microplastics; and nanosilver.</td></tr>
<tr><td>Toxicity to aquatic organisms</td><td>The criterion is mostly controlled with critical dilution volume (CDV) which is calculated by multiplying the weight of ingoing substance, degradation factor of ingoing substance, 1/toxicity factor, and 1000 for unit conversion.

The value of CDV is limited for certain rinse-off products as such;
- 18,000 l/g active content (AC) for shampoo, shower products, and liquid soaps;
- 3,300 l/g AC for solid soaps;
- 25,000 l/g AC for hair conditioners;</td></tr>
<tr><td>Biodegradability</td><td>Surfactants should be either readily biodegradable in aerobic conditions or biodegradable in anaerobic conditions. In addition to surfactants, all organic substances should obey limit values determined for aerobically non-biodegradable (aNBO) and anaerobically non-biodegradable (anNBO) given below.
<table>
<tr><th>Product</th><th>aNBO (mg/g AC)</th><th>anNBO (mg/g AC)</th></tr>
<tr><td>Shampoo, shower products, and liquid soap</td><td>25</td><td>25</td></tr>
<tr><td>Solid soaps/shaving solid soaps</td><td>10</td><td>10</td></tr>
<tr><td>Hair conditioner</td><td>45</td><td>45</td></tr>
</table></td></tr>
<tr><td>Packaging</td><td><u>Limitations for packaging waste:</u>
No extra packaging except primary packaging.
Packaging Impact Ratio < 0.28 g of packaging/g of product.
Design of the primary packaging must ensure that minimum 90 % of the product can be obtained by users.
<u>Limitations for packaging elements:</u> Certain materials and components in the use of label/sleeve, closure, and barrier coatings must be excluded to be compatible with the EU Ecolabel.</td></tr>
</table>

2.2.1.2. Blue Angel, Germany. This is the first label which was introduced in 1978, Germany by the Federal Ministry of the Interior and since then, it has been considered a pioneer in the developing process of environmental labels. Blue Angel applies stringent standards for green products design over the past 40 years as a guide for sustainable production and consumption.

This ecolabel was awarded to products which are eco-friendlier than others serving for the same function. It also contributes to lower environmental impacts of products on water bodies, to limit packaging waste, and to requirements for renewable options for procurement stage (Table 2.2) (Blue Angel, 2021).

Table 2.2. German ecolabel criteria set for rinse-off cosmetic products (Blue Angel, 2021).

Criterion Name	Requirements
Excluded or limited substances and mixtures	Excluded substances having specific qualities; - Substances of very high concern (SVHC) identified in accordance with the Regulation (EC) 1907/2006. - Substances that are assigned to the H phrase as a "hazard" statement according to the Regulation (EC) 1272/2008. Prohibited substances; Alkylphenol ethoxylates (APEOs) and alkyl phenol derivatives; phosphates and aerobically not readily biodegradable phosphonates; nitromusks and polycyclic musks; EDTA and its salts; diethylenetriaminepentaacetic (DTPA) acid and its salts; 5-bromo-5-nitro-1,3-dioxane; formaldehyde and formaldehyde releasers; HICC, atranol, chloroatranol; microplastics; and nanosilver.
Toxicity to aquatic organisms	Critical dilution volume (CDV) is calculated like explained in Table 2.1. and also, limit CDV values for certain rinse-off products are the same with the EU Ecolabel criteria. - Additionally chronic CDV value is summed of the CDV for each substance in the end product, standardised for AC of the end product.
Biodegradability	Organic substances should obey limit values (same with the EU Ecolabel criteria) determined for aerobically not readily biodegradable (aNBO) and anaerobically non-biodegradable (anNBO). Abrasives should be neglected.
Packaging	Requirements for packaging; - No halogenated polymers and aluminium. - Adhesive labels should be removable for recycling. - Paper and cardboard used in primary and secondary packaging operations must be produced by (at least, 80 %) recycled materials. - Packaging Impact Ratio < 0.28 g of packaging/g of product. - Design of the primary packaging must give correct dosage ensuring that minimum 90 % of the product can be emptied from the bottle.

2.2.1.3. Nordic Ecolabel (Swan), Nordic Countries. The Nordic Ecolabel, dominated mostly in northern countries, has a symbol of "Swan" which indicates a product is of an environmentally good

choice in regards to overcoming certain requirements of that certification or scoring system (Ecolabel Index, 1989).

Nordic Swan Ecolabel can be applied in nearly 60 different product groups, additionally in hundreds product types including textile products for babies, office supplies, cleaning agents used in food industry, toys, grocery stores, furniture, solid fuels, firelight products and so on (Nordic Ecolabel, 2021). Similar to the EU Ecolabel and Blue Angel, four criteria of Nordic Ecolabel were examined primarily, too (Table 2.3).

Table 2.3. Nordic ecolabel criteria set for cosmetic products (Nordic Ecolabel, 2021).

Criterion Name	Requirements
Excluded or limited substances and mixtures	Prohibited substances in the products as raw material; Octamethylcyclotetrasiloxane (D4); decamethylcyclopentasiloxane (D5); dodecamethylcyclohexasiloxane (D6); butylated hydroxytoluene (BHT); butylated hydroxyanisole (BHA); borates and perborates; perfluorinated and polyfluorinated substances; nitromusks and polycyclic musks; EDTA and its salts (except for solid soaps); triclosan, parabens, phthalates; hypochlorite, chloramine and sodium chloride; benzalkonium chloride; microplastics; halogenated and aromatic solvents; nanomaterials. Substances considered to be endocrine disruptors according to EU' report, substances regarded as persistent, bioaccumulative and toxic (PBT) according to the REACH regulation, and the substances on the list of SVHC.
Toxicity to aquatic organisms	CDV must be under the threshold values indicated as 2,000 l/g AC for solid soap, and 12,000 l/g AC for other rinse-off products.
Biodegradability	Organic substances must not exceed the thresholds indicated for liquid soap, shampoo, hair conditioner, and shower gel as 15 mg/g AC for both aNBO an anNBO while they are indicated as 5 mg/g AC for solid soap.
Packaging	Requirements for packaging; - No extra layer of packaging is allowed unless more than one product is on sale or the extra packaging material is recycled (80 %, at least). - All parts of the packaging must be able to be sorted separately, and parts made up of mixed materials that cannot be separated are forbidden (except pumps). - Metal packaging may only be applied in spray bottles (small metal parts used in pumps or sealing parts are not forbidden). - Pumps of liquid soap bottles must not provide more than 2 g of soap at one press. - Bottles that have a pump/dispenser must have an emptying level of 90 %.

2.2.1.4. Ecocert, France. Ecocert is a non-profit organization that certifies sustainable development. and founded by agronomists who support environmentally friendly agriculture and production in France. The Ecocert certification criteria has focused on organic agricultural products. Furthermore, this ecolabel has paved the way for organic farming (Ecolabel Index, 1991).

Ecocert Ecolabel, which certifies over 150 different programs that have been chosen for their environmental and social requirements, is regarded as the world's leading organization in the certification of sustainable products and practices in more than 130 countries as well as in France. The extent of the certification also covers textile industry, cosmetic sector, and home care products apart from agro-food and forestry (Ecocert, 2021). One of the most applied certifications in the cosmetic industry is Cosmetic Organic and Natural Standard (COSMOS) that ensures the friendly production to both ecological and human health, establishment of the green chemicals concept, and recyclable packaging of products. Main criteria focused on within the study were listed in Table 2.4.

Table 2.4. France ecolabel criteria set for natural and organic cosmetics (Ecocert, 2021).

Criterion Name	Requirements
Excluded or limited substances and mixtures	Eliminated substances in the products and final environment; Nanoparticular ingredients, nutrients such as trace elements, salts, and vitamins. Restricted substances; Formol, EDTA, chlorine and chlorinated products, products based on genetically modified microorganisms; based on ammoniac and phosphates and/or phosphonates.
The biodegradability and ecotoxicity of ingredients	Processes that allow for the formation of biodegradable, non-toxic molecules are prioritized. - Substances defined bioaccumulative and non-biodegradable are forbidden. - Minimum aquatic toxicity requirement (LC50) > 1 mg/l. - Aquatic toxicity > 10 mg/l while the biodegradability > 70 % (in 28 days of testing) or 1 mg/l < aquatic toxicity < 10 mg/l while the biodegradability > 70 % (in 14 days of testing).
Packaging	Requirements for packaging; - No extra layer of packaging is allowed unless more than one product is on sale or the extra packaging material is recycled (80 %, at least). - All parts of the packaging must be able to be sorted separately, and parts made up of mixed materials that cannot be separated are forbidden (except pumps). - Metal packaging may only be applied in spray bottles (small metal parts used in pumps or sealing parts are not forbidden). - Liquid soap bottle's pumps must provide max 2 g soap, at one press. - Bottles that have a pump/dispenser must have an emptying level of 90 %.

2.2.3. ISO Standards

The International Standard Organization released the standard ISO 14020 which contributes to definitions and principles for the foundation of voluntary ecolabels. ISO 14020 refers to three main types of ecolabels named Type I (ISO 14024), Type II (ISO 14021), and Type III (ISO 14025) that each one has specified principles and procedures which should be applied in conjunction with ISO 14020.

Type I environmental programs take place under ISO 14024 (ISO 14024, 2018). These types of labels are based on multi-criteria that are issued by third parties and are aimed to meet specified product environmental criteria on the basis of life cycle aspects (Minkov et al., 2020). Type I is the most commonly used label typology from the perspective of applicants. It states rigorous environmental quality requirements for a product have been fulfilled among the items awarded with the highest environmental standard in the market. There is a subprogram assessed under Type I typology, called Type I-like (or *single issue*), that has a system to be verified and certified but solely focuses on a single issue (e.g. water efficiency) rather than the entire life cycle (UNOPS, 2009). The most known ecolabels of the Type I environmental program can be exemplified with EU Ecolabel, Blue Angel, and Nordic Swan.

Type II environmental labels (self-declared environmental claims) take place under ISO 14021 (ISO 14021, 2016). Type II claims are dependent on self-declarations by practitioners. Self-declarations can be presented without the necessity for third party certification. However, they must be precise, explicit, verifiable, and specific for particular environmental aspects which must be taken into account as significant components of the products' life cycle (Rusko and Koraus, 2013). The most notable difference between Type I and Type II labels is that the latter is not awarded by a third party; on the contrary, Type II labels are created by companies internally (Allison and Carter, 2000).

Type III environmental declarations, which is also known as Environmental Product Declaration (EPD), take place under ISO 14025 (ISO 14025, 2006). Similarly to Type I environmental labels, EPD also depends upon product information in relation to life cycle considerations. Type III declarations are primarily designed to be used in companies' engagement on the responsibility to follow the report stage which is independently validated (UNOPS, 2009). Type III environmental declarations provide an advantage to be capable of comparison between various products or conditions by utilizing environmental impacts. However, it does not evaluate or measure the environmental performance of products, yet demonstrates the data objectively. PlasticsEurope and Carbon Leadership Forum can be given as examples to the most recognized international declarations.

In addition to ecolabel standards, ISO also released the standard ISO 14040 namely Life Cycle Assessment – Principles and Framework for carrying out life cycle evaluations which are performed with the practitioners handling the real practicalities of data collection, calculation, standardization, interpretation, and so on (Pryshlakivsky and Searcy, 2013). ISO 14040 covers four other standards that can be listed as ISO 14041 which analyses the inputs as resources used either qualitative or quantitative or both together and outputs as emissions released (ISO 14041, 1998); ISO 14042 which

analyses classification, characterization, and valuation processes (ISO 14042, 2000); ISO 14043 which analyses the conclusions as interpreted ideas, deductions in regards to evaluation and suggestions (ISO 14043, 2000); and ISO 14044 which comprises of the requirements for life cycle assessment (ISO 14044, 2006).

2.3. Life Cycle Assessment (LCA)

Since the beginning of the industrial revolution, production and consumption of consumer goods have been accelerating with social demand in the modern world. Even if the resources used are renewable, they are not infinite. For these reasons, sustainability principles must be applied in all fields today. The notion of sustainability balances the need for human progress with its consequences in the framework of protection and conservation of nature and the ecosystem services with its offerings. The life cycle initiative, launched by the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC), has drawn major attention in the first decade of the 2000s (Guinée et al., 2011). The book named "Code of Practice" has been adopted as a guideline for Life Cycle Assessment (LCA) practices to improve the collaboration and coordination between users and scientists. SETAC has gathered all LCA practitioners in the market under a single roof by coordinating and leading them to set standards for LCA applications (Klöpffer, 2012). Thus, life cycle evaluation practices have gained a significant role after the standardization process for the method was announced by international institutions.

LCA is a commonly applied method to evaluate environmental impacts of a product/a service by considering all the stages in the lifetime (Muralikrishna and Manickam, 2017). The LCA methodology, which determines possible opportunities in comparative life cycle evaluations, informs stakeholders about product design, redesign, or production process, and leads the marketing steps, is defined with a framework that consists of four main phases, goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO 14040, 2006). First of all, goal definition is required for the determination of functional units, product systems, and system boundaries. After inventory analysis that evaluates all collected data are completed, life cycle impact assessment (LCIA), which enables to understand the physical flows and interventions of the system by correlating with relevant environmental impacts, is carried out to make LCI results more manageable in terms of resource, environmental, and health concerns. Lastly, the interpretation phase comprehensively commentates on the results of inventory and impact assessment analysis in an organized structure to ease the obtained outcomes for decision-makers (Frankl and Rubik, 2000).

LCA is a data-based methodology and requires comprehensive datasets in terms of environmentally related material and energy flows. As gathering the required dataset for a specific process is the most complex part of the inventory analysis, there have been many databases developed to collect datasets easily. Ecoinvent database is widely used for information collection that offers inventory and impact assessment results. Impact assessment methods have been specified to solve different implementation problems comparatively with a variety of software programs. For example, CML 2001, released by the Institute of Environmental Sciences in Leiden University, is an operational guide for assessment methods for LCA practitioners (Frischknecht and Rebitzer, 2005). GaBi is one of the leading software applications to operate LCA studies developed by the University of Stuttgart in collaboration with PE International which has been rebranded as Thinkstep, Sphera Solutions GmbH in Germany. The GaBi database, like ecoinvent, draws attention with integrated, accessible, and dedicated resources to be applied in LCA studies (Martínez-Rocamora et al., 2016).

2.4. Ecolabel and LCA

The ecolabelling scheme that cannot be fully completed and successfully implicated without the contribution of life cycle evaluations and its impact assessment approach. The utmost significant improvement of the LCA approach to ecolabel schemes is the establishment of a tool to support the decision-making process. The question mark on the association between LCA and ecolabels had been enlightened, and the consensus of how LCA methodology can be adapted to ecolabels occurred; as a result of that, environmental labels were contemplated to be one of the most suitable approaches to represent and discuss the principles of LCA. Neitzel (1997) put emphasis on the major contribution of LCA in the improvement process of environmental labels in terms of defining the targets and product types to be competed, foregrounding the most crucial life cycle stages throughout the product chain, prioritizing particular impacts that ends up with specific criteria definition, and interpreting the results by addressing weighting procedure and certain impacts to establish a scoring system (Neitzel, 1997).

Having a broader context of product-based policy, the influence of ecolabels that imply the environmentally friendly products presented with an ecolabel logo as a market-based instrument, which are manufactured according to scientific and technical procedures conducted by trustworthy, competent and independent institutions, promotes environmentally conscious behavior patterns and provides guidance to consumers by improving economic efficiency while reducing the time and energy (Loprieno, 1998). Mungkung and her colleagues concluded that the LCA framework, which contains leading phases (scope definition, emphasizing impact categories) to structure an ecolabel,

was the best approach so as to apply for analyzing the efficiency of either alternative or ecolabelled product with reduced impact upon the nature over conventional products with regards to environmental concerns. It was also determined that LCA provides a foundation for assessing a number of criteria connected to qualitative impacts such as the use of abiotic resources even if it is not a well-supported method to quantify all the environmental impacts such as the use of biotic natural resources (Mungkung et al., 2006).

To decrease environmental impacts of products, LCA has been used as a tool in many industries in terms of defining hotspots, classifying potential risks, adopting a road map and ensuring an ecolabel certificate as it is a scientific based method to associate with environmental declaration and labelling (Eryuruk, 2015). On the one hand, LCA has been a considerably adopted method that ensures better environmental performance by analyzing the effects both qualitatively and quantitatively throughout the life cycle of a product. On the other hand, ecolabelling has become a widely acclaimed approach by green consumerists and environmentalists as it promotes the products manufactured with meeting the conditions of specific environmental criteria in the market (Pereira and Soares, 2016). Although the utilization of LCA as a supportive tool for the determination process of ecolabel criteria in the personal care and cosmetic product sector has not become widespread yet in consideration of proprietorship of the product formula, it has been promising that necessity of an assessment method to observe the chemical nature of these products with life cycle analyses rather than a risk assessment methodology (Bernardo, 2012). The LCA approach supports ecolabels to guarantee the transparency of the evaluation process of a product, and builds a basis for sustainable consumer behavior through raising awareness (Prieto-Sandoval et al., 2016).

Ecolabelling programs conduct a thorough and complete assessment of environmental impacts according to ISO 14024, which is often accomplished using the LCA approach. This practice has grown increasingly popular, insomuch that almost all Type I ecolabelling schemes give priority to the environmental impacts of the product over its full life cycle. Thus, the LCA that analyzes the impacts to issue an ecolabel has become one of the cornerstones of the labelling programs (Iraldo et al., 2020). As the ecolabel was defined that commits to influencing demand by acquainting consumers with ecological effects of a product connected with all elements in the product's life cycle (Global Ecolabelling Network, 2021), the substantial contribution of life cycle methodology to the ecolabelling scheme is unignorable from the perspective of governmental entities.

2.5. LCA Applications in Personal Care and Cosmetic Products

Environmental evaluations are in great demand as the life cycle environmental implications of consumer products are extensively studied for sustainable decision-making mechanisms in product design and in the consumption phase. Even though there is a growing demand for such evaluations and accessibility of trustworthy tools for policymakers, there is still a lack of LCA studies published which comprehensively analyzed the impacts of personal care products on nature and the human body starting from raw material acquisition to post-consumer stages. The LCA studies, which point out the raw material selection, ecological design of packaging materials, distribution alternatives, and the wastewater treatment applications in the literature, were examined within the scope of this study.

In terms of the raw material supply chain, it is widely acknowledged that the cosmetics industry is being compelled to investigate alternative feedstock to be used in formulations in regards to both green consumerisms and limiting the availability of petrochemicals. Notwithstanding, there are lots of efficient green technologies that can be chosen to diminish water and energy consumption in addition to waste and emissions during the raw material acquisition. For instance, the preference of the cold emulsification method, which can be used to make cosmetic moisturizing emulsions with lower energy consumption and CO_2 generation because it operates without high temperatures, can be given as an example to green technologies (Bom et al., 2019). In comparison with hot processing emulsions, the cold process also eases control of the emulsion structure aside from it eases to operate due to the absence of heating and cooling down phases. As another comparative example study carried out by Martinez and his colleagues (2017), the impact of palm kernel oil extraction in the base and alternative scenarios showed that manufacture of vegetable oils was the major consideration in cosmetic cream production, followed by refined palm kernel oil (RPKO) and wheat derivatives. The RPKO generation in the base scenario, which was a non-negligible agricultural input in terms of feedstock mass, had only minor effects (Martinez et al., 2017). The third example study that signifies raw material supply is of utmost significance for a products' environmental performance is the comparison of the benchmark formulation with two innovative options. The conventional formulation includes dimethicone and caprylic/capric triglyceride, while the two alternative formulations of which the former offers to use palmitic/stearic triglycerides and C17-21 alkane group as new single ingredients, and the latter offers two new preformulated ingredients that are comprised of C15-17 alkane, palmitic/stearic triglycerides, titanium dioxide, zinc oxide for the first; C21-28 alkane, hydrated silica, and glass bubble for the second. Palmitic/stearic triglycerides can be formed as a by-product in the olive oil business and can be directly included in the context of a pre-formulized compound. According to the results, the latter option that implies the benefits of ecological

innovations was found to be more advantageous from an environmental point of view (Secchi et al., 2016).

LCA studies examine the packaging of PCCPs, which are relatively more common than those focused on chemical ingredients, and generally put emphasis on the production process of packaging materials (Pauer et al., 2020). Apart from the package production, the environmental impact variations depending on the packaging type was also analyzed in a study that the achievement of altering cosmetic tubes with eco-designed bottles, manufactured by using recycled materials and mineral fillers to reduce the use of virgin petrochemicals, is stressed (Civancik-uslu et al., 2019). They compared the environmentally produced two other tubes with the current tube in terms of raw material extraction, transport, and processing. According to the result of the study, if mineral fillers and recycled content were used in cosmetic tubes, six out of nine considered environmental impacts decreased around 12 % due to the replacement of petrochemical-based raw materials by minerals. In other words, cosmetic tubes with lower environmental emissions can be made by substituting mineral fillers for petrochemicals while maintaining technological feasibility and lowering costs. In a recent study conducted in Italy, Croci and his colleagues analyzed the changes of environmental footprint in global warming, photochemical smog creation, and acidification impact categories with LCA methodology by shifting transport operations from diesel-powered vehicles (current situation) to electric vehicles. The findings demonstrate that, as compared to the current delivery system, electric vehicles accomplished a reduction in the environmental effect of 40 %, 50 %, and around 20 % for global warming, photochemical smog formation, and acidification, respectively (Croci et al., 2021).

Since personal care products, which are usually associated with pharmaceuticals, include emerging pollutants in their formulations, removal of these pollutants entered with post-consumer to sewage systems is a major problem in WWTPs where considerable amounts of chemicals and energy are consumed (Lorenzo-Toja et al., 2016). Given the fact that there are many analyses and tests to show the detrimental impacts of pharmaceutical and personal care products (PPCPs) on the environment, determining the characterization factors is one of the frequently adopted method to foresee the effects of such diverse chemicals on aquatic habitats like ecotoxicity, in the light of such extensive measurement and treatment methods in life cycle evaluations (Ortiz de García et al., 2017). An LCA study compared the life cycle impacts of advanced treatment techniques such as nanofiltration, granular active carbon, and ozonation shows that even if the removal efficiency varies depending on the treatment techniques, the average removal efficiency is usually succeeded in 65 % at least (Zepon Tarpani and Azapagic, 2018).

3. MATERIALS AND METHODS

This study was conducted by using life cycle assessment (LCA) methodology, which is based on the related ISO standards to evaluate the contribution of production and consumption phases of selected personal care and cosmetic products (bar soap, liquid soap, and shower preparations as shampoo, hair conditioner, shower gel and bath soap) in accordance to analyzed environmental impact categories. Two different products providing the same service chosen from the market for each product category were evaluated comparatively. With this (having real industrial data for all of the products) in mind, for each product category, one type of product was determined as the reference based on the number of operations to be improved while the other type of product was adopted as an alternative which includes relatively upgraded circumstances such as using less chemical ingredient or less packaging material. It is expected that the change in obtained results will reveal the importance of the variable inputs utilized in concordance with more environmentally friendly options.

Every product's life cycle evaluation was framed with a common scheme consisting of eight main processes (raw material supply, production unit, packaging materials supply, primary packaging, secondary & tertiary packaging, pretreatment of wastewater generated in the production unit, waste transportation of solid wastes generated from the factory, and distribution of manufactured products) before delivering products to the consumer. In the post-consumer phase, waste management of packaging materials, which was assumed as landfilling and recycling for plastic waste or landfilling and incineration for cardboard waste, was taken into account in addition to wastewater management operations. The manufacture of the consumer product in sufficient amounts to fulfill the needs of an individual's entire lifetime, which is estimated approximately 73 years according to the United Nations (Roser et al., 2019), was assigned as the functional unit of the selected personal care and cosmetic product in this study. The required sectoral data were obtained in cooperation with the leading manufacturers in the sector that have significant export rates in Turkey and were supported by utilizing the industrial data with related literature and GaBi software as well as the database of ecoinvent.

3.1. Methodology Selection and Analyzed Impact Categories

The LCIA methodology can be established on the basis of either problem-oriented or damage-oriented approaches to evaluate the result of life cycle assessment in terms of human health, resource depletion, and ecosystem quality which are attributed to damage categories. Midpoint level impact

categories vary from acidification, eutrophication, climate change, ozone layer, land use, etc. to respiratory inorganics and human ecotoxicity, while the endpoint level impact categories are framed with more general contexts, such as damage to human health, damage to ecosystem diversity, and resource scarcity (ILCD Handbook, 2010). Midpoint impact assessment was carried out in this study because of the fact that endpoint impact evaluations have a larger level of uncertainty than midpoint impact evaluations (Temizel, 2016), and have more complexity to evaluate impact assessment results comparatively.

Selected midpoint impact categories were determined following the urgent actions to cope with the global crisis (climate change), in addition to the objectives of ecolabel standards to ameliorate the products/services provided to the public. Global warming and photochemical ozone creation impacts of analyzed product systems were examined within the scope of the former. The criteria, which are considered challenging for the control mechanism of the ecolabel scheme, are related to the chemical and biological properties of raw materials; therefore, acidification and eutrophication impacts of considered chemical materials were examined in the scope of the latter.

Besides raw materials' chemical and biological properties, their damaging potential, which is expressed with hazard codes defined in Globally Harmonized System (GHS) for living organisms, was required to be assessed since they are most likely categorized into limited and excluded substances such as fragrances, preservatives, and color substances causing bioaccumulation on aquatic organisms. For these reasons, experimental tests that must be maintained by well-known organizations are critical to fulfill the requirements of an ecolabel certificate in order to claim environmentally friendly products with minimized chemical and water footprints.

Within the determination period of the ecotoxicity impact category, reports published by the European Commission and literature data have been utilized. To give an example, according to the CDV (Critical Dilution Volume) method definition stated in the Technical Report (No. 127) published by the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC), the model only considers direct emissions to freshwater and the damage on freshwater ecosystems (ECETOC, 2016). Therefore, freshwater toxicity was taken into account among the other ecotoxicity impact categories. Analyzed midpoint impact categories as can be seen in Table 3.1.

Table 3.1. Selected impact categories and the analyzed LCI data in the study.

Impact categories	Unit	Analyzed LCI Data
Global Warming Potential (GWP)	kg CO_2-Eq.	CO_2, CH_4, N_2O, SF_6
Photochemical Ozone Creation Potential (POCP)	kg Ethene-Eq.	CO, CH_4, NO_x, NMVOC (unspecified)
Acidification Potential (AP)	kg SO_2-Eq.	NH_3, NO_x, SO_2, H_2SO_4
Eutrophication Potential (EP)	kg Phosphate-Eq.	NH_3, NO_x, N_2O, P, PO_4^{3-}
Freshwater Aquatic Ecotoxicity Potential (FAETP)	kg DCB-Eq.	Be, Co, Cu, Ni

Environmental impacts of emerging pollutants or micropollutants that are known to exist in the formula of personal care products in addition to pharmaceuticals, which were referred to in the last part of the literature, were commonly examined by using the USETox model. Having said that, the endocrine-disrupting chemicals (bisphenol-A from the alkylphenols and triclosan from disinfectants) mentioned in the articles of Lorenzo-Toja and his colleagues with Ortiz de García and her colleagues or fragrances (celestolide, galaxolide, and tonalide) evaluated by Alfonsin and his colleagues (Alfonsín et al., 2014) due to their toxic potentials does not exist in the analyzed personal care and cosmetic products (PCCPs) in this study. The chemicals, which exist in the formula of analyzed PCCPs and were common with those examined within the ecolabelling scheme in which they are subjected to experimental tests to prove not exceeding limit values, are mainly composed of some fragrances and preservatives which can be specified as follows; fragrances as citronellol, hexyl cinnamal, coumarin, geraniol, limonene, linalool, butylphenyl methylpropional (lilial), and preservatives as methylchloroisothiazolinone (MCI) and methylisothiazolinone (MI).

It should be reworded that lilial was recently classified into the category known as toxic substances for reproduction according to the amendment of CLP Regulation, thus the consumption of lilial in personal care products is expected to be banned from 1st March 2022. In the direction of this regulation update, the EU Ecolabel Standard is also expected to evaluate lilial under the excluded substances. Leaving lilial aside, there is no available data about the bioaccumulation potential of fragrances; however, all fragrances have already been subjected to laboratory tests to prevent toxic effects on aquatic organisms and allergic reactions on human skin in the long term. For instance, the EU Ecolabel standard has made it obligatory to control a fragrance by following the code of practice of the IFRA before adding an ingoing substance to the product. Besides, it is required to have a signed declaration together with a datasheet of each preservative added to the product. Additionally, the EU Ecolabel standard has directed manufacturers to OECD guidelines (numbered 106) for the biodegradability testing methods of substances. The preservatives mentioned above are known as

readily biodegradable and not bioaccumulative (Bioconcentration factor (BCF) < 100 and/or octanol-water partition coefficient (log K_{ow}) < 3).

CML92, which was released in 1992, was the first impact assessment methodology that encompasses a wide variety of midpoint impact categories (Hauschild et al., 2018). CML2001 methodology, which was used for impact assessment in five midpoint categories, includes four main stages (goal and scope definition, inventory analysis, impact assessment, and interpretation) of which the first two will be specified in materials part while the last two will be detailed in the results. Furthermore, this methodology ensures the qualifications required in life cycle assessment studies determined by the SETAC.

GaBi, which released the version of 8.0 in 2017, is the software used to assess environmental impacts within the scope of this study as it provides recommendations and solutions by considering both environmental and economic concerns, as well as social and technical aspects. One of the databases utilized within this study was the ecoinvent database because it also provides data collection for inventory. The Ecoinvent LCI database was released with its first version (version 1.01) in 2003 (Hauschild et al., 2018) and since then it has been regularly updated (version 3) (Wernet et al., 2016) of which has known as the most current version 3.7.1., in detail (Ecoinvent, 2020). GaBi consists of the ecoinvent integrated extension database to sustain a complete matching of flow hierarchies between GaBi and ecoinvent databases for ensuring an extensive compliance (Sphera, 2021).

3.2. Goal and Scope Definition

The first stage of life cycle assessment methodology is goal and scope definition. The goal and scope definition of an LCA study should contain a clear statement of the study's purpose, a scheme of the system with its' borders to be taken into account, and functional unit in addition to the allocation of the obtained results according to the ISO standard (ISO 14044, 2006).

The goal of the study is to analyze the environmental profile considering from material supply which can be defined as "cradle" to waste management which can be defined as "grave" in accordance with life cycle approach and to compare the ecological burdens of personal care and cosmetic products within the context of soaps (bar and liquid) and shower preparations (shampoo, hair conditioner, shower gel, and bath soap). For that purpose, the data obtained from the sectoral manufacturers to demonstrate the production process including stakeholders such as packaging suppliers, waste management policies of municipal administrators was evaluated in line with

literature and software databases for obtaining an integrated approach. Within the context of this study, environmental impacts of cosmetic and personal care products in defined conditions (Table 3.2) were calculated with selected midpoint impact categories.

Table 3.2. Product definition in reference cases and alternative cases.

Product Type	Reference Case	Alternative Case
Bar Soap	600 g bar soap (organic oil formulation) of company A; Primary packaging: OPP	900 g bar soap (pomace oil formulation) of the same company; Primary packaging: Cardboard
Liquid Soap	750 ml liquid soap of company B; Primary packaging: PET bottle and dispenser	400 ml liquid soap of company A; Primary packaging: PET bottle and dispenser
Shampoo	600 ml shampoo of company B; Primary packaging: PET bottle with dispenser	650 ml shampoo of company C; Primary packaging: PET bottle with plastic cap
Hair Conditioner	600 ml hair conditioner of company C; Primary packaging: PET bottle with plastic cap	600 ml hair conditioner of company B; Primary packaging: PET bottle with dispenser
Body cleaning products	400 ml shower gel of company A; Primary packaging: PET bottle with plastic cap	600 g bath soap, classic formulation of the same company; Primary packaging: OPP

3.2.1. Functional Unit

The functional unit is a quantitative expression of the system which serves as a foundation for defining the product reference flow that scales data collection in inventory analysis (Hauschild et al., 2018). Moreover, it should be in keeping with the scope of the study, as well as clearly defined and measured. Accordingly, “the manufacture of the sufficient amount of bottled personal care and cosmetic product for an individual’s entire lifetime (73 years)” was determined as the functional unit of this study.

3.2.2. System Boundaries

System boundaries which should be covering the entire product system analyzed and surrounding interventions by demarcating outer limits (Hauschild et al., 2018). The system boundaries of this LCA study consists mainly of eight processes before consumption, which was illustrated in Figure 3.1, and three end-of-life processes (wastewater and packaging waste management) after consumption. As it was noted before, the first step of the life cycle evaluations, which was defined as “cradle” within the context of the study, corresponds to material supply for both raw materials and packaging materials. The extraction stage of the aforementioned materials was not

included in the system boundaries due to the lack of accessibility to data. The extraction stage of water consumed in the use phase was also excluded from the system boundaries because it was assumed to be readily withdrawn from the municipal water system. The specific number of processes in the system boundaries may solely vary depending upon the scheme of selected care products either method of packaging material supply or means of transport for raw material supply.

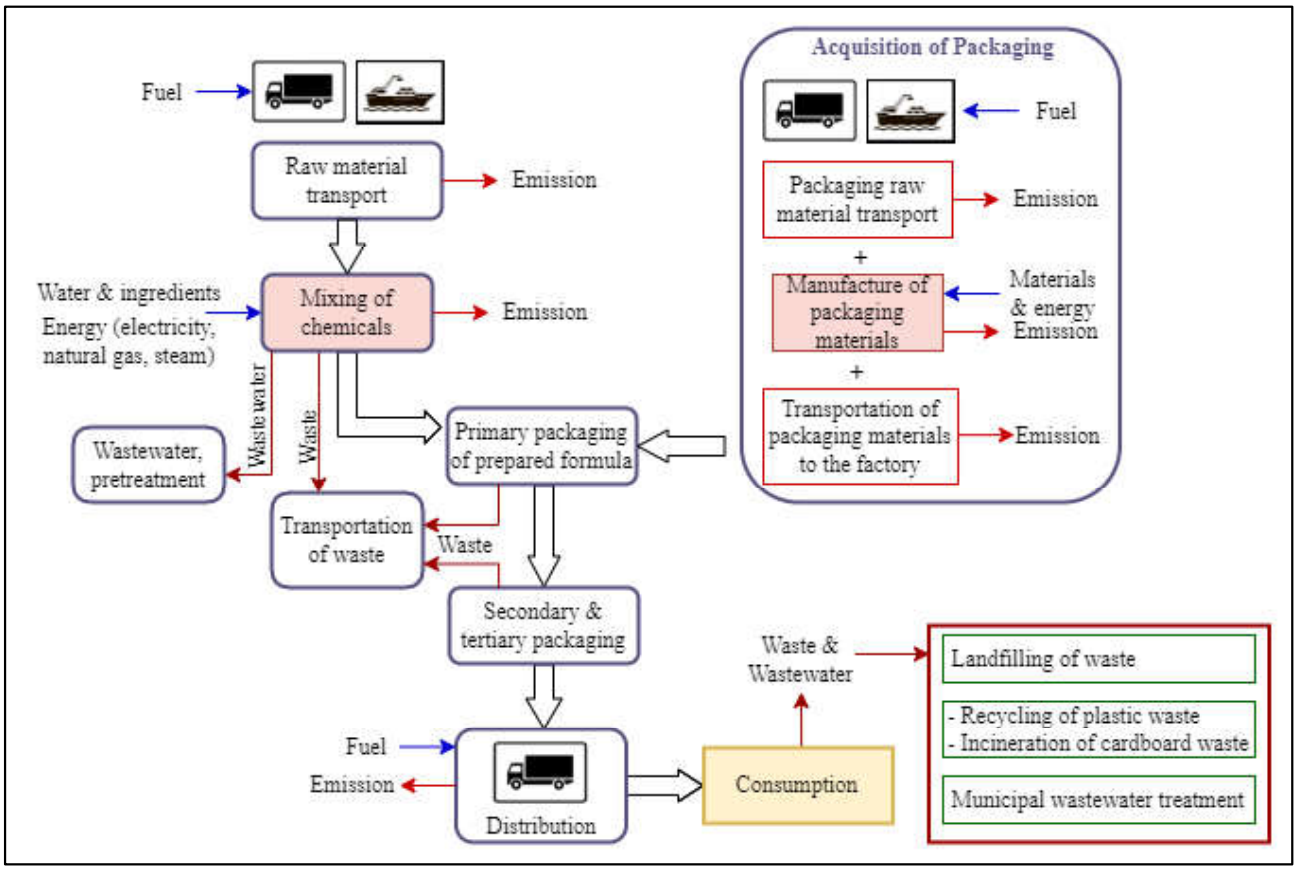

Figure 3.1. General system boundaries for selected PCCPs.

System boundaries for bar soaps in the reference product and in the alternative product consist of similar stages as the producing company is the same. On the other hand, the circumstances of liquid soap production processes are different from various perspectives. As the producing companies are altered, the means of packaging supplier, the volume of packaging, and the formulation of products has therefore showed variety. To be more precise, while the supply of raw materials has been only conducted with a highway in company B, both highway, and ocean-going ships have been operated in company A. Another difference has been observed in the type of energy used in production and packaging processes; company A has utilized electric and steam energy in the factory, whereas company B has only used electricity as an energy source.

For shower preparations, a comparison between the companies of C and B has been evaluated for the environmental impacts of shampoo and hair conditioner. Natural gas was used as an energy source as well as electricity in company C for production and packaging processes in contrast to company B, which has only used electricity. In addition, the hair products of company C have been packaged in the PET bottle with a plastic cap as closure, while company B has used a dispenser part in the packaging of hair care products. Furthermore, the product formulations of company B contain more ingredients compared to the hair products of company C. For body cleansing products, a shower gel is compared with a bar soap (assumed to be used in the bath), which are both produced by the same producer, company A. For the reference product, the packaging material is the combination of a PET bottle with a cap used in the shower gel packaging. On the other hand, the packaging material of classic soap (bath soap) is OPP. The production data of OPP was one of the built-in processes chosen from the GaBi database.

Waste management operations in the post-consumer phases consist of either landfilling and recycling of plastic waste or landfilling and incineration of cardboard waste in addition to the treatment of wastewater in a municipal wastewater treatment plant (WWTP). The requirements of the Regulation on Water Pollution Control made it obligatory to treat industrial wastewater before discharging into the sewage system. For this reason, industrial wastewater generated from the production was accepted to be treated in biological pretreatment which enables the removal of oil & grease, COD, and TSS with an efficiency of 80 %, 40 %, and 60 %, respectively (Dlamini et al., 2021), then discharged to the combined system of industrial zone for further treatment methods. Most of the processes used for waste management are adopted from the GaBi database and modified to the tailor-made process to meet the requirement.

3.3. Life Cycle Inventory Analysis

Life cycle inventory (LCI) analysis defines the product system, including all processes that are expected to contribute to the environmental impacts emphasized in the scope definition (Hofstetter, 2000). All input and output data of the evaluated systems are gathered and processed at this step. Obtained data from sectoral fields and the data belonging to the processes and flows which were chosen from databases are documented (Table 3.3) in this part.

Table 3.3. The inventory data sources for the key processes included in system boundaries.

Phases	Required data	Chosen processes	Chosen flow from database
Transport processes	Transport	EU-28: Articulated lorry, max payload 27t EU-28: Lorry, max payload 17.3t EU-28: Small lorry, max payload 3.3t EU-28: Container ship ocean 27500 dwt payload EU-28: Diesel mix at filling station (100 % fossil) EU-28: Liquefied petroleum gas (LPG)	Transport [Others], Diesel [Refinery products]; GaBi 8.0
Production unit	Energy Waste	EU-28: Electricity grid mix EU-28: Process steam from heavy fuel oil (HFO) 85 % EU-28: Natural gas mix	Electricity [Electric power], Steam (MJ) [steam], Natural gas, at consumer EU-27 [Natural gas, at consumer], Hazardous waste (unspecified), Waste (solid) [waste for disposal]; GaBi 8.0
Packaging units	Energy Waste	EU-28: Electricity grid mix EU-28: Natural gas mix RER: Polypropylene film (PP) PlasticsEurope EU-28: Corrugated board excl. paper production 2015	Electricity [Electric power], Steam (MJ) [steam], Polypropylene-film (oriented) (PP), Waste (solid) [waste for disposal]; GaBi 8.0 RER: packaging, corrugated board, mixed fiber, single wall, at plant; Ecoinvent
Use	Energy Water Waste	EU-28: Electricity grid mix	Electricity [Electric power], Hazardous waste (unspecified), Waste (solid) [waste for disposal]; GaBi 8.0 RER: tap water, at user; Ecoinvent database
Wastewater treatment	Wastewater	EU-28: Municipal wastewater treatment mix EU-28: Waste water treatment	Water (wastewater, untreated) [Production residues in life cycle]; GaBi 8.0
Landfilling	Packaging waste	EU-28: Plastic waste on landfill EU-28: Paper waste on landfill	Landfill of plastic waste [consumer waste], Landfill of paper waste [consumer waste]; GaBi 8.0
Recycling of plastic waste	Packaging waste	EU-28: Polypropylene granulate secondary (biobased) EU-28: Polyethylene terephthalate (PET) granulate secondary (biobased)	Plastic granulate (unspecified) [Plastics]; GaBi 8.0
Incineration of paper waste	Packaging waste	EU-28: Waste incineration of paper fraction in municipal solid waste (MSW)	Waste incineration of paper fraction in municipal solid waste (MSW) [waste for recovery]; GaBi 8.0

3.3.1. Data Collection and Key Assumptions

In the scope of this study, inputs as resources (organic and inorganic intermediate products, valuable materials, operating materials, etc.) and energy flows are taken into account as well as the outputs as waste (solid waste, packaging waste, and hazardous waste), wastewater, emissions to fresh water, and emissions to air. Industrial data obtained from producers have been utilized with the literature data and some assumptions based on the information supported by credible sources to complete the system assessments.

For the consumption phase, hand washing products (bar soap and liquid soap) were assumed that they do not require to heat tap water while using, and the amount of water consumed was calculated on the strength of the literature data (Koehler and Wildbolz, 2009) and determined as wastewater discharge. On the other hand, shower preparations require heating of water which was assumed the temperature change occurred with a 25°C increase (from 15°C which is the degree of tap water to 40°C which is the utmost shower temperature proposed by dermatologist and researchers at the University of Freiburg in Germany) (Mackenzie, 2015). The findings of Biesterbos et al. (2013) were used in this study to determine the consumption patterns of shower products (shampoo, hair conditioner, and shower gel). The detailed date related to consumption patterns of selected reference care products was stated in Table 3.4.

Table 3.4. The determination of consumption pattern for each reference product.

Consumption Pattern	**Soaps**		**Hair care products**		**Body cleaning product**
	Bar	**Liquid**	**Shampoo**	**Hair Conditioner**	**Shower Gel**
Capacity of one package	600 g	750 ml (765 g)	600 ml (621 g)	600 ml (582 g)	400 g
Dosage for per use	0.35 g (Koehler and Wildbolz, 2009)	2.3 g (Koehler and Wildbolz, 2009)	4.8 g (Biesterbos et al., 2013)	4.9 g (Biesterbos et al., 2013)	6.3 g (Biesterbos et al., 2013)
Number of uses/package	1714	333	129	119	64
Average consumption time/product	170 d	34 d	301 d	277 d	158 d
Number of products/a lifetime	156	784	92	100	186

The calculated amount of wastewater was based on the flowrate information about the showerheads. In compliance with the federal regulations (U.S. Department of Energy, 2021), which have limited showerhead manufacturers to a maximum flow rate of 2.5 gallons per minute according to the WaterSense label (EPA, 2021a), the optimum flow assumption was restricted for each minute with 2 gallons (7.57 L) on the average (Delta, 2020). Since any specific regulation for water flow arrangement related to individual water consumption at homes has not been arranged yet in Turkey, the data of the U.S. Department of Energy was considered as an approximation for consumption habits. In this context, the rinsing duration of hair care products was assumed as one minute which consumes 7.57 L, while it was assumed 30 seconds which consumes 3.785 L for body cleaning products.

As one of the processes that highly contributes to environmental impact categories, transportation distances of raw materials to the factory were analyzed. Additionally, the distances from factories to the main distribution point (Istanbul) of products after production were also determined. All information related to distances were listed in Table 3.5. Since solid waste generated during the production and packaging processes in the factory of which the amount of it is quite few, only transportation of these wastes to the nearest waste treatment center was considered. For the waste management of plastic packaging after consumption of the products, landfill of plastic waste was assumed as 40 % while the recycling of packaging material was expected to accomplish around 60 % in accordance with the predictions stated in the 11th Development Plan (Turkish Presidential Strategy and Budget Department, 2019).

Table 3.5. Transportation data related to distances to factories and to the main distribution point.

Distance, km		**The number of raw materials**	**Factory**		
Raw material transportation to factory, km (total)			**A**	**B**	**C**
Bar soap	Reference bar soap, R1	23	79,642	-	-
	Alternative bar soap, A1	7	53,598		
Liquid soap	Reference liquid soap, R2	24	-	10,580	-
	Alternative liquid soap, A2	17	34,940		
Shampoo	Reference shampoo, R3	38	-	17,020	-
	Alternative shampoo, A3	24		-	13,600
Hair conditioner	Reference hair conditioner, R4	17	-	-	8,600
	Alternative hair conditioner, A4	23		10,120	-
Body cleaners	Reference shower gel, R5	19	50,190	-	-
	Alternative bath soap, A5	17	106,298		
Product transportation to the main distribution point (Istanbul), km			416	423.5	660
Transportation of solid waste originated from the operations in the factory to waste treatment center, km			48	18.5	28.5

3.3.2. Inventory Analysis of Selected PCCPs

In this section, chemical ingredients of each cosmetic and personal care product were documented with their functions in the composition instead of chemical names for the main products and alternative products, separately.

3.3.2.1. Selected Bar Soap Products. Two different products were analyzed for the life cycle assessment of the bar soap. The former is an organic formulation (Table 3.6) that contains 23 ingredients while the latter is an alternative formulation (Table 3.7) based on pomace oil derivatives that contains only 7 ingredients. Both products are manufactured by the same company.

Table 3.6. The input data for R1 – organic essential oils.

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Solvent	Water for industrial use		
Emulsifier		RER: fatty acids, from vegetarian oil, at plant	
Surfactant	Tallow fatty acid (16-18) (valuable)		
		RER: fatty acids, from vegetarian oil, at plant	
Moisturizer	Glycerin		
		RER: fatty acids, from vegetarian oil, at plant	
pH adjuster	Triethanolamine (TEA) (valuable)		
Viscosity controller	Sodium chloride (rock salt)		
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		
			Etidronic acid
Colorant		GLO: chemicals organic, at plant	
Emollient		RER: fatty acids, from vegetarian oil, at plant	
Fragrance		RER: benzyl alcohol, at plant [organics]	
	Benzoic acid		
			Butylphenyl methylpropional
			Coumarin
	Limonene (valuable)		
			Cinnamyl alcohol

The packaging material for the first product is OPP of which volume is 600 g, and cardboard material for the alternative product of which volume is 900 g. The production process of OPP material and cardboard packaging is selected from built-in processes existing in the GaBi 8.0 database.

Table 3.7. The input data for A1 – pomace oil derivatives.

Input Data	**Selected Flow from GaBi database**		**Created Flow in GaBi**
	Thinkstep	**Ecoinvent**	
Solvent	Water for industrial use		
Surfactant		RER: fatty acids, from vegetarian oil, at plant	
Viscosity controller	Sodium chloride (rock salt)		
Essential oil	Limonene (valuable)		
Fragrance			Isobornyl acetate
		RER: fatty acids, from vegetarian oil, at plant	
		RER: diphenylether-compounds, at regional storehouse	

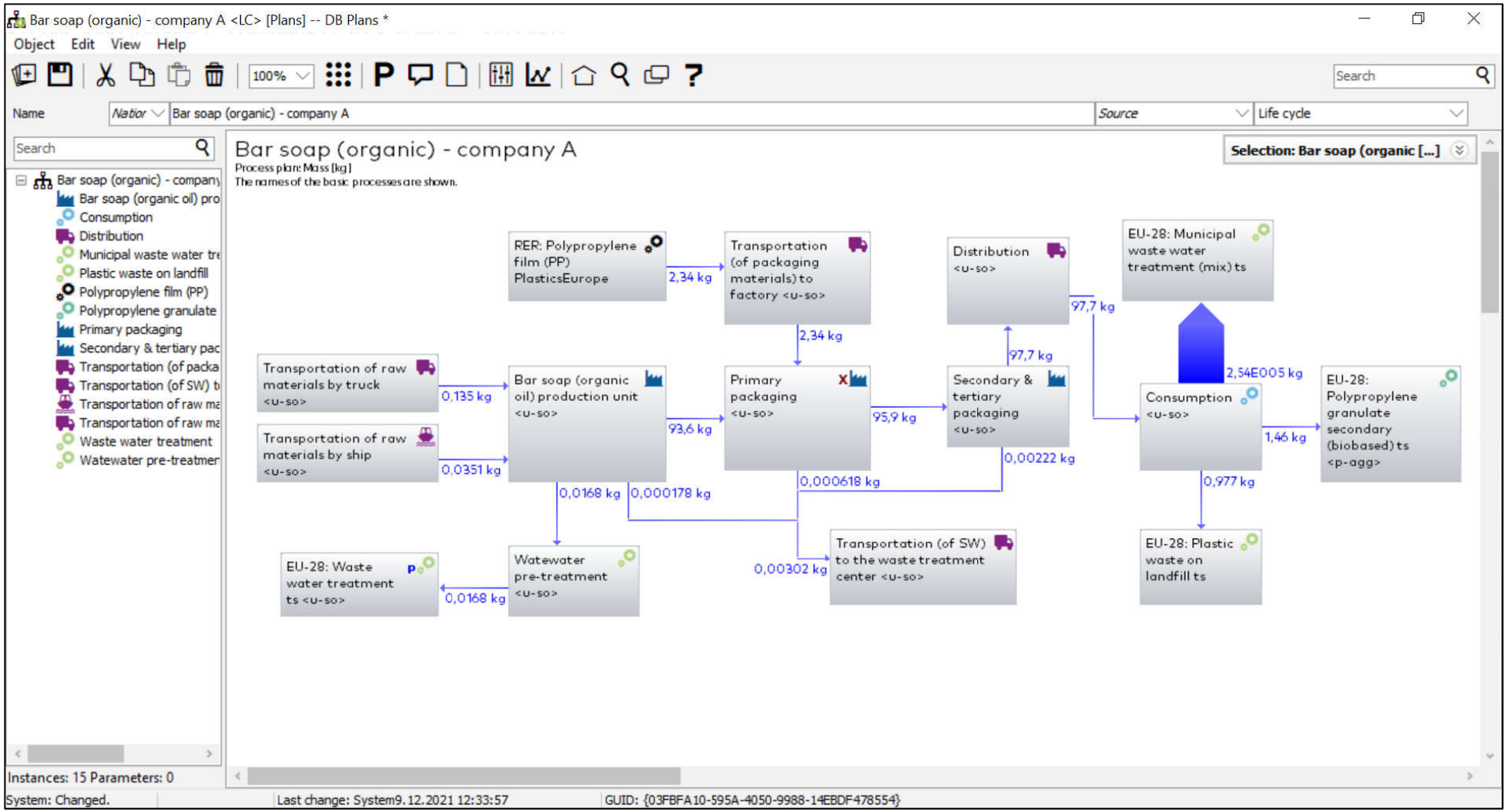

Figure 3.2. Life cycle flow for R1 – formulation based on organic essential oils.

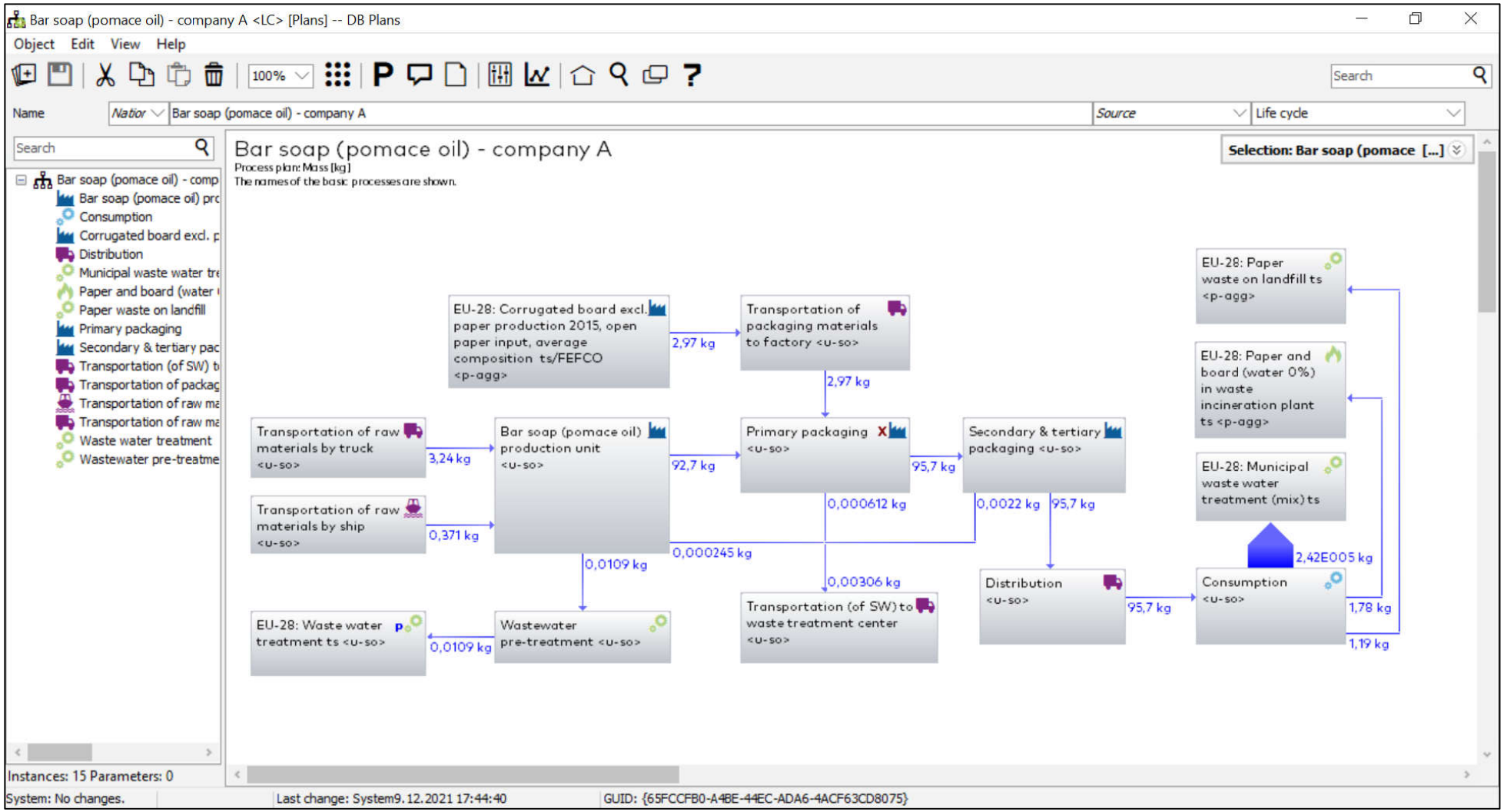

Figure 3.3. Life cycle flow for A1 – formulation based on pomace oil derivatives.

3.3.2.2. Selected Liquid Soap Products. The manufacturing processes of two different liquid soap formulations were investigated. The first formulation of liquid soap, which was considered as a reference product manufactured by company B, contains 24 ingredients listed in Table 3.8. The first product was bottled in the volume of a 750 ml polyethylene terephthalate (PET) bottle in addition to a dispenser. The data related to production processes of packaging material was obtained from a plastic packaging supplier in the sector.

Table 3.8. The input data for R2 – formulation of company B.

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Solvent	Water for industrial use		
Foaming agent	Sodium sulphate		
Surfactant		RER: fatty alcohol, from coconut oil, at plant	
Moisturizer	Glycerin		
Viscosity controller	Sodium chloride (rock salt)		
Emulsifier		RER: Diethanolamine, at plant	
	Ethylene oxide		
		RER: polycarboxylates, 40% active substance, at plant	
	Canola (rapeseed) oil, refined		
Emollient		FR: glycerine, from vegetable oil, at esterification plant	
		RER: fatty acids, from vegetarian oil, at plant	
Preservative	Formaldehyde (100%)		
		RER: biocides, for paper production, unspecified, at plant	
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		
	Citric acid (valuable)		
Colorant		GLO: chemicals organic, at plant	
Essential oil	Limonene (valuable)		
Fragrance		RER: benzyl alcohol, at plant	
	Limonene (valuable)		
			Alpha-isomethyl ionone
			Butylphenyl methylpropional

The second formulation of liquid soap, which was considered as an alternative product manufactured by company A, contains 17 ingredients listed in Table 3.9. The alternative product was bottled in the volume of a 400 ml PET bottle with a dispenser. The data related to production processes of packaging material was modified in accordance with real data of the packaging supplier.

Table 3.9. The input data for A2 – formulation of company A.

Input Data	**Selected Flow from GaBi database**		**Created Flow in GaBi**
	Thinkstep	**Ecoinvent**	
Solvent	Water for industrial use		
		RER: fatty acids, from vegetarian oil, at plant	
Surfactant	Sodium sulphate		
		RER: fatty alcohol, from coconut oil, at plant	
Moisturizer	Glycerin		
Viscosity controller	Sodium chloride (rock salt)		
			Isostearamide mipa
		FR: glycerine, from vegetable oil, at esterification plant	
Emollient		RER: fatty acids, from vegetarian oil, at plant	
pH adjuster	Triethanolamine (TEA)		
Fragrance		RER: benzyl alcohol, at plant	
Chelating agent	Ethylenediaminetetraacetic acid (EDTA)		
Preservative		RER: benzyl alcohol, at plant [organics]	
		RER: biocides, for paper production, unspecified, at plant	
	Triethylene glycol		
	Propylene glycol		

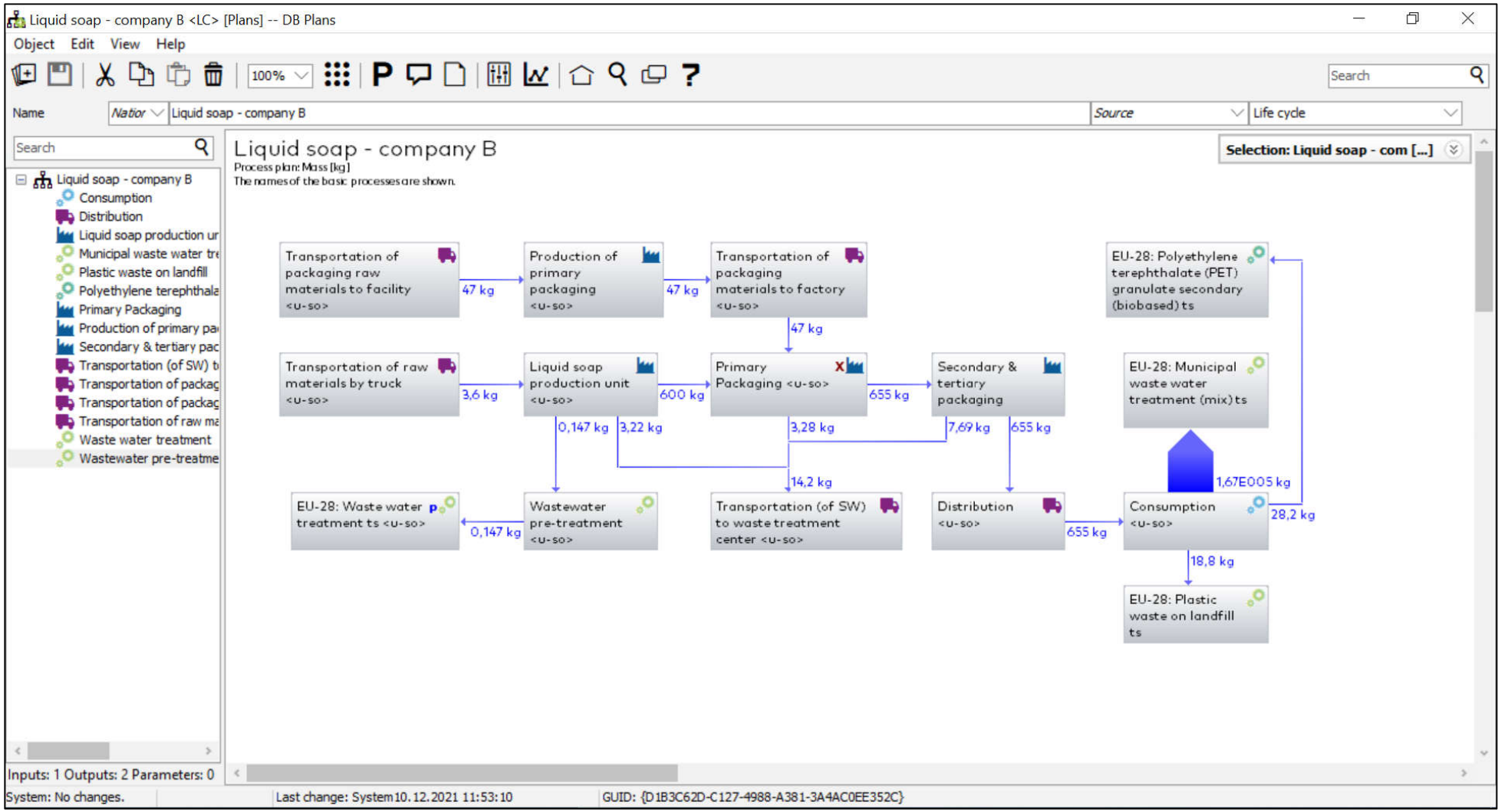

Figure 3.4. Life cycle flow for R2 – formulation of CB.

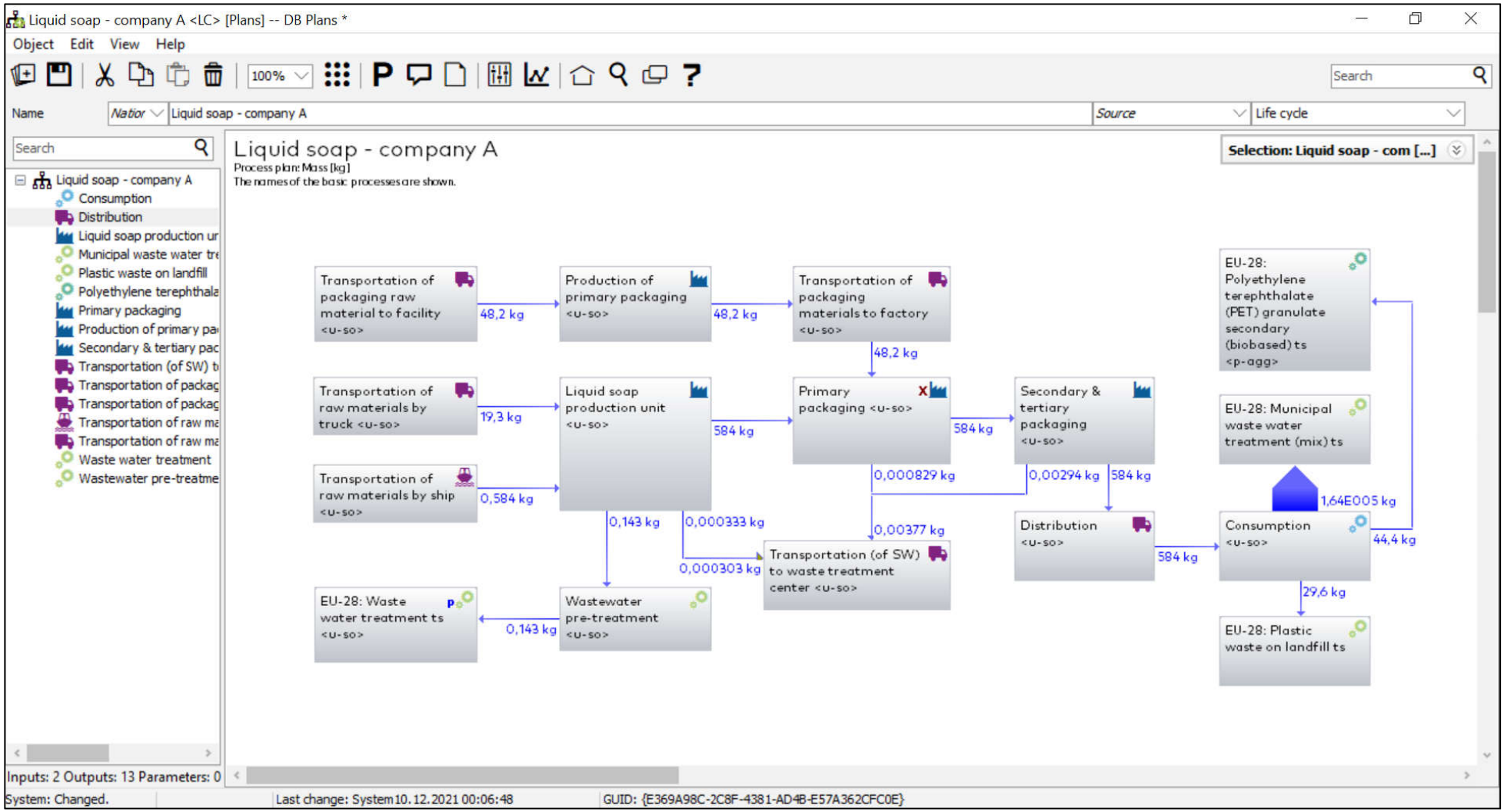

Figure 3.5. Life cycle flow for A2 – formulation of CA.

3.4.2.3. Selected Shampoo Products. The processes belonging to two different shampoo products were investigated. The first shampoo formulation (Table 3.10) that contains 37 ingredients was manufactured by company B. The reference product was bottled in the volume of a 600 ml PET bottle closed with a dispenser.

Table 3.10. The input data for R3 – formulation of company B.

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Solvent	Water for industrial use		
Foaming agent	Sodium sulphate		
	C12-C13 AS (SLS) (51.7 %)		
Surfactant		RER: fatty alcohol, from coconut oil, at plant	
		RER: esters of versatic acid, at plant	
	Diethylene glycol		
Emulsifier		RER: fatty acids, from vegetarian oil, at plant	
		RER: glycerin, from rape oil, at esterification plant	
		RER: Diethanolamine, at plant	
	Ethylene oxide		
		RER: fatty acids, from vegetarian oil, at plant	
		RER: ethoxylated alcohols, unspecified, at plant	
Antistatic agent			Vitamin
		RER: urea, as N, at regional storehouse	
Emollient		RER: fatty acids, from vegetarian oil, at plant	
Film forming		RER: modified starch, at plant	
Viscosity controller		RER: modified starch, at plant	
	Sodium chloride (rock salt)		
Buffering agent	Lactic acid (2-Hydroxypropanoic acid)		
Moisturizer	Glycerin		
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		

Table 3.10. The input data for R3 – formulation of company B (continued).

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Conditioner	Sulphur		
	Ethylene glycol (valuable)		
	Hydroxycarboxylic acid		
	Quaternary ammonium compounds		
Thickener		RER: ethoxylated alcohols, unspecified, at plant	
pH adjuster	Triethanolamine (TEA)		
Preservative	Formaldehyde (100%)		
	Benzoic acid		
		RER: biocides, for paper production, unspecified, at plant	
Fragrance		RER: benzyl alcohol, at plant	
	Limonene (valuable)		
			Alpha-isomethyl ionone
			Butylphenyl methylpropional

The second shampoo formulation (Table 3.11) that contains 23 ingredients was manufactured by company C. The shampoo of company C was bottled in the volume of 650 ml PET bottle in addition to a plastic cap as closure material. For both products, the data related to production processes of packaging material was modified in accordance with real data of a packaging supplier.

Table 3.11. The input data for A3 – formulation of company C.

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Solvent	Water for industrial use		
Surfactant		RER: fatty alcohol, from coconut oil, at plant	
Suspending agent			Carbomer
Antistatic	Quaternary ammonium compounds		
Foaming agent	Ethylene glycol		
	Cellulose (fibers)		
	Sodium sulphate		
Antifoaming	Silicon (valuable)		
Colorant	Silicate (valuable)		
Fragrance		RER: benzyl alcohol, at plant	

Table 3.11. The input data for A3 – formulation of company C (continued).

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Oxidant agent	Corn starch		
Moisturizer		RER: modified starch, at plant	
			Keratin (hydrolyzed)
Oxidant agent	Sodium sulphate		
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		
	Citric acid		
Preservative	Benzoic acid		
pH adjuster	Sodium hydroxide (50%; caustic soda)		
Viscosity controller	Sodium chloride (rock salt)		
	Ethylene glycol		
Conditioner		RER: fatty acids, from vegetarian oil, at plant	
			Ceramide NG
Nourishing agent			Vitamin

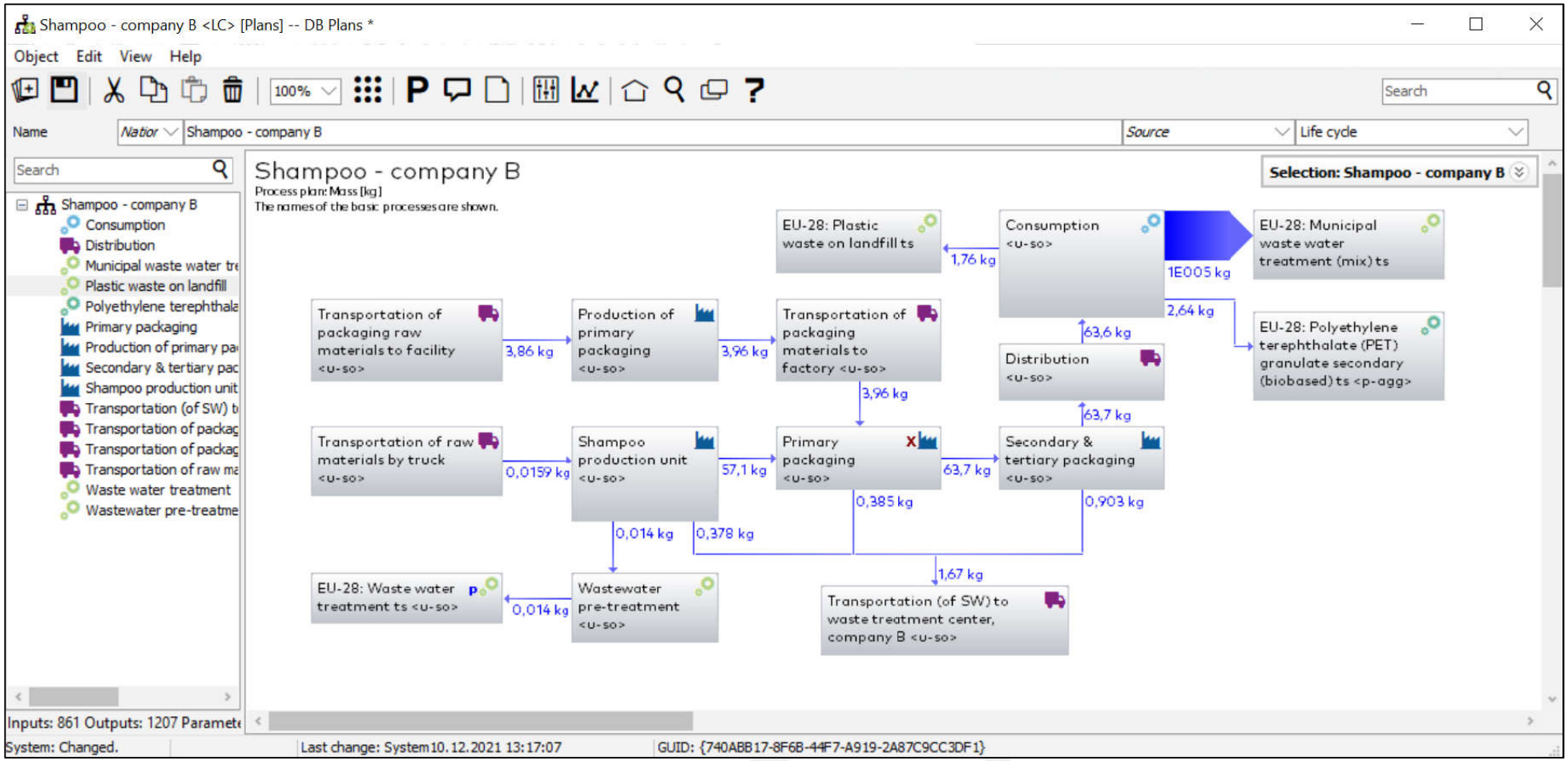

Figure 3.6. Life cycle flow for R3 – formulation of CB.

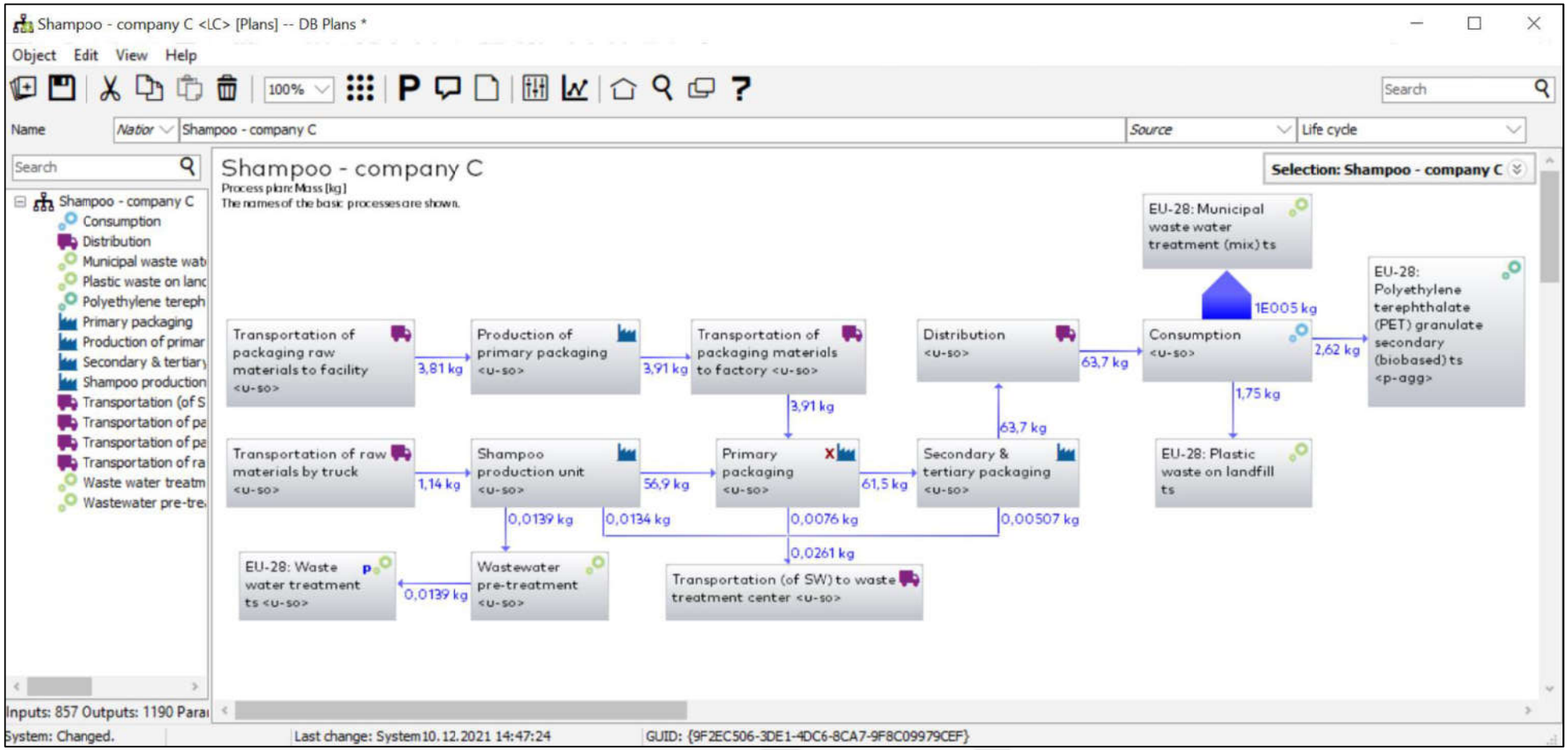

Figure 3.7. Life cycle flow for A3 – formulation of CC.

3.4.2.4. Selected Hair Conditioner Products. The formulations belonging to two different hair conditioners manufactured by the same companies (CB and CC) were investigated.

The first hair conditioner formulation (Table 3.12) that contains 17 ingredients is manufactured by company C (the reference product). The product manufactured by company C was bottled in the volume of 600 ml PET bottle in addition to a plastic cap.

Table 3.12. The input data for R4 – formulation of company C.

Input Data	**Selected Flow from GaBi database**	
	Thinkstep	**Ecoinvent**
Solvent	Water for industrial use	
Emulgator		RER: fatty alcohol, from coconut oil, at plant
Surfactant	Dimethylamine (valuable)	
Antistatic agent		RER: Trimethylamine, at plant
Buffering agent	Lactic acid (2-Hydroxypropanoic acid)	
Viscosity controller	Sodium chloride (rock salt)	
Chelating agent	Ethylenediaminetetraacetic acid (EDTA)	
Antifoaming agent	Silicon (valuable)	
Moisturizer	Glycerin	
	Crude coconut oil	
	Vegetable raw oil	
Preservative		RER: biocides, for paper production, unspecified, at plant
	Magnesium chloride (valuable)	
Fragrance		RER: benzyl alcohol, at plant
Conditioner		RER: fatty acids, from vegetarian oil, at plant

The second hair conditioner formulation (Table 3.13) that contains 23 ingredients is manufactured by company B (the alternative product). The alternative product was bottled in the same volume of PET bottle closed with a dispenser. For both products, the data related to packaging material was modified from the data of the packaging supplier.

Table 3.13. The input data for A4 – formulation of company B.

Input Data	Selected Flow from GaBi database		Created Flow in GaBi
	Thinkstep	Ecoinvent	
Solvent	Water for industrial use		
Emulgator		RER: fatty alcohol, from coconut oil, at plant	
Antistatic agent (antimicrobial)		GLO: ammonium chloride, at plant	
Emollient	Lubricating oil vegetable		
		RER: fatty acids, from vegetarian oil, at plant	
		RER: silicone product, at plant	
	Fatty alcohol (C16-C18) (valuable)		
	Fatty acid (valuable)		
		RER: fatty acids, from vegetarian oil, at plant	
Moisturizer	Glycerin		
Fragrance		RER: benzyl alcohol, at plant	
Antistatic agent		RER: trimethylamine, at plant	
Conditioner		RER: dimethylamine, at plant	
	Aromatic Polyester Polyols (valuable)		
	Hydroxycarboxylic acid		
		Ethylene glycol	
Preservative		RER: diphenylether-compounds, at regional storehouse	
Antioxidant		FR: glycerine, from vegetable oil, at esterification plant	
Chelating agent	Citric acid (valuable)		
Fragrance	Limonene (valuable)		
			Alpha-isomethyl ionone
			Butylphenyl methylpropional

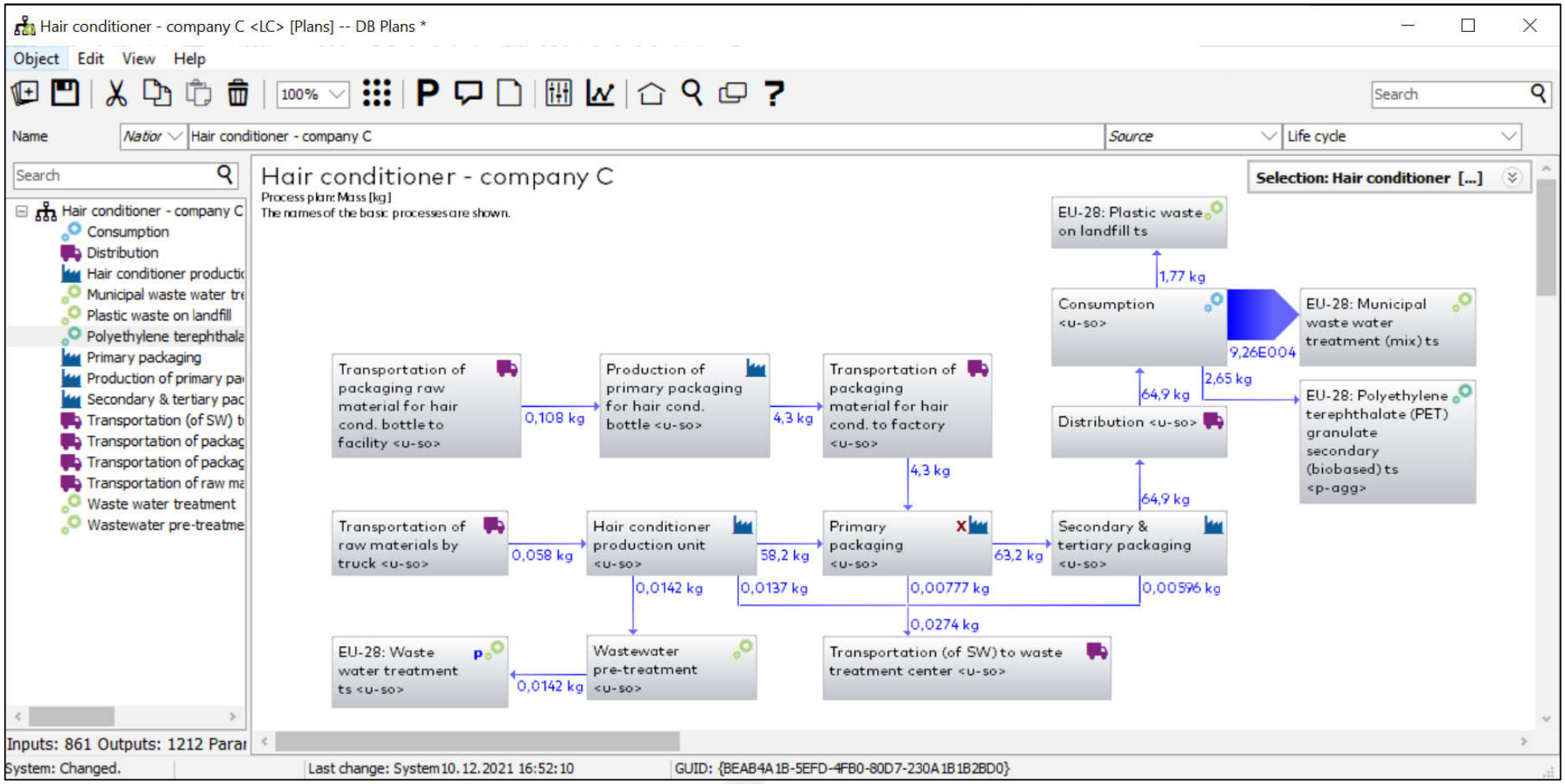

Figure 3.8. Life cycle flow for R4 – formulation of CC.

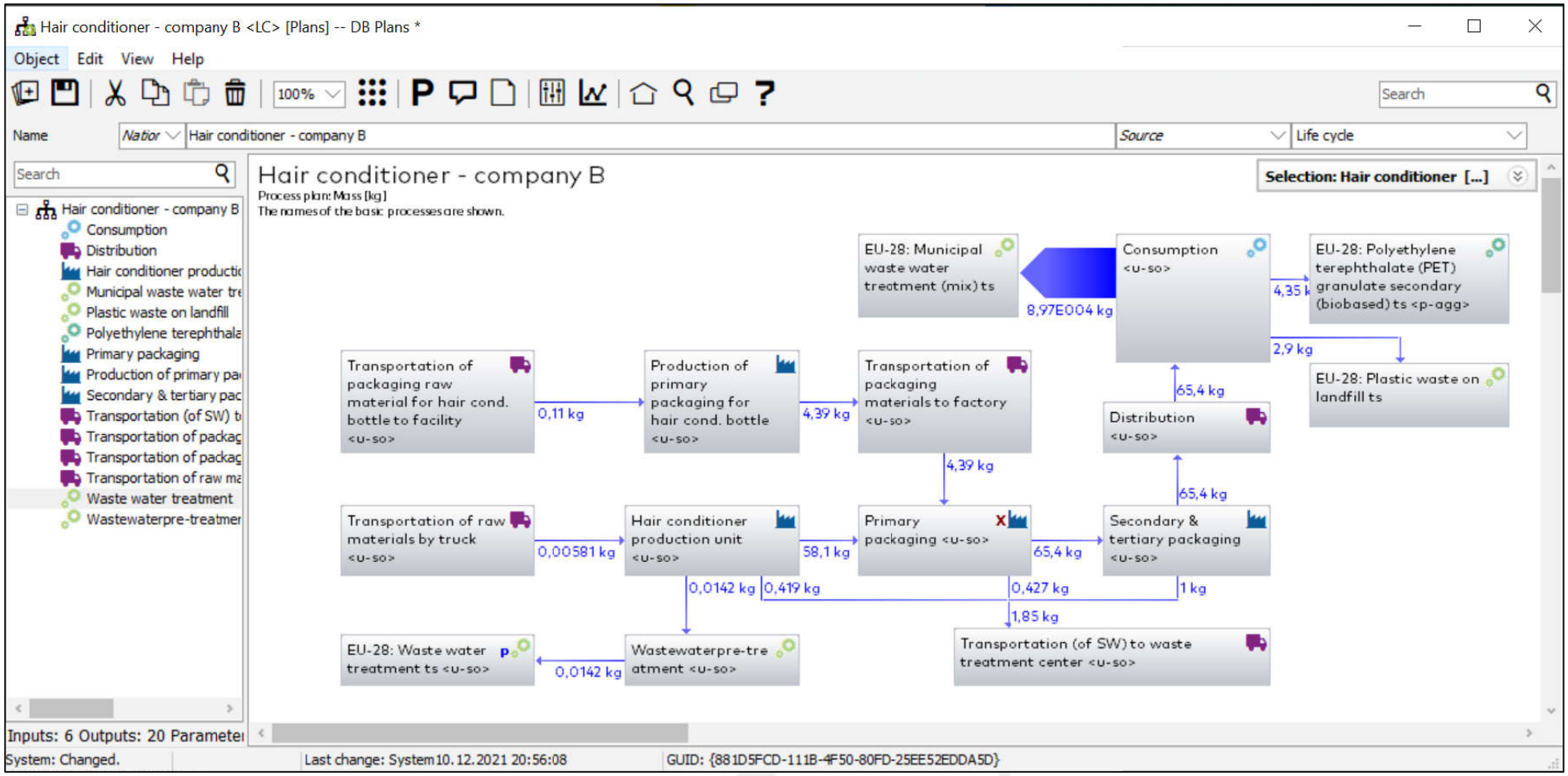

Figure 3.9. Life cycle flow for A4 – formulation of CB.

3.4.2.5. Selected Body Cleaning Products. The bath soaps can be one of the shower preparations as well as a shower gel. For body cleaning products, the environmental performances of shower gel and bar soap were intended to evaluate owing to this comparison.

Two different types of bath preparations manufactured by the same company (CA) were analyzed. The first product formulation (Table 3.14) belongs to a shower gel that contains 19 ingredients and is packaged with a PET bottle (400 ml) and a plastic cap. The packaging data was modified from the data of a similar product packaging obtained from the packaging supplier.

Table 3.14. The input data for R5 – shower gel formulation.

Input Data	**Selected Flow from GaBi database**		**Created Flow in GaBi**
	Thinkstep	**Ecoinvent**	
Solvent	Water for industrial use		
Surfactant	Sodium sulphate (valuable)		
		RER: fatty alcohol, from coconut oil, at plant	
	3-dimethylamino-propylamine		
Moisturizer	Glycerin		
Conditioner	Quaternary ammonium compounds		
Viscosity controller	Sodium chloride (rock salt)		
			Isostearamide mipa
		FR: glycerine, from vegetable oil, at esterification plant	
Solvent		RER: fatty acids, from vegetarian oil, at plant	
Emollient			
pH adjuster	Triethanolamine (TEA)		
Fragrance		RER: benzyl alcohol, at plant	
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		
Preservative		RER: benzyl alcohol, at plant	
		RER: biocides, for paper production, unspecified, at plant	
	Triethylene glycol		
	Propylene glycol		

On the other side, the second product formulation (Table 3.15) belongs to a classic bar soap that contains 17 ingredients. Bath soap, considered as an alternative product, is packaged with OPP which is enfolded in the amount of 600 g of the product. The production process packaging material is utilized from built-in processes that exist in the GaBi 8.0 database.

Table 3.15. The input data for A5 – classic bath soap formulation.

Input Data	**Selected Flow from GaBi database**		**Created Flow in GaBi**
	Thinkstep	**Ecoinvent**	
Solvent	Water for industrial use		
Emulsifier		RER: fatty acids, from vegetarian oil, at plant	
Surfactant	Tallow fatty acid (16-18) (valuable)		
		RER: fatty acids, from vegetarian oil, at plant	
Viscosity controller	Sodium chloride (rock salt)		
Fragrance		RER: benzyl alcohol, at plant [organics]	
	Limonene (valuable)		
			Butylphenyl methylpropional
	Benzoic acid (valuable)		
			Alpha-isomethyl ionone
		RER: diphenyl ether-compounds, at regional storehouse	
Chelating agent	Ethylenediaminetetra-acetic acid (EDTA)		
			Etidronic acid
Optical brightener	Emulsifier (valuable)		
Essential oil	Limonene (valuable)		
Colorant		GLO: chemicals organic, at plant	

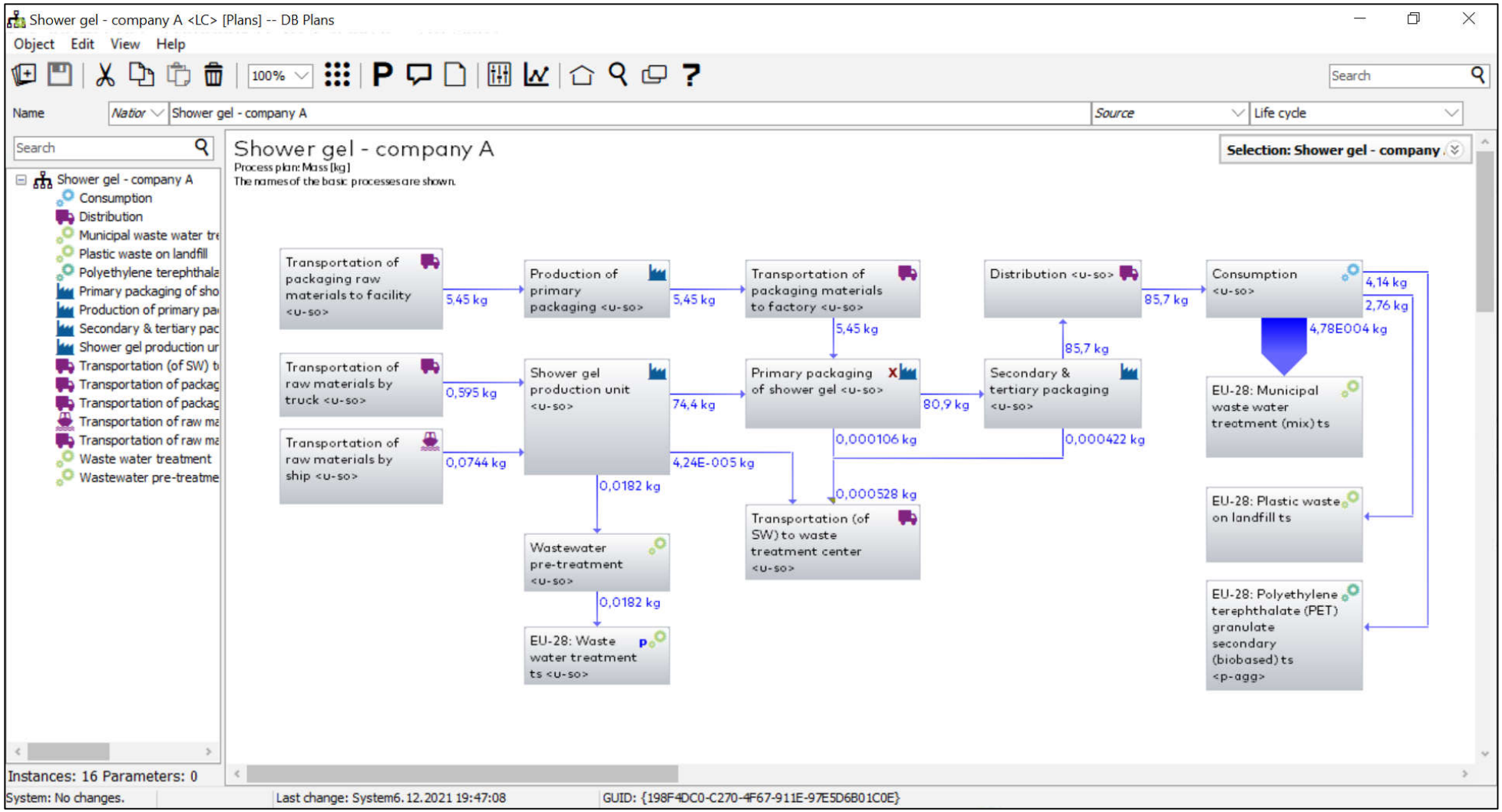

Figure 3.10. Life cycle flow for R5 – shower gel formulation of CA.

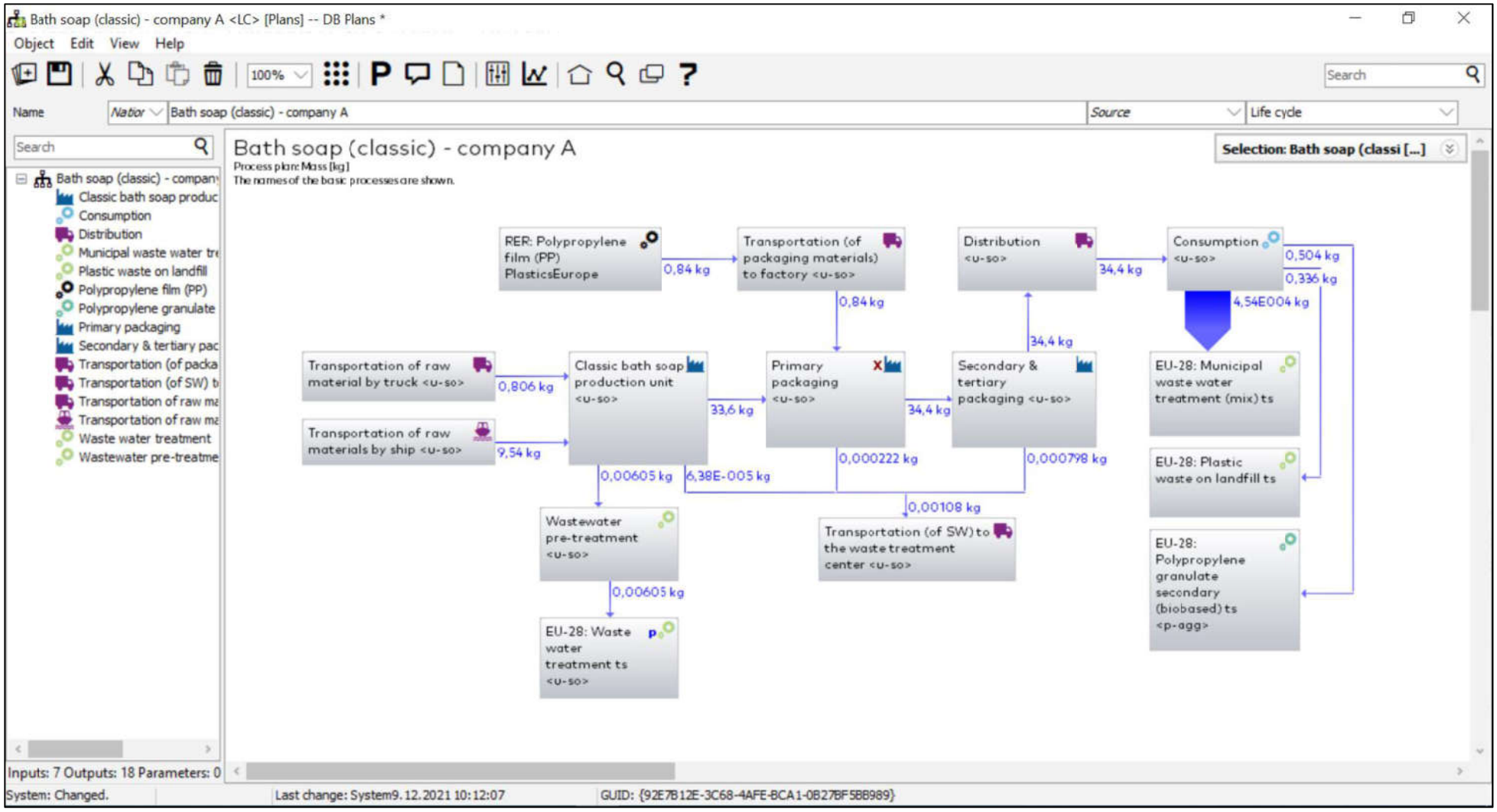

Figure 3.11. Life cycle flow for A5 – bath soap formulation of CA.

4. LIFE CYCLE IMPACT ASSESSMENT AND DISCUSSION

Life cycle impact assessment (LCIA), which involves the potential environmental impacts evaluation of the analyzed system including resources and releases, consists of four elements; classification that incorporates categorizing LCI results into the specified impact categories, characterization that calculates the results of selected categories numerically with its' units, normalization that entails calculating the quantity of category results in comparison to reference data, and weighting which entails converting and aggregating indicator results across impact categories. The former two are obligatory while the latter two are optional (ISO 14040, 2006). The categorization, characterization, normalization, and weighting were performed in this LCA study. CML methodology, which was developed by Leiden University, is used to assess the results of the LCA study that are classified with midpoint impact categories. (UNEP, 1996)

4.1. Classification

As the classification method is based on environmental impact categories, classification is required for the analysis of impact measurements to complete in a study that can be framed depending upon the researcher's selection (Chevalier and Rousseaux, 1999). The impact categories, on the one hand, are connected to inventory analysis (LCI) with the midpoint impacts such as climate change, water ecotoxicity, resource depletion, and so on. On the other hand, these midpoint impacts are linked to the endpoint impacts which resulted in damage categories expressing the hazards to natural resources, human health, and ecological health (Jolliet et al., 2004). Global warming potential, photochemical ozone creation potential, acidification potential, eutrophication potential, and freshwater aquatic ecotoxicity potential are the impact categories analyzed in this study for the classification of inventory results. The analyzed impact categories are selected in accordance with the relevant interventions (raw material extraction, emissions to air, emissions to water, etc.) occurring as a consequence of the industrial activities for the production of personal care and cosmetic products.

4.2. Characterization

Characterization quantifies the ability of each elementary flow assigned to the indicator of impact categories by using environmental models. For each impact category, the impact scores, which are obtained from characterization results, are expressed in a single measure. This enables all contributions to be combined into a single score that represents the total impact of the product system

on that category. The specified impact profile of the product system is composed of aggregated indicator scores for the several effect categories (Zampori et al., 2016).

The characterization results of the LCA studies conducted within this study were presented under the following subtitles. Two different products were analyzed and compared in each product category, and to clarify any complexity, R (reference) and A (alternative) initials were attributed to products in accordance with an order.

4.2.1. Global Warming Potential (GWP)

The first impact category analyzed is global warming potential (GWP). The global warming effect, which increases with trapping of the earth's heat and drives climate change, is referred to as global warming potential (EPA, 2021b). The mass of a global warming gas released into the atmosphere is multiplied by a GWP equivalency factor to generate impact scores for global warming (global climate change) contribution (EPA, 2021c). As the main contributor gas is carbon dioxide, the unit of this impact category is known as kg CO_2 equivalent.

The magnitude of environmental impacts of analyzed personal care and cosmetic products in the global warming potential category can be seen in Figure 4.1. As it was stated earlier, the results of each product group correspond to two sequential columns illustrated in the figure. As it was assumed the tap water was directly used (no energy consumption to heat the water) for rinsing of hand washing products, any impact of the consumption stage was calculated as opposed to shower products. On the whole, it can be concluded that the shampoo category has the biggest impact in GWP.

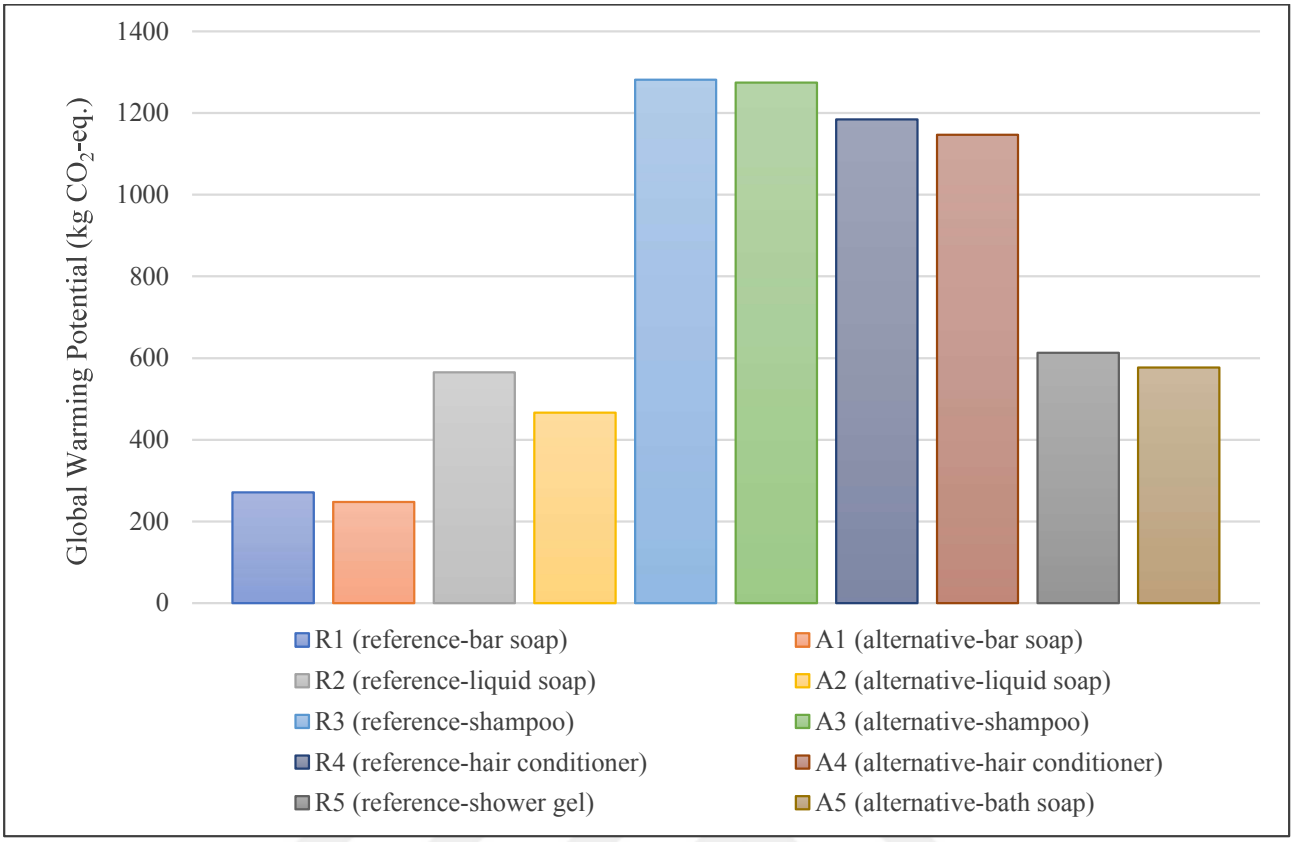

Figure 4.1. Total global warming potential for each product.

4.2.1.1. Bar soap category. Considering the obtained numerical results, the stage of raw material supply contributes more emissions to be released for R1 due to the raw material in higher amounts. Correspondingly, since the amount of electric energy used in the production stage of this soap is higher according to the sectoral data, the contribution to global warming was more dominant than the production stage of A1 in which steam energy is preferred rather than electric energy. To conclude, an 8.7 % decrease in GWP would be obtained by choosing A1.

The municipal wastewater treatment process as one of the post-consumer stages causes the highest global warming impact (89.0 % of the total impact of R1, 92.6 % of the total impact of A1). Besides, the distribution stage is determined as the second highest contributor for both types of soaps.

4.2.1.2. Liquid soap category. The main contributor to GWP impact category is observed as the municipal wastewater treatment process in the life cycle of R2 (27.9 %). It is followed by the packaging material supply processes including the transportation of packaging raw materials, production of primary packaging, and the transportation of packaging materials to the factory (20.3 %). On the other hand, the main contribution to GWP for the life cycle of A2 comes from the

packaging supply processes (36.1 %) which is followed by the municipal wastewater treatment process (33.2 %).

The third outstanding stage is distribution which corresponds to 19.6 % of the total impact of R2 while it is 23.4 % of the total impact of A2. Considering the total impact of the characterized results, A2 performed less GWP contribution in all life cycle stages except packaging supply processes. When the alternative option for liquid soap is preferred, GWP would be diminished by 17.5 % in total.

4.2.1.3. Shampoo category. Different from analyzed hand washing products of which the highest contributor was the municipal wastewater treatment process, the consumption stage of this hair washing product is determined as the main contributor to global warming (89.7 % of the total impact of R3, 90.2 % of the total impact of A3).

The role of A3 for global warming is higher due to the stages of packaging supply (by 83.8 %) and distribution (by 6.9 %) mainly because of the distance between factory location, packaging supplier and the main distribution point. However, considering the comparison of the total global warming impacts for the shampoo product group, A3 (1,274.2 kg CO_2-eq.) performed slightly better taking into account all life cycle stages that of R3 (1,281.8 kg CO_2-eq.). If the distance of suppliers and distributors to the company (producer of the A3) were optimized, the difference in GWP impacts between two shampoo products would be more noticeable.

4.2.1.4. Hair conditioner category. The impact of consumption is the most dominant stage among others for the life cycle of hair conditioners which is calculated as 1,184.6 kg CO_2-eq. for R4 and 1,146.4 kg CO_2-eq. for A4.

In addition to the post-consumer processes, the transportation process of raw materials and packaging materials for R4 has resulted in relatively higher impacts than that of A4. Although the impact of production, packaging, and distribution processes belonging to the alternative product is higher, a 3.2 % decrease in GWP would be obtained if A4 is chosen over R4.

4.2.1.5. Body cleaning products category. Similar to other shower products, the highest contribution to this impact belongs to the consumption stage of which is calculated as 550 kg CO_2-eq. (89.8 % of the total impact) for R5, and 522 kg CO_2-eq. (90.5 % of the total impact) for A5.

As one of the major contributors to global warming, fuel types, and distances related to transport processes maintained with ocean-going ships highly affect the amount of emission released by means of vehicles. This can be concluded from the comparison of raw material acquisition impact on GWP which is five times more in A5 than in R5. In spite of that, a 36.1 % decrease in GWP would be obtained by using the bath soap instead of the shower gel.

4.2.2. Photochemical Ozone Creation Potential (POCP)

The second impact category taken into account is photochemical ozone creation potential (POCP). Photochemical oxidants (ozone, hydrogen peroxide, peroxyacetyl nitrate (PAN), etc.) are formed in the atmosphere when sunlight reacts with volatile organic carbons (VOCs), non-methane volatile organic carbons (Group NMVOC) and nitrogen oxides (NO_x). They may either generate or worsen health problems, plant toxicity, and material deterioration at higher quantities (Boisvenue and Running, 2013). The release of the substances that may contribute to this adverse effect is included in this impact category. The magnitude of environmental impacts of analyzed personal care and cosmetic products in this category can be seen in Figure 4.2. It can be emphasized that hair products have the biggest impact in POCP among selected products.

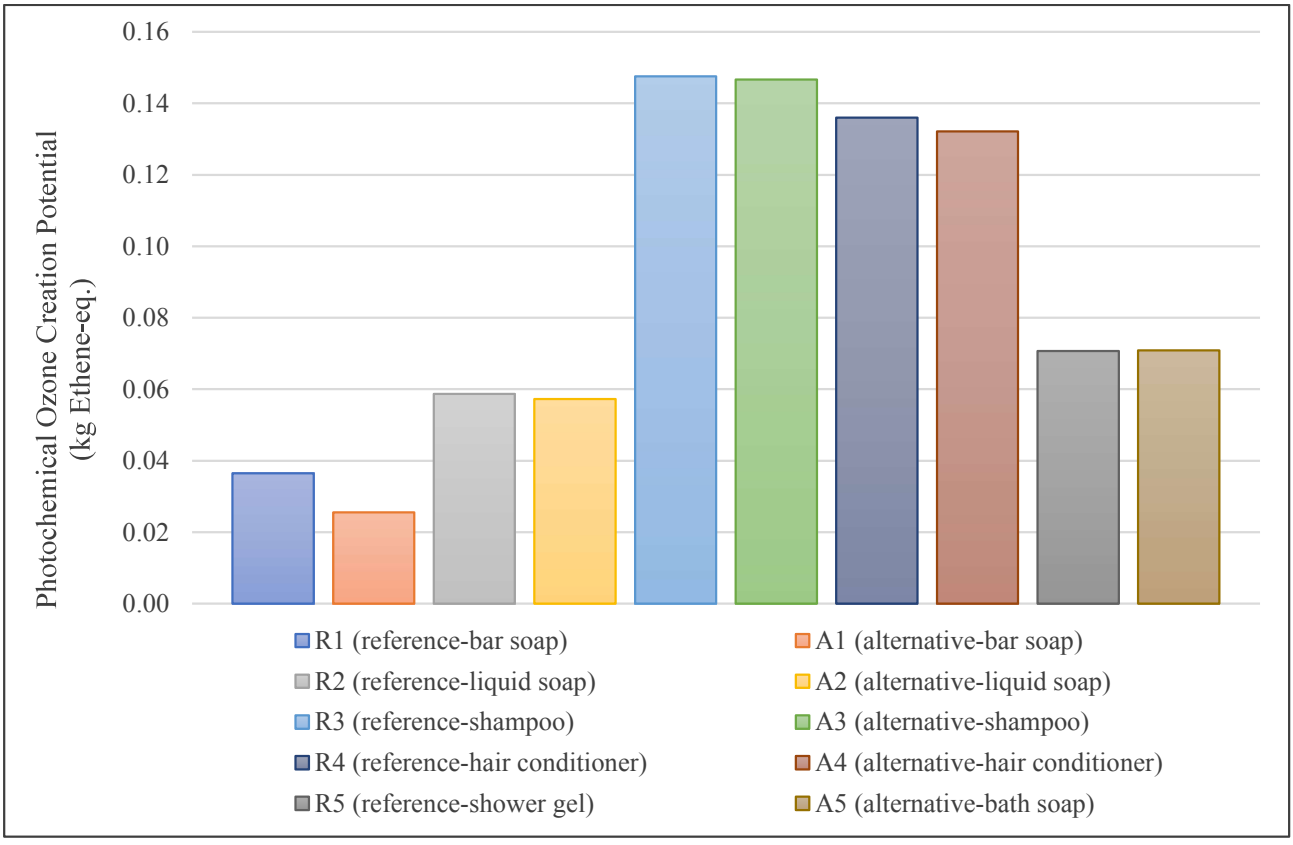

Figure 4.2. Total photochemical ozone creation potential for each product.

4.2.2.1. Bar soap category. According to the results, the wastewater treatment process causes the highest photochemical ozone creation impact in the life cycle of both types of bar soap (68.2 % of the total impact of R1, 92.6 % of the total impact of A1). Except that, raw material supply is observed as the second highest contributor for R1 because the amount of chemicals is excessively higher. On the other hand, the distribution process of A1is the second highest contributor to this impact in its life cycle. Compared to the all stages of two products, total impact in POCP can be decreased by 29.4 % if A1 is preferred.

4.2.2.2. Liquid soap category. Observing the figure above, the total impact of POCP for the reference product is seen as higher than the alternative one, and by choosing the A2 as liquid soap, it is possible to decrease this impact by 2.3 %. To be more precise in this comparison, it can be said that distribution process (19.6 % of the total impact of R2, 19.5 % of the total impact of A2) ranked second as the main contributor to POCP after wastewater treatment stage (27.78 % of the total impact of R2, 27.90 % of the total impact of A2).

4.2.2.3. Shampoo category. For hair washing products, the consumption stage was observed as the main contributor (90.7 % of the total impact of R3, 91.3 % of the total impact of A3). For this reason, the total impact of the compared shampoos was not calculated too differently because of the similar consumption patterns. According to the impact results of each stage, it was concluded that A3 performed lower acidification potential except the transportation processes of packaging raw materials to the supplier and manufactured packages to the factory. Considering the calculated results, the total impact of AP will be decreased by 6.3 ‰ if the alternative liquid soap is chosen.

4.2.2.4. Hair conditioner category. The impact of consumption is the most dominant stage among others in the life cycle of both hair conditioners of which 91.1 % of R4's total impact and 90.7 % of A4's total impact. Consumption stage is followed by the processes of wastewater treatment, distribution from the factory and packaging materials transportation to the factory for both products, respectively. Even though there is not a major difference between the results of the reference and alternative product, a 2.8 % decrease in AP would be obtained when A4 is chosen over R4.

4.2.2.5. Body cleaning products category. The highest contribution to this impact belongs to the consumption stage in this product category, too (90.5 % of the total impact of R5, 85.3 % of the total impact of A5). Analyzed bath soap contributes to photochemical creation more than the reference product with a ratio of 3.2 ‰ in total. This is because the impact of bar soap production is higher due to the saponification emissions. However, a 59.8 % and 5.5 % decrease would be obtained in POCP

impact originating from the distribution and consumption stages, respectively, by using the bath soap instead of the shower gel.

4.2.3. Acidification Potential (AP)

The third impact category is acidification potential which refers to the generation of acid precipitation caused by the release of pollutants. The amount of a chemical discharged into the air that may just cause acidification and the acidification potentials (AP) equivalency factor for that chemical are used to quantify the impact. Sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrogen chloride (HCl), nitric acid (HNO_3), sulphuric acid (H_2SO_4), and ammonia (NH_3) can be given as the examples of contributing substances to acidification (Stranddorf et al., 2005). As the major contributor gas to this impact category is sulphur dioxide, the unit is expressed with kg SO_2 equivalent. The total environmental impacts of analyzed products to acidification was illustrated in Figure 4.3.

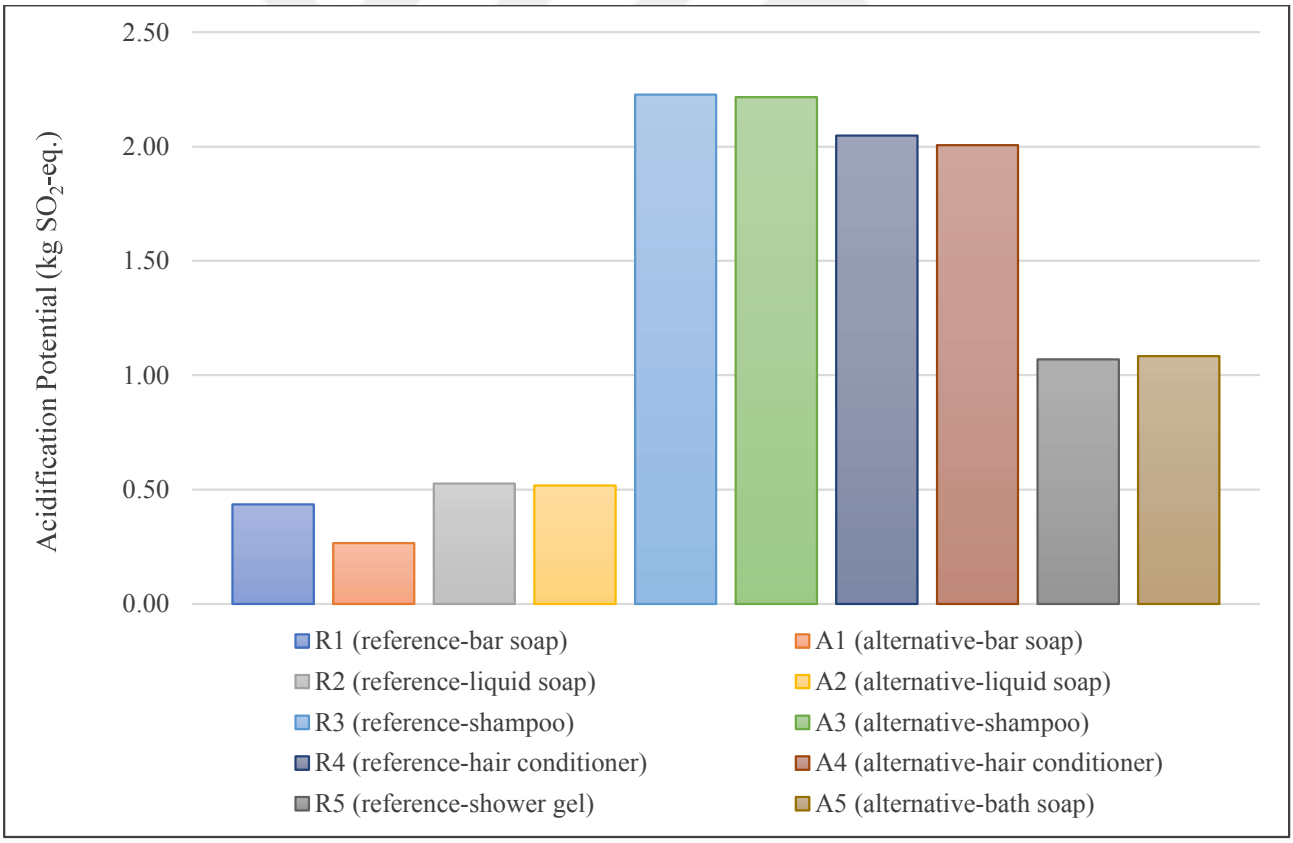

Figure 4.3. Total acidification potential for each product.

4.2.3.1. Bar soap category. According to the impact results of each stage, it was concluded that R1 has the higher acidification potential in material supply, production, and distribution processes. Only packaging of A1 causes more acidification potential because of the higher energy consumption. The

major impact is generated from the wastewater treatment processes which is calculated as 0.265 kg SO_2-eq. for R1 and 0.252 kg SO_2-eq. for A1. If the A1 is chosen over R1, the AP generated throughout its life cycle can be decreased from 0.436 kg SO_2-eq. to 0.271 kg SO_2-eq. (by 37.75 %).

4.2.3.2. Liquid soap category. It was concluded that R2 performed higher acidification potential in most of its life cycle stages except packaging material supply and landfilling of plastic waste after consumption. This is because the number of liquid soap packages required to fulfill the functional unit in the reference case is less than that of the alternative case. Considering the results shown in the figure, the total impact of liquid soap will be decreased by 1.5 % if A2 is chosen.

4.2.3.3. Shampoo category. After the impact of the consumption stage of which corresponds to 94 % (overall) of the entire life cycle of both shampoos, production processes come forward in R3's life cycle stages as the second contributor while it is the packaging material supply for A3. It can be concluded that even if the R3 has produced environmentally friendly and minimized acidification impact, it also has caused more emissions to be released because of transportation distances. Considering the all stages, 4.8 ‰ of AP impact caused from shampoo production and consumption can be reduced by preferring the alternative product.

4.2.3.4. Hair conditioner category. Consumption is seen as the biggest contributor to acidification impact for both hair conditioners, of which equals 94.2 % of R4's total impact and 93.7 % of A4's total impact. It is followed by the processes of wastewater treatment, distribution from the factory and packaging materials supply, respectively. Although the results of R4 and A4 are quite approximate, a 2 % decrease in AP can be obtained by choosing A4 over R4.

4.2.3.5. Body cleaning products category. The highest contribution to this impact belonged to the consumption stage which is 93.5 % for R5 and 86.9 % for A5. The bath soap contributes to total acidification potential more than the shower gel with a ratio of 1.4 %. The reason is that the impact of bar soap production is higher due to the saponification. However, a 5.8 % decrease in AP originating from the consumption, which is the most determinative stage, would be obtained by using the bath soap instead of the shower gel.

4.2.4. Eutrophication Potential (EP)

Eutrophication potential is the fourth impact category evaluated in the study. Eutrophication, nutrient enrichment in other words, is the reason of oxygen depletion in the bottom layers in aquatic

environments which ends up with the increase in the number of plankton, algae, and other aquatic plants and paves the way for decrease in water quality (Stranddorf et al., 2005). Eutrophication equivalency factors have been developed on the basis that nitrogen (N) and phosphorus (P) are the two most important limiting nutrients for eutrophication. The total environmental impacts of analyzed products to eutrophication was demonstrated in Figure 4.4. Unlike the previous impact categories analyzed within the scope of this study, the bar soap category has the biggest impact in EP as can be observed in the figure. The reason for that is the bar soaps involve inorganic chemicals, which are used as surfactants to increase the detergency by softening the water hardness, in the product formulations and to cause enhancing the phosphate concentration in water bodies after consumption.

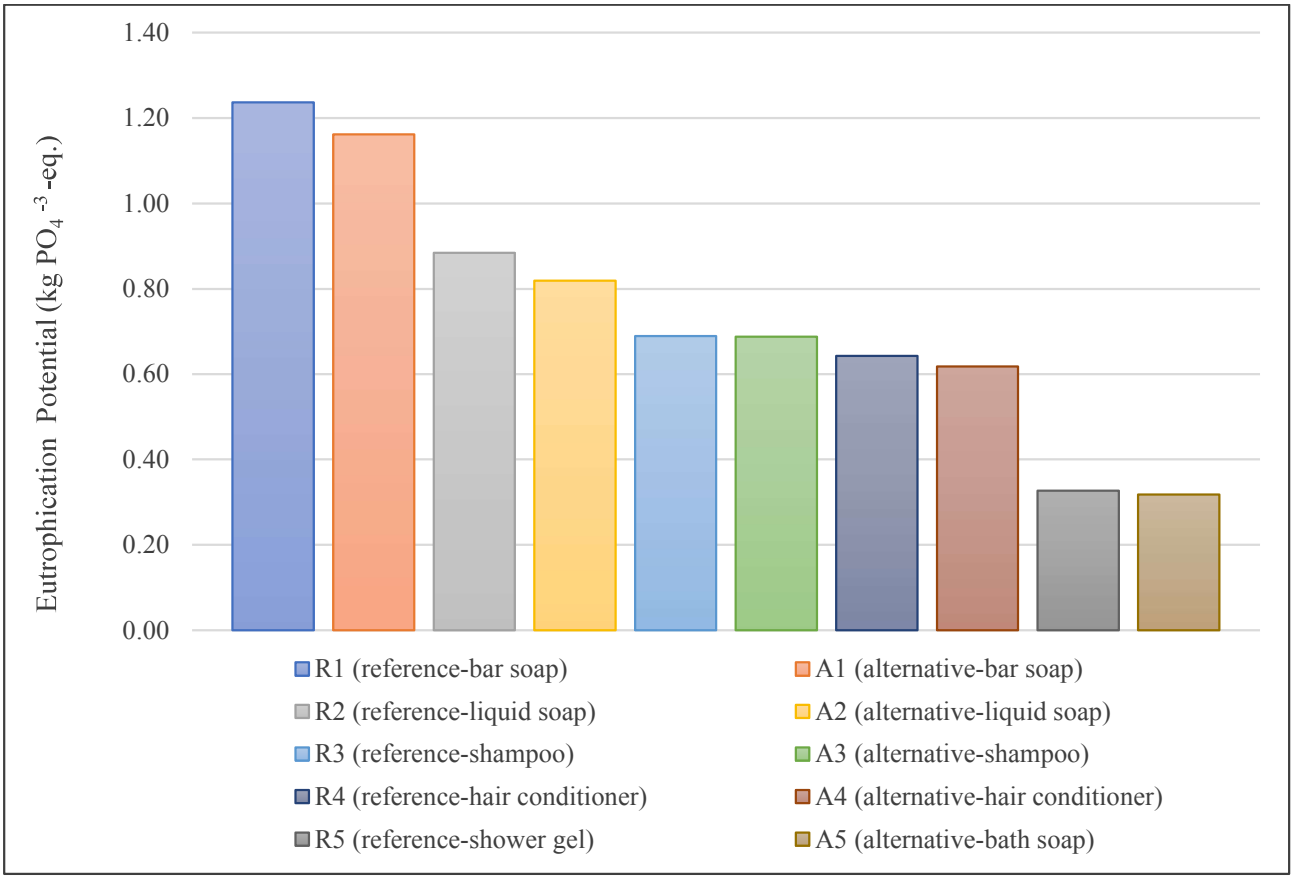

Figure 4.4. Total eutrophication potential for each product.

4.2.4.1. Bar soap category. It is observed from the results that reference bar soap contributes to eutrophication potential more in all life cycle stages, except packaging processes of the product. Considering the impacts of each life cycle stage, the highest impact originated from the municipal wastewater treatment plant. To conclude, the EP of bar soap can be diminished by 6.0 % when the alternative product is preferred.

4.2.4.2. Liquid soap category. According to the results, the reference liquid soap performs higher eutrophication potential in most of the life cycle stages. Similar to other impact categories, packaging processes including packaging raw material supply, packaging production, and transport to the factory of A2 cause slightly higher EP. The reason for this is the longer transportation distance from the packaging supplier to the factory that produces the alternative liquid soap. However, 7.3 % of calculated impact in the eutrophication impact category would be decreased by opting for the A2.

4.2.4.3. Shampoo category. As can be seen from the figure, the total results of compared shampoo products are nearly even because the volume of two shampoos are too close, and this directly affects the impacts of the consumption stage due to the similar consumption patterns. Nevertheless, the EP can be decreased by 83.4 % in raw material supply, 65.4 % in the production unit, and 70.4 % in packaging processes by choosing the alternative shampoo.

4.2.4.4. Hair conditioner category. The municipal wastewater treatment process is the biggest contributor to the EP impact category. It is calculated as 69.1 % of R4's total impact and 69.6 % of A4's total impact. The amount of ammonium, phosphate, and phosphorus emissions originating from the wastewater treatment process are extremely higher. Although the total EP impact results of R4 and A4 are quite approximate, a 3.8 % decrease can be obtained by choosing A4 over R4.

4.2.4.5. Body cleaning products category. The municipal wastewater treatment process is the main source of the environmental impact in the EP category for body cleaning products, too. It corresponds to 69.1 % of the total impact on average for shower gel and bath soap. The shower gel contributes to the total EP more than the bath soap. On the whole, a 2.7 % decrease in EP would be provided by using the bath soap instead of the shower gel.

4.2.5. Freshwater Aquatic Ecotoxicity Potential (FAETP)

The last impact category investigated for the study is freshwater aquatic ecotoxicity potential (FAETP). In the context of an LCA, ecotoxicity refers to a variety of consequences on different species, including acute and chronic toxicity. The fate of the chemical compounds (biodegradability, bioaccumulation, and distribution between compartments) is also taken into account when evaluating the ecotoxicological impacts (Stranddorf et al., 2005). The total environmental impacts of analyzed products to freshwater aquatic ecotoxicity was shown in Figure 4.5. At the first glance, the similarity of the pattern of results in this impact category to the eutrophication results, albeit with different values, drew attention. It is seen that the bar soap category has the greatest impact on FAETP.

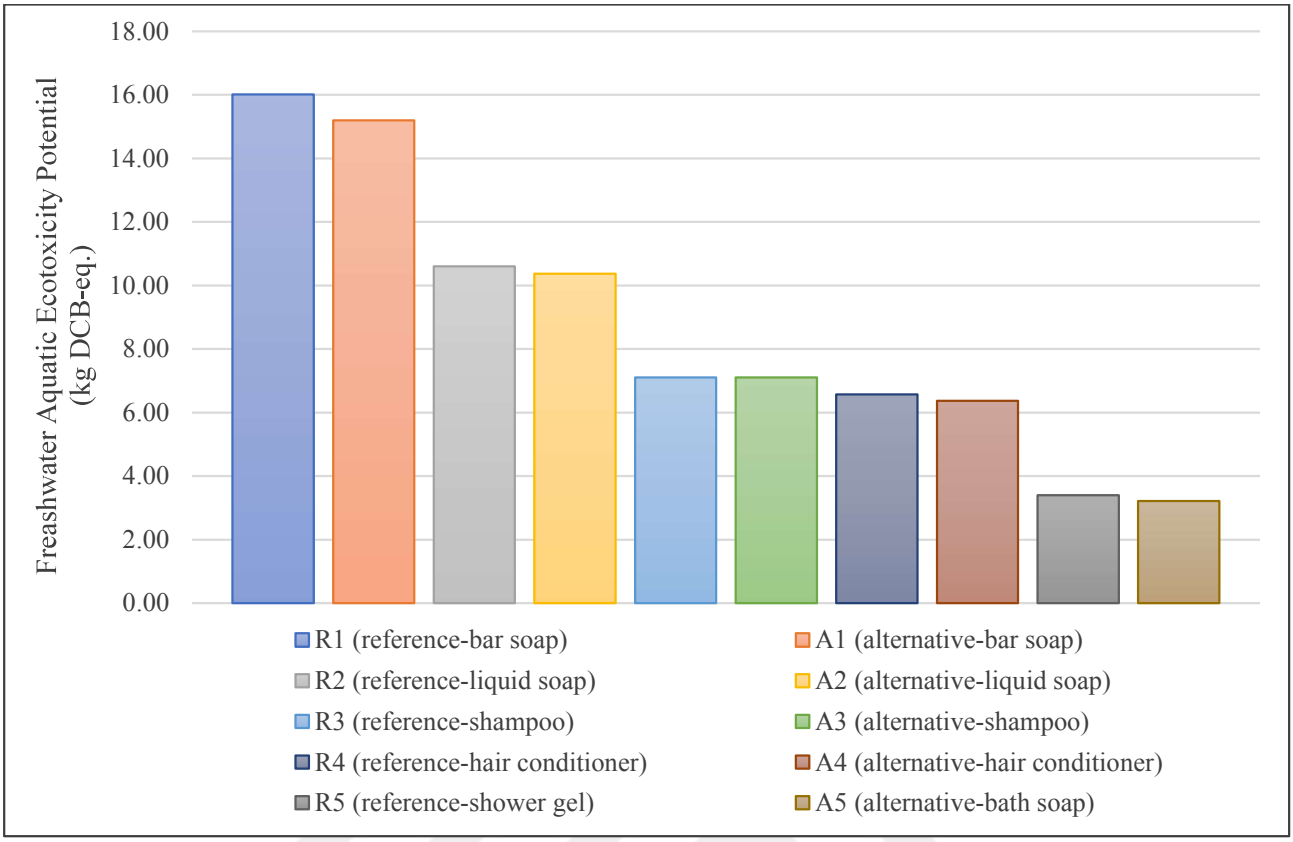

Figure 4.5. Total freshwater aquatic ecotoxicity potential for each product.

4.2.5.1. Bar soap category. The FAETP of both soaps has the biggest impact among other products analyzed in this study. Almost all of this impact originated from the municipal wastewater treatment process in the post-consumer stages. If A1 is changed over R1, the FAETP can be decreased by 95.9 % in raw material supply; 88.6 % in the production unit of bar soap; and 73.8 % in the supply processes of packaging materials. On the whole, 5.1 % of the FAETP can be avoided by choosing the alternative bar soap.

4.2.5.2. Liquid soap category. Within the total FAETP impact, the municipal wastewater treatment process is the main contributor for both types of liquid soaps. It is followed by the recycling process of plastic packages, and production of primary packaging. Since the consumption frequency of liquid soap is considerably high, plastic pollution after consumption has become a significant problem that needs to be managed properly. The total impact of FAETP can be decreased 2.2 % on the whole by preferring the alternative liquid soap.

4.2.5.3. Shampoo category. The total results of analyzed shampoo products in FAETP are quite similar since the impact of consumption results are literally even because of the approximate amount of shampoo in two packages. Notwithstanding, the FAETP can still be reduced by 83.4 % in raw

material supply, 71.9 % in the production unit, and 67.6 % in packaging processes by choosing the alternative shampoo even if the total impact can only be diminished by 0.4 ‰.

4.2.5.4. Hair conditioner category. The municipal wastewater treatment stage has the biggest contribution to ecotoxicity impact, which is calculated as 88.9 % of the total impact on average for both products. It is followed by the consumption and packaging supply processes. Up to 3 % decrease from the total FAETP impact results can be obtained by choosing A4 over R4.

4.2.5.5. Body cleaning products category. The main source of the environmental impact in the FAETP category for body cleaning products is the municipal wastewater treatment process with an average ratio of 88.9 % for both products. The shower gel contributes to total ecotoxicity potential more than the bath soap with a ratio of 5.4 %. This amount could be downsized by shifting body cleanser product from shower gel to the selected bath soap.

4.3. Normalization and Weighting

Normalization calculates the magnitude of category indicator results by dividing them according to the respective reference value which is generally chosen as the impact result (Thrane and Schmidt, 2007). Normalization in life cycle assessment enables the comparison several environmental impact categories because these categories are assigned to a common reference without a unit. CML 2001 – January 2016, World, year 2000 method was used for the normalization step in this study.

Weighting combines all of the weighted impact scores for the analyzed system into a single overall environmental impact score (Thrane and Schmidt, 2007). That provides a base to compare LCA results quantitatively with other circumstances in the decision making process. Accordingly, CML 2001 – January 2016 option of thinkstep LCIA Survey 2012, Global method for weighting was utilized in the study so as to reduce uncertainty by limiting quantitative modelling in the cause – effect chain.

To evaluate LCIA results in a common reference with unitless and weighted impact scores, a worst case scenario was constituted in regards to a particular product group choosing one product from each category in regards to a single function (one of the soaps, shampoos, hair conditioners, and body cleaning products) of which have the highest environmental impacts in analyzed impact categories. With a similar approach, a best-case scenario, which comprises a particular product group having the lowest environmental impacts and was constituted.

4.3.1. Normalization and Weighting Results for the Worst Case

The normalization and weighting results belonging to the products having relatively higher adverse impacts on the environment were shown in Figure 4.6 and Figure 4.7, respectively. In the worst case scenario, reference liquid soap, which has the highest environmental impact among the hand washing products, was selected as the most disadvantageous hand washing product. In the product group of shower preparations, reference shampoo and hair conditioner were selected as hair washing products for the worst scenario while the shower gel was selected as body cleaning product.

According to the normalization results (Figure 4.6), it was seen that the GWP impact category is the major contributor in the life cycle of all chosen products for the worst case scenario. In the life cycle of the hand washing product, GWP is followed by the EP and FAETP. For the shower preparations, AP is observed as the second biggest contributor, followed by the EP.

On the other hand, the figure of the weighting results (Figure 4.7) which express a quantitative measure of how severe one impact category in respect to the others, has shown a similar pattern with the graph of the normalization results, albeit with various magnitudes. GWP has the greatest impact among the analyzed impact categories. In the life cycle of liquid soap, GWP is followed by EP and FAETP impact categories, whereas in shampoo, hair conditioner, and shower gel, it is followed by AP and EP impact categories.

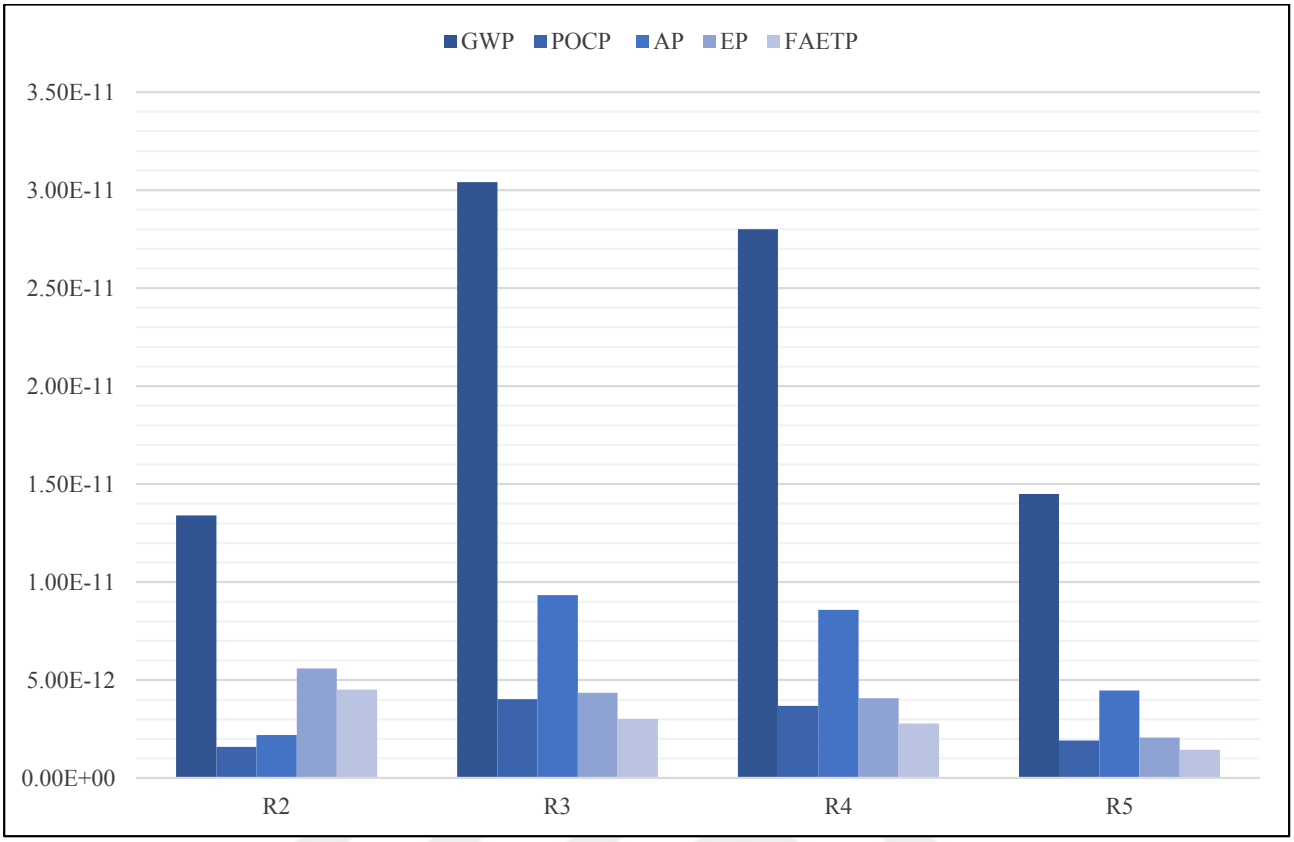

Figure 4.6. Normalization results of the chosen products for the worst case.

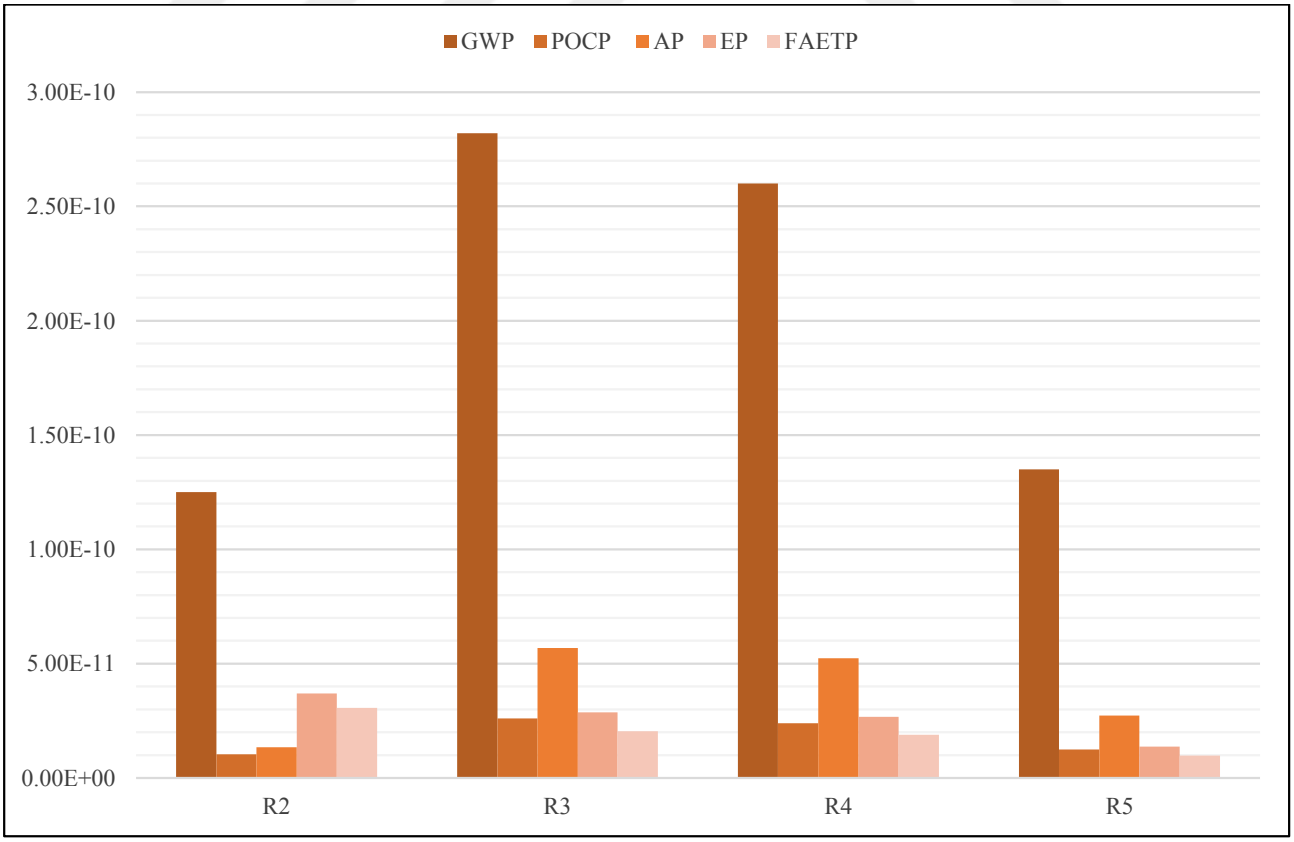

Figure 4.7. Weighting results of the chosen products for the worst case.

4.3.1. Normalization and Weighting Results for the Best Case

The normalization and weighting results for the products, which were grouped for the best case scenario, were demonstrated in Figure 4.8 and Figure 4.9, respectively. The alternative bar soap was selected as ideal among the hand washing products because it has the lowest environmental impacts among those products. In the product group of shower preparations, alternative shampoo and hair conditioner were selected as hair washing products for the best case scenario while the bath soap was selected as body cleaning product.

According to the normalization results of the ideal case, GWP impact category is seen as the major contributor in the life cycles of shower preparations (shampoo, hair conditioner, and bath soap), whereas EP is the biggest contributor for the bar soap. In the life cycle of the A1 of which formulation is based on pomace oil derivatives, EP is followed by FAETP and GWP impact categories. For the shower preparations, GWP is followed by AP and EP as the second and third highest impact categories.

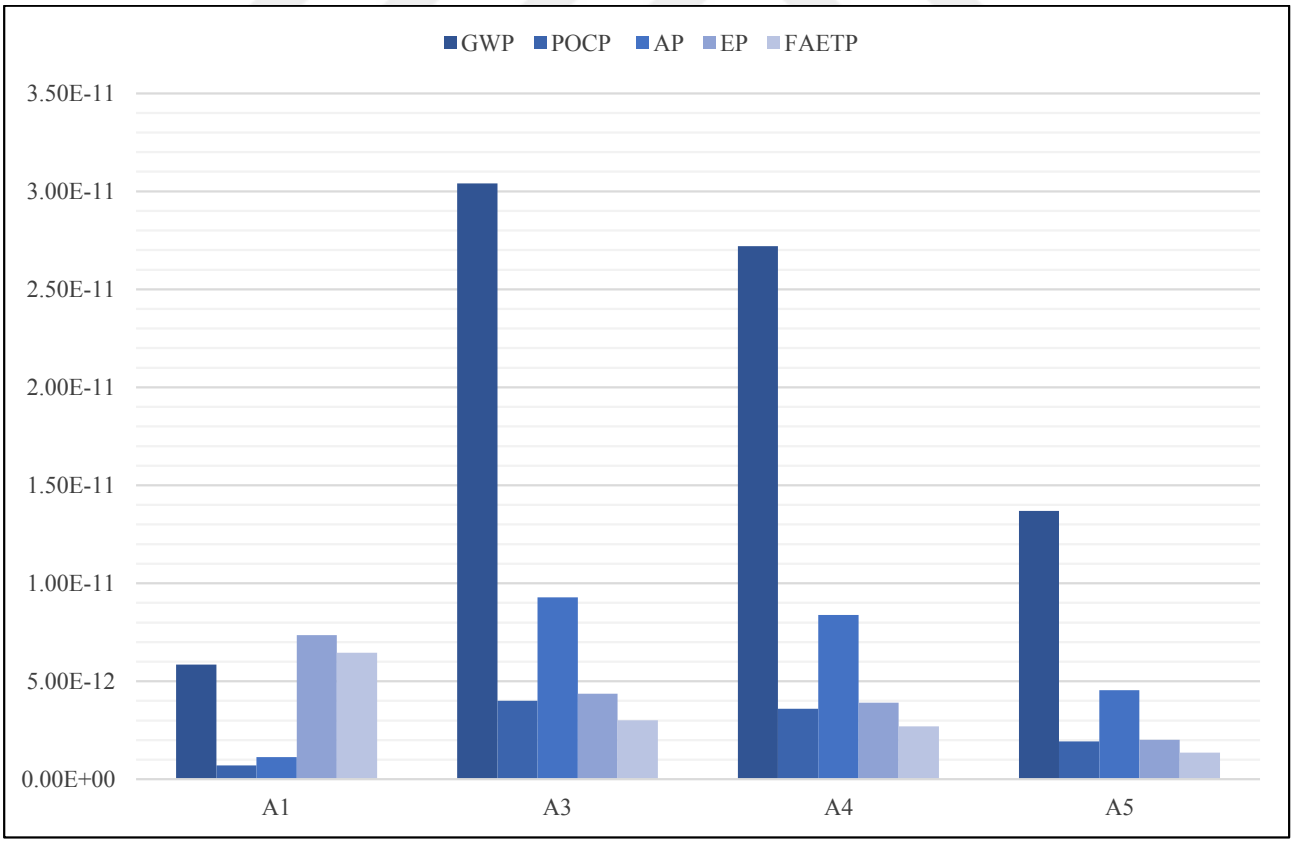

Figure 4.8. Normalization results of the chosen products for the best case.

When the figure below was considered, it was seen that hair products' weighting results are in agreement with their normalization results. On the other hand, the pattern between normalization and weighting results of soap products (A1 for hand soap, A5 for bath soap) is slightly different. To be more precise, GWP is followed by AP and EP impact categories in the weighting results of bath soap as body cleaning product, whereas, EP is followed by FAETP and GWP impact categories in the weighting results of bar soap as hand washing product.

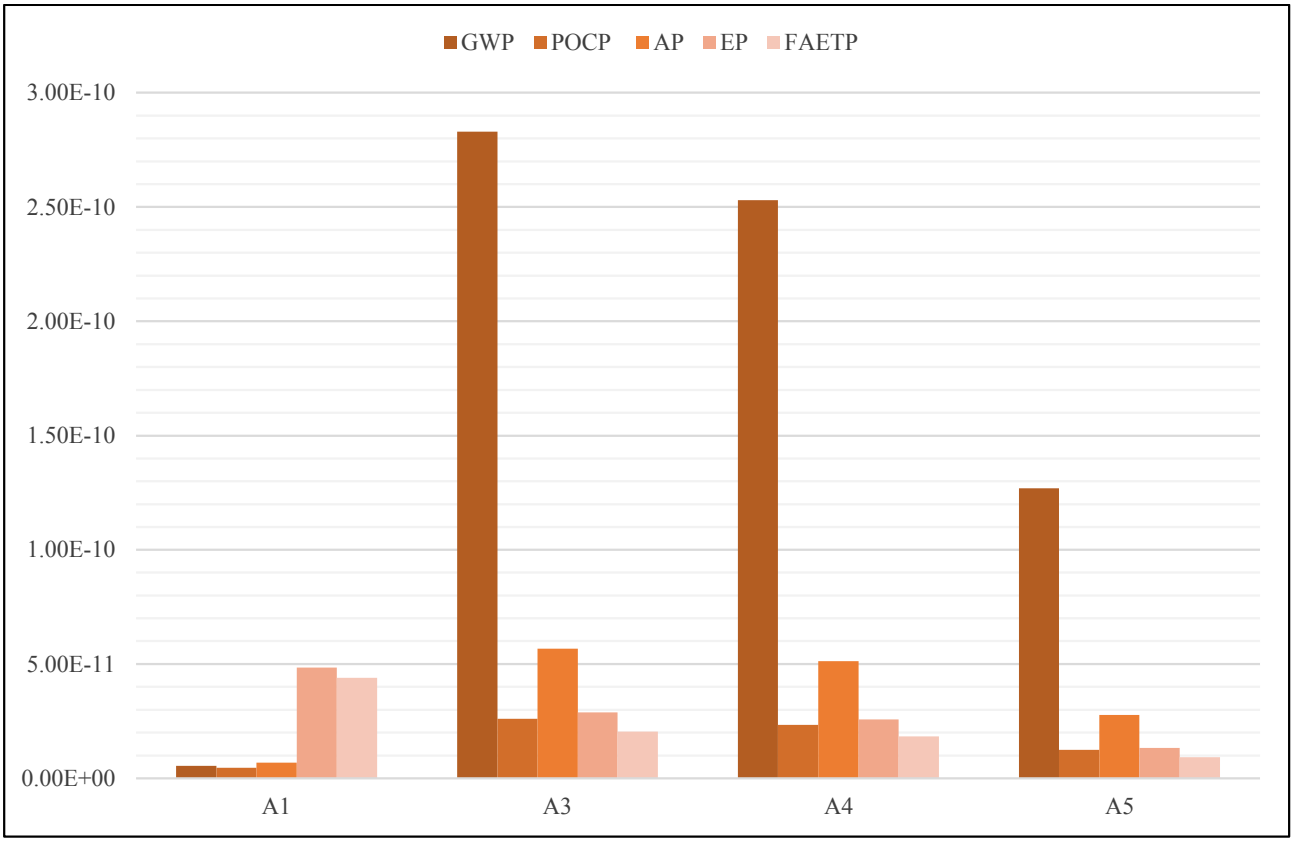

Figure 4.9. Weighting results of the chosen products for the best case.

4.4. Discussion

Selected PCCPs have been evaluated regarding the whole life cycle and its environmental impacts on analyzed impact categories within the context of ecolabelling criteria related to resource conservation, human health and aquatic environments. Comparative results of each product group have provided advantages to detect environmental hotspots in the product chain. In this direction, the evaluated results have been interpreted to highlight significant points.

In the first product group, bar soaps were analyzed in terms of energy usage and packaging type. The major differences in the impact categories of compared products result from the transport

emissions released during the raw material supply, and the energy amount as well as energy type consumed in production and packaging units. When the distinction between results originated from truck transportation and ocean-going ship transportation for these products was observed, it was seen that the impact of transport-related emissions in global warming potential explicitly depends on the distance. To reduce that, local market-based policies that limit the delivery mileage as well as charging companies to a carbon tax with regulations or directives could be adopted with a broader framework as in carbon offsetting agreements. In addition to these major steps, some minor applications, which also need to be supported by the policy and regulations of the governments, could be put into practice such as boosting the trade of local materials to be manufactured on a local scale, insisting on using more environmentalist transportation methods and fuels if the materials cannot be provided from the local market in any way. Considering the other varieties due to packaging type, not only the impact of the production process of packaging material but also the impacts of the waste management processes of the compared packaging materials can be diminished. When examining the former, if the extraction stage of packaging materials could be included in the system boundaries, the impact originated from the raw material extraction of alternative soap packages would be even less than that of the reference soap because of the lower emission levels stemming from the obtainment of cardboard packaging compared to the OPP packaging, which is a resulted supported by the studies conducted in this issue. When examining the latter, it can be deduced that the reason for the relatively higher value obtained in recycling and incineration processes compared to landfill options is the energy consumption to operate either recycling of the plastic or the energy recovery of the cardboard. Even though landfilling is evaluated as a better option for the management of packaging waste according to the numerical results, recycle and recovery applications are more environmentally friendly options in the long run. These applications not only help to improve industrial symbiosis, but also can diminish the degradation of land which are meant to be used as dumping sites.

In the second product group, two liquid soaps, which were produced by using different amounts of raw materials, volume of packaging, and energy, were inspected. Even if the R2's volume is nearly twofold of the A2 which caused two times more consumption if the latter is chosen, the environmental impact of the A2 was lower. On top of that, the impact of A2 can be decreased more if the refill application is applied instead of wasting the plastic package every time. For instance, considering that the refill application is put into practice in our country to refill each cosmetic package three times at least, a great amount of decrease in GWP impact by 75.06 % and by 74.97 % from packaging supply processes and waste management of plastic packages, respectively, can be obtained. For hand washing products that cause a huge pollution load in water streams, the biggest impact originated from the municipal wastewater treatment process. In this sense, ecolabel criterion of either excluded

or prohibited substances and mixtures is a significant step to take the action of eliminating the use of chemical substances that are not readily biodegradable in the formulations of PCCPs and to prefer to use more organic and natural ingredients, which should be capable of fulfilling the function of substituted ingredients and also biodegradable, even if the substitution ends up with a higher cost for the product.

For hair cleaning products, energy consumption to heat the water during the use phase, which directly contributed to the impacts of the consumption stage, has become dominant in the impact results of the LCA. In these two product categories, the consumption stage had the highest impact, which is followed by the municipal wastewater treatment stage in all the impact categories, due to excessive amounts of water consumption. In the impact results of compared shampoo products in similar volumes, the number of raw materials which are transported to the factory causes higher impact in R3's GWP results, while the amount of PO_4^{3-} and NH_4^+ emissions to freshwater from the production unit gives rise to A3's FAETP results. Similarly, in R4's GWP results, the number of raw materials carried to the production has a slightly higher impact, whereas in A4's AP results, the amount of NO_x and NH_3 emissions released to air from the production unit has a greater impact. Numerical results of the LCIA revealed that any improving operations, such as substitution from fossil fuel to renewable energy sources, applied inside of the factory can make a more notable change in the results compared to the outside of the factory such as transportation.

Other than the hair cleaning products, either shower gel or bath soap as body cleaning products has also caused a huge impact regarding hot water consumption. Within the scope of this comparison, the importance of product formulation, consumption pattern and packaging type on the environmental impacts was observed. When evaluating the total impact, it was seen that bath soap has less impact than shower gel in GWP, EP, and FAETP impact categories, whereas it has slightly higher impacts in POCP and AP impact categories. As higher energy was consumed in the production of bath soap, the production stage belonging to bath soap caused more impact than shower gel in all analyzed categories. On the other hand, impact of the consumption and municipal wastewater treatment processes in all impact categories resulted in a higher value for shower gel. It can be concluded that if some ingredients such as butylphenyl methylpropional (lilial), which was considered having toxicity impact, were excluded, the acidification, eutrophication, and freshwater toxicity impact of bath soap would decrease more to some extent.

From the perspective of product formulations, certain chemicals, which are evaluated under the excluded chemicals group stated in ecolabel standards, and included in the formulation of PCCPs,

should be elaborately examined by taking into account the criteria of the standard, which is intended to be applied. For instance, considering the example given in the previous paragraph, EU Ecolabel Standard will most likely evaluate lilial under the excluded substances as of 1st March 2022 and make it obligatory to eject this chemical for manufacturers of the companies trying to get EU Ecolabel. On top of that, the requirement for the substitution of this type of chemical will encourage the other ecolabel standards to update the respective criteria in keeping with the updated CLP regulation and the most famous ecolabel standard among the European Countries. It will pave the way for growing demand for the product with reduced environmental and health concerns associated with such chemical components. In addition to the benefits obtained from an environmental point of view, participating in the ecolabelling scheme, offering eco-friendly products to consumers, and showing how the products that conserve the environment are manufactured will influence both individuals and the competitive companies/manufacturers in the market. Thus, it will enable rival companies to balance the prices of ecolabelled products abiding by fair trade in comparison with the conventional products to a certain extent and correspondingly persuade the consumers to choose the better option for the environment by increasing their willingness to pay more. This might even lead to a change in consumption patterns since the consumers become willing to pay a higher price, they might start to consume fewer amounts of products per application.

It is also expected that international companies operating in Turkey with a vast export capacity to Europe will be affected to improve their product content in accordance with the update in the regulations related to production and consumption conditions of PCCPs as mentioned before. Not only international companies but also national manufacturers will be expected to participate in such improvements for both offering products with reduced impacts upon the environment and promoting the sustainable development with the image of their market products. With the widespread application of the National Environmental Label, it is expected that each relevant body will be eager to take part in this scheme to be able to compete to get ahead of the game in the sector.

5. CONCLUSION

The goal of this research was to determine environmental hotspots throughout entire life cycle stages of selected personal care and cosmetic products (PCCPs) through a comparative aspect that evaluates and compares two products in each product category providing the same function. It was aimed to assess and compare their environmental impacts, to specify particular stages that can be ameliorated by preferences of suppliers, manufacturers and consumers in accordance with the guidance of ecolabelling applications in the industry. A group of selected PCCPs manufactured in Turkey were analyzed comparatively by considering the real, reliable, current, and convertible sectoral data of these products. For the Life Cycle Impact Assessment (LCIA) of the study, CML2001 methodology was applied for five impact categories (GWP, POCP, AP, EP, and FAETP). Normalization and weighting (on the global basis) were also utilized in the study to eliminate uncertainty in the cause – effect chain by limiting quantitative modeling, although they are optional steps of the LCA methodology.

According to the LCIA results of hand washing products, the municipal wastewater treatment stage has the greatest impact. Considering the packaging material, the total impact of OPP package production for R1 in analyzed categories can be decreased by 94.8 % if the OPP is altered with the cardboard. For the packaging waste management of bar soap category, landfilling was indicated as a superior alternative; however, recovery applications which help to promote industrial symbiosis and to reduce the deterioration of land, are more environmentally friendly in the long term. In the comparison of liquid soaps, it was seen that GHG emissions increase in connection with the amount of raw material transportation. In the waste management of liquid soap category, it was indicated that a significant reduction in GWP impact (75.01 % on average with three times refill, at least) was obtained from packaging supply operations and waste management of plastic packages if the refill obligation would be implemented in Turkey. The LCIA results of shower preparations showed that the most adverse impact has been caused from the consumption stage of these products. In the evaluation of hair cleaning products, the main difference was observed in the production method and the location of the factories. For example, the GWP impacts of emissions released from the production units and emissions released from the transportation processes in the life cycle of compared shampoo products would be decreased by 39.29 % and 11.47 %, respectively, if the A3 was chosen. In the comparison of body cleaning products, it was observed that a 55.7 % decrease from the impacts of the production, transportation, and waste management stages of PET material can be obtained when

bath soap is chosen over shower gel because of the lower impacts generated by OPP material in those life cycle stages.

The normalization and weighting results of chosen product groups for the worst-case and best-case scenarios were evaluated in the scope of this study. Since the characterization results of alternative products was lower, the best-case scenario was considered as a more ideal option. According to the normalization results of this scenario, GWP is seen as the most driven impact category in almost all the chosen products except the alternative bar soap of which the highest impact category is seen as the EP. Some inorganic chemicals, which are utilized in bar soap compositions as surfactants, cause the entrance of phosphate compounds in high concentrations to aquatic environments. On the other hand, according to the weighting results, GWP (68.12 % for A3, 68.10 % for A4, and 66.92 5 for A5) is followed by AP (13.70 % for A3, 13.78 % for A4, and 14.60 % for A5) and EP (6.96 % for A3, 6.89 % for A4, and 7.01 % for A5) impacts in chosen shower products; however, GWP (34.41 %) is followed by EP (30.62 %) and then FAETP (27.72 %) in chosen hand washing product.

The evaluation process of the product chain was structured by the LCA methodology and harmonized with the criteria of ecolabel applications, especially from the perspective of resource conservation, human health, and ecosystem health. These two approaches, which were standardized by ISO 14040 and ISO 14020, respectively, were preferred not only for detecting the hotspots along the product chain and exploring the potential threats to decrease the environmental impacts but also enabling relevant stakeholders to interpret the conditions successfully and implement the required actions. When the LCA results are evaluated in conjunction with ecolabelling schemes, they facilitate the credibility of the entire value chain as well as the certifier, and the applicability in the personal care and cosmetic products sector.

Regarding the obtained results, some fundamental recommendations can be given to manufacturers, policymakers, and the relevant stakeholders partaking in the product chain to improve their operations day by day and fulfill the significant targets like decarbonization for 2050 as implied in both SDG13 and Green Deal. Taking waste and emission generation in each life cycle stage into account, transportation impact on GWP can be notably diminished with the help of legislative regulations and monetary policy instruments such as incentives, or taxes that lead manufacturers to operate their supply processes with local suppliers. In addition to that, substitution of conventional energy sources for renewable energy sources will lessen the impact of these products' manufacturing, filling, transportation and even consumption stages. It was concluded that the effects of acidification,

eutrophication, and freshwater toxicity of analyzed products would be reduced to some extent if certain chemicals having toxic effects used in the formulation, such as butylphenyl methylpropional, were excluded. Altering synthetic chemicals with organic and natural ingredients would also help to reduce the eutrophication and freshwater ecotoxicity potential originating by the use of non-biodegradable components. Taking everything into account, it can be concluded that environmental label applications are fundamental in terms of strongly addressing the issues of lowering air and water pollution originating from the consumption stage, which is, on the one hand, directly related to individual's conviction to do the right thing for the sake of nature, and on the other hand, is unintentionally left out of the implied points within the life cycle perspective most of the time.

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