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MASTER THESIS IN ENVIRONMENTAL ENGINEERING

SUSTAINABILITY OF THE COSMETIC INDUSTRY: EVALUATING THE ENVIRONMENTAL IMPACTS OF A REFORMULATED BODY BUTTER PRODUCT

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Abstract

This thesis investigated the environmental impact of reformulated body butter by analyzing sustainability in the cosmetics industry. The study focuses on replacing synthetic ingredients with environmentally friendly alternatives and includes a detailed assessment of the industry's environmental footprint. The research measures the emissions of creams in different formulations using a life cycle analysis (LCA) approach using a cradle-to-gate approach. The analysis reveals significant differences in the environmental performance of the reformulated products compared to the original but does not always show a lower carbon footprint of natural ingredients as thought. The study also explores the role of certification standards in guiding consumers toward more sustainable choices. It emphasizes the importance of transparency and safety in green cosmetic products. This research, which provides detailed information on the sustainability of reformulated cosmetics, also aims to inform stakeholders in the sector and adopt practices that reduce environmental impacts. The findings contribute to the growing knowledge of sustainable cosmetics, providing valuable suggestions for future product development.

Keywords: life cycle assessment, environmental impact, sustainable cosmetics, methodology, carbon footprint analysis

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List of Acronyms

PCCPs	Personal Care and Cosmetic Products
LCA	Life Cycle Assessment
EC	European Commission
GMOs	Genetically Modified Organisms
MPs	Microplastics
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PMMA	Polymethyl methacrylate
μBs	Microbeads
CO2	Carbon dioxide
CO2eq	Carbon dioxide equivalent
ISO	International Organization for Standardization
NOI	Natural Origin Index

1. Introduction

Personal care and cosmetic products (PCCPs) have been used for years that their existence has become a necessary part of human life in modern times for sanitation and improvement of beauty. As global trends and consumption habits change over time, demand for cosmetics and personal care products has improved the number of earnings in both domestic and overseas markets. The expansion of demand for these products has led to the growth of the sector, especially in the last decade.

With the effects of global warming, the sustainability approach in cosmetic products first gained momentum. This approach emerged in the cosmetic industry due to various factors, including a scarcity of storage areas, the fact that cosmetic products become harmful after a certain amount of time on their shelf, and the discussion of the safety of chemical ingredients in cosmetic products in articles published on social media (Liobikiene_ and Bernatoniene_, 2017).

Sustainability refers to addressing social, environmental, and economic considerations along a product's entire life cycle (Table 1.1) to achieve an overall beneficial impact. In the context of natural cosmetics, sustainability encompasses not only the sourcing of components and manufacturing processes, but also the materials used in production and post-production. But not all natural cosmetics are sustainable. To be considered natural, a product must be made from raw elements found in nature, but this is not enough for a cosmetic to be sustainable (European Commission, 2015).

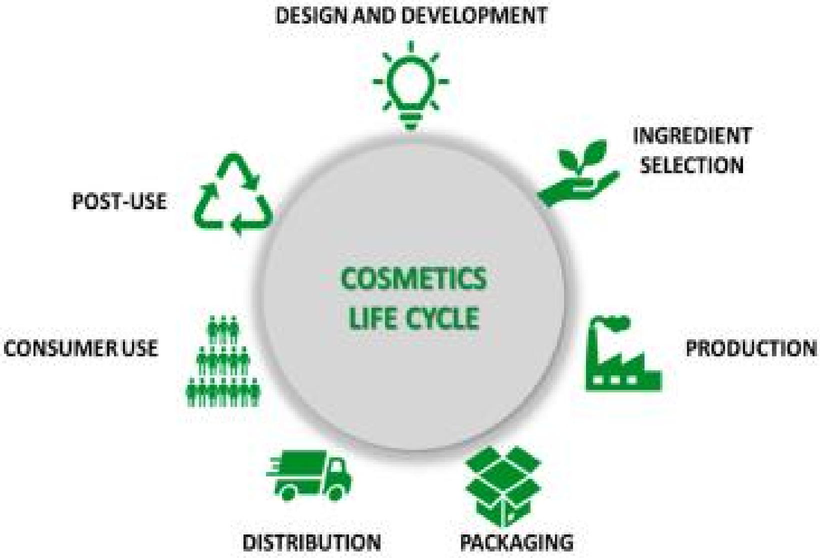


Table 1.1 Main phases of the life cycle of a cosmetic product (Martins, A. M., 2023).

The introduction of sustainable practices in the cosmetic industry is often guided by certification standards, which serve as benchmarks for environmental performance. These standards are crucial in ensuring that products marketed as "green" or "eco-friendly" genuinely contribute to environmental sustainability.

There is not a single European standard for defining natural and organic cosmetics, but there are guidelines like ISO 16128, which help to determine how much of a product's ingredients are natural or organic. Some private certification organizations in Europe, like BDIH (Germany), Natrue (Belgium), and Ecocert Greenlife (France), have set their own standards for natural and organic cosmetics, which are accepted in different countries (Beerling and Sahota, 2014).

Furthermore, the environmental effects of cosmetics are complex and wide-ranging, encompassing not just the components utilized but also the manufacturing procedures. A strong framework for assessing these effects is offered by the Life Cycle Assessment (LCA) technique, which enables a thorough examination of the carbon emissions connected to various product formulations. This study analyzes the carbon footprint of the reformulated body butter using a cradle-to-gate methodology, offering a comparison between the reformulated and original products.

The structure of this thesis is as follows: After this introduction, the literature review will provide an overview of the current state of sustainability in the cosmetic industry, highlighting key challenges and opportunities. The methodology section will outline the research design, including the goal and scope of the study, the selection of ingredients, and the application of the LCA methodology. The interpretation will present the findings of the carbon footprint analysis, followed by these results in the context of the broader sustainability discourse. Finally, the conclusion will summarize the key insights gained from this research and offer recommendations for industry stakeholders and policymakers.

2. Literature Review

2.1 Sustainability in the Cosmetic Industry

Although the concept of cosmetics and sustainability may seem very separate at first glance, green cosmetics are products that are produced with a sustainability approach due to issues such as avoiding the use of synthetic raw materials, compliance with green chemistry principles, carbon footprint, and waste management (Šniepienė G., Jankauskienė, R., 2021). The sustainability approach in cosmetic products first gained importance with the effect of global warming. Factors such as the multiplicity of storage areas, cosmetic products becoming waste by completing their shelf life after a certain period, the discussion of the safety of chemical ingredients used in cosmetic products in the articles published on social media are the reasons for the emergence of this approach in the cosmetic industry (Liobikiene_ and Bernatoniene_, 2017).

The green approach to cosmetics generally aims for sustainability using biodegradable packaging, a reduction in the use of synthetic raw materials and plastic packaging, the development of reusable products or packaging, the creation of products with multiple benefits, the use of recyclable materials, and the production of less hazard environmental chemicals.

Laws and regulations are also acting as deterrents and proponents of sustainability. With Cosmetics Europe's recommendation, some European Union nations have already prohibited the use of microplastics in rinse-off cosmetics (Xanthos and Walker, 2017). Between 2012 and 2017, the usage of plastic microbeads in cosmetic and personal care products fell by 97,6%, equivalent to 4250 tons of plastic being replaced and eliminated (Cosmetics Europe - The Personal Care Association, 2018a).

In the cosmetic industry, adopting sustainable methods is a need if you want to be successful and even financially viable in the long run. Working to enhance sustainability within the industry does not always require large investments, and it can have numerous positive effects on the business, including cost savings, increased sales, and enhanced brand recognition (Cosmetics Europe - The Personal Care Association, 2012a).

2.2 Ingredients for sustainable cosmetics

Each cosmetic's impact on the skin is determined by its composition and choice of cosmetic ingredients. Because each ingredient's safety and function, formulation stability, and consumer desire for particular features must be taken into consideration, choosing the ideal ingredients can be difficult.

According to the regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009, a cosmetic product can be defined as: "Any substance or mixture intended to be placed in contact with the external parts of the human body (epidermis, hair system, nails, lips and external genital organs) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly to cleaning them, perfuming them, changing their appearance, protecting them, keeping them in good condition or correcting body odours"

Currently, there is a critical need to replace "regular" ingredients with ingredients that comply to sustainability requirements while also considering the effects of such a replacement on formulation (i.e. performance, aesthetical and sensorial properties and marketability). When creating a sustainable cosmetic product, it's crucial to comprehend the various kinds of ingredients (European Commission, 2015)

In order to achieve an overall beneficial impact, sustainability refers to taking into account social, environmental, and economic factors along the entire production chain of a product. Sustainability in the context of natural cosmetics includes both the materials used in production as well as post-production, in addition to the method ingredients are sourced and how the product is made. However, natural cosmetics are not always sustainable because in order for cosmetics to be called natural, they must be products developed from raw materials existing in nature, but this is not enough to be sustainable. For example; carrageenan is a natural and ready biodegredable ingredient that used for cosmetic and food industry, however a large amount of water is consumed during the extraction of carrageen and therefore the environmental impact is very high.

In organic cosmetics, at least 95% of the formulation ingredients are organic raw materials, or the raw materials have been derived from organic sources using extraction techniques recognized by the certifications. So an organic ingredient is also natural. But the natural ingredient is not organic (Šniepienė G., Jankauskienė, R., 2021). Among the buzzwords that are popular are synthetic, natural, natural derived, nature identical, organic, and green, it's essential to identify some ingredients, as shown in Table 2.1, in order to comprehend how a cosmetic product might become more sustainable.

Table 2.1 Ingredient classification

Ingredient Classification	**Definition**
Synthetic	A chemically produced substance or material: a substance or material produced by chemical processes and not occurring naturally (Beerling, 2014).
Natural	A natural cosmetic ingredient is any material that has been harvested, mined or collected, and which subsequently may have been processed, without chemical reaction, to yield a chemical or chemicals that are identifiable in the original source material. For the purpose of this statement, ‘without chemical reaction’ would permit physical processes such as washing, decolorizing, distilling, grinding/milling, separation and/or concentration of the material (Beerling, 2014).
Naturally Derived	A naturally derived ingredient is usually accepted to mean one where a natural raw material is used as the starting point of a chemical process to produce a new chemical or chemicals that in themselves may not be available in nature or in the starting material (Beerling, 2014).

Nature Identical	This is defined as a substance that has been produced synthetically, not usually from a natural starting material, in order to produce a material that is identical to that naturally occurring in nature. Examples of common synthetically produced nature identical ingredients are: Vitamin E (tocopherol), Farnesol, L-menthol, Ceramides and Parabens can also be considered to be nature identical since very similar materials are found in nature (Beerling, 2014).
Organic	A natural ingredient that result from organic agricultural methods (e.g. agriculture which avoids the use of synthetic fertilizers, pesticides, plant growth regulators and livestock feed additives; practices crop rotation, integrated pest management, crop residues, animal manures and mechanical cultivation to maintain soil productivity and tilth to supply plant nutrients and to control weeds, insects and other pests; prohibits the use of Genetically Modified Organisms (GMOs), radiation and similar substances) (Beerling, 2014).

2.2.1 Microplastics in Cosmetics

Plastic pollution in the environment, especially that caused by microplastics (MPs), has drawn attention from the scientific community and the general population (Anderson et al., 2016). MPs are primarily linked to their presence in personal care and cosmetic products (PCCPs), particularly primary microplastics that originate directly rather than because of a bigger plastic breakdown. Although they make up a small percentage of all microplastic particles (MPs) in the environment, these components, also known as microbeads (µBs), have a considerable influence nonetheless (Isobe, 2016; Cheung and Fok, 2017; Syberg et al., 2018).

Microbeads in PCCPs function as abrasive agents on surfaces like skin and teeth. The main reasons for their extensive use instead of natural materials such fruit stones, crushed shells, and inorganic powders are their long-lasting nature, affordability, and consistent performance (Fendall and Sewell, 2009; Chang, 2018). But the main problem with µBs is that they are so small—usually less than 0.8 mm, and frequently less than 0.1 mm (Kalcikovà et al., 2017a). Because of their tiny size, many organisms—many of which are found at the base of trophic chains—can consume them (Isobe, 2016; Cheung and Fok, 2017). In addition, like other MPs, microbeads have the ability to lodge in the stomachs of living things, causing harm upon consumption. From there, they can move up the food chain by passing through trophic levels (EFSA, 2016).

About 4% of plastics are made up of chemical additives, which include things like bisphenol A and phthalates. Plastics can also absorb harmful compounds from the environment (Mato et al., 2001; Ogata et al., 2009; Fossi et al., 2014; Scopetani et al., 2018). They can move these dangerous substances throughout living things, including humans, thanks to this trait (Mato et al., 2001). Thus, contamination by MPs presents an extra risk of encountering substances that are highly toxic and may have an impact on the endocrine system (La Rocca et al., 2014; Giari et al., 2015; La Rocca et al., 2015; Predieri et al 2015).

Microbeads found in hair shampoo, µBs obtained from cosmetic products, and an example of the µB content listed in a cosmetic product are also shown in the Figure 2.1 below.

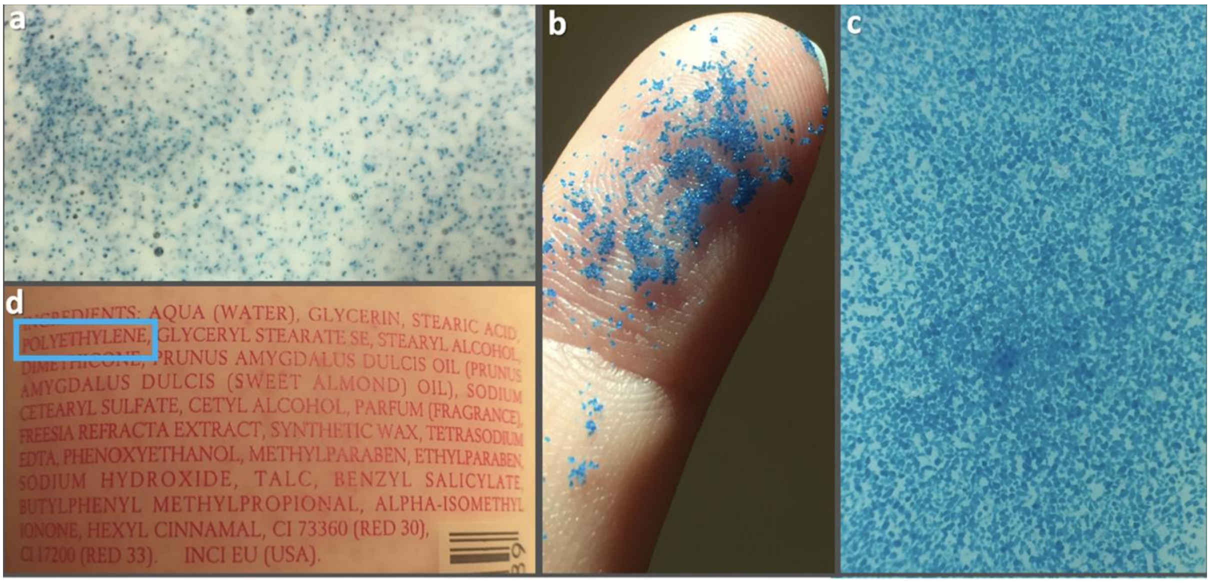


Figure 2.1 a) µBs contained in a hair shampoo (polyethylene, as from INCI ingredients list); b–c) µBs extracted from cosmetic products; d) example of a listed µB's ingredient in a cosmetic product (Guerranti. C, 2019).

2.3 Certification and standards for cosmetic industry

There is currently no European harmonized standard set of criteria for what constitutes natural and organic cosmetics. There are, however, standards such ISO 16128 that provide a framework for determining out the amount of natural, natural origin, organic, and organic origin ingredients in products based on the ingredient characterization. In addition, there are a few private certification organizations in Europe that have criteria for natural and organic cosmetics that have been adopted at the national level, but the top three are BDIH (Germany), Natrue (Belgium), and Ecocert Greenlife (France) (Beerling and Sahota, 2014).

COSMOS was created in recent years because of efforts to create a regional or international standard based on the harmonization of the many national standards (COSMetics Organic Standard). The COSMOS certification, which was created by BDIH, Ecocert Greenlife, CosmeBio (France), ICEA (Italy), and Soil Association (UK), is currently recognized as a global standard for organic and natural cosmetics (Cosmos-standard, 2013).

Natural, organic, and green, however, do not always mean sustainability. In contrast to sustainable, which considers all potential effects related to the product life cycle, natural, organic, and green refer to product ingredients that are categorized by agriculture, originating source, or the absence of synthetic substances. The differences between the classifications of these various certification bodies depend on the percentage of natural, herbal or organic ingredients required, these differences are detailed in (Table 2.2). Additionally, a detailed explanation of the pros and cons of cosmetic certifications is shown in table 2.3.

Table 2 .2 Certification standards for Natural and Organic cosmetics.

Standard	**Types**	**Requirements**
COSMOS **(Cosmos-standard, 2013)**	Organic	• Min. 20% organic content (exception: rinse-off products, non-emulsified aqueous products, and products with at least 80% minerals or ingredients of mineral origin, at least 10% of the total product must be organic) • At least 95% of physically processed agro-ingredients must be organic. • Only permitted Chemically Processed Agro Ingredients (CPAI).
	Natural	• 100% natural/naturally derived ingredients (except approved synthetic preservatives & petrochemical moieties). • No requirement to use a minimum level of organic ingredients.
ECOCERT (Ecocert Greenlife, n.d.)	Organic	• Min. 95% ingredients natural or derived from natural sources. • Min. 95% of vegetable ingredients are produced by organic farming. • At least 10% of entire product contents (including water) are produced by organic farming.
	Natural	• Min. 95% ingredients natural or derived from natural sources. • Min. 50% of vegetable ingredients are produced by organic farming. • At least 5% of entire product contents are produced by organic farming.
NATRUE **(Natrue, 2017)**	Organic	• Specific levels of required natural and “derived natural” substances quoted by product type. • Most products e min 20% of natural and max. 15% of derived natural substances. • Min. 95% of the natural substances of plant and animal origin must be organic.
	Natural with organic portion	• Min. 15% of chemically unmodified natural substances and max. 15% of derived natural substances. • Min. 70% of the natural substances of plant and animal origin must be organic.
	Natural	• Min. level of natural content and max. level of derived natural materials specified by the product type. • No requirement to use min. level of organic ingredients.
BDIH **(BDIH, n.d.)**	Natural	• Natural sourced raw materials: of plant origin, preferably organically cultivated or from controlled wild collection; substances that are produced by animals are allowed; inorganic and mineral salts, acids and bases are generally allowed. • Only certain ‘mild’ chemical processes are allowed using prescribed types of natural feedstock. • Only certain synthetic preservatives are permitted

Table 2.3 Pros and cons table for Cosmetic Certifications (COSMOS, 2021; ECOCERT, 2021; NATRUE, 2021; BDIH, 2021).

Certification	**Pros**	**Cons**
COSMOS	1. Recognized globally, particularly in Europe. 2. Promotes the use of organic agriculture and respects biodiversity. 3. Advocates for green chemistry principles, reducing environmental impact. 4. COSMOS-certified products contain a significant proportion of organic ingredients.	1. The certification process can be rigorous and time-consuming. 2. Smaller brands might find the certification cost prohibitive.
ECOCERT	1. Widely recognized internationally. 2. Certifies a broad range of products, from cosmetics to textiles. 3. ECOCERT emphasizes sustainable practices and corporate responsibility 4. Two levels of certification: ECOCERT Natural and ECOCERT Organic.	1. Certification process might be complex and costly for small producers. 2. The use of some synthetic substances is allowed, which some purists might not prefer.
NATRUE	1. Focuses on maintaining strict natural and organic cosmetic standards. 2. No animal testing. 3. Does not allow the use of synthetic fragrances and colors, petroleum-derived products, or genetically modified organisms (GMOs). 4. NATRUE certification provides a clear indication of the percentage of organic content.	1. Might be less well-recognized outside Europe. 2. Certification can be costly for smaller brands. 3. The certification process can be complex.
BDIH	1. One of the oldest and most respected standards for certified natural cosmetics in Germany. 2. Prohibits the use of synthetic dyes, fragrances, silicones, and petroleum-derived products. 3. Focuses on ecological responsibility, including no testing on animals.	1. May is not as recognized globally as other standards. 2. Some consumers might find the criteria for permissible synthetics to be too lenient. 3. Does not have a differentiation between 'natural' and 'organic' certifications.

2.4 Main concerns about certified green cosmetics products

Certifications for organic and natural cosmetics, such as those offered by COSMOS, ECOCERT, NATRUE, and BDIH, play a crucial role in shaping industry norms and consumer expectations. These bodies aim to promote sustainable practices, biodiversity protection, and consumer health by implementing stringent standards for product formulation and production (COSMOS, 2021; ECOCERT, 2021; NATRUE, 2021; BDIH, 2021).

2.4.1 Greenwashing:

Greenwashing is a significant concern within the cosmetics industry, where companies may use deceptive marketing tactics to portray their products as environmentally friendly, despite lacking genuine sustainability credentials. This misrepresentation can mislead consumers, leading them to make choices based on false claims. Greenwashing undermines the trustworthiness of green cosmetic certifications, as consumers may question the accuracy and reliability of existing eco-labels (Griskevicius, V., 2010).

2.4.2 Limited Criteria:

Some green cosmetic certifications narrowly focus on specific aspects, such as the exclusion of certain harmful chemicals, while neglecting broader environmental and ethical considerations. A myopic approach may not accurately assess a product's overall sustainability performance. To ensure a comprehensive evaluation, green cosmetic certifications should encompass multiple dimensions, including resource use, manufacturing processes, social responsibility, and packaging sustainability (Guerrero, M., 2018).

2.4.3 Lack of Transparency:

Insufficient transparency in the certification process and criteria can create confusion among consumers. When certifications do not provide clear information on how they assess sustainability attributes, consumers may struggle to differentiate between genuinely sustainable products and those that may be engaging in greenwashing. Enhanced transparency can build consumer trust and encourage responsible purchasing decisions (Lee, S., 2021).

2.4.4 Variability in Standards

The cosmetics industry lacks a unified standard for green certifications, leading to variations in criteria and interpretation among different certification bodies. This lack of harmonization creates confusion for consumers, who may find it challenging to navigate the diverse range of eco-labels. Establishing a global or industry-wide standard for green cosmetics can provide clarity and consistency for consumers and foster greater confidence in eco-labels (Lwin, M. O., 2018).

2.5 Overview of Life Cycle Assessment

The process known as Life Cycle Assessment (LCA) is a systematic, all-encompassing, and globally standardized approach. It measures all relevant resource consumption and emissions, as well as the effects on the environment and human health and the problems with resource depletion connected to any goods or services (referred to as "products").

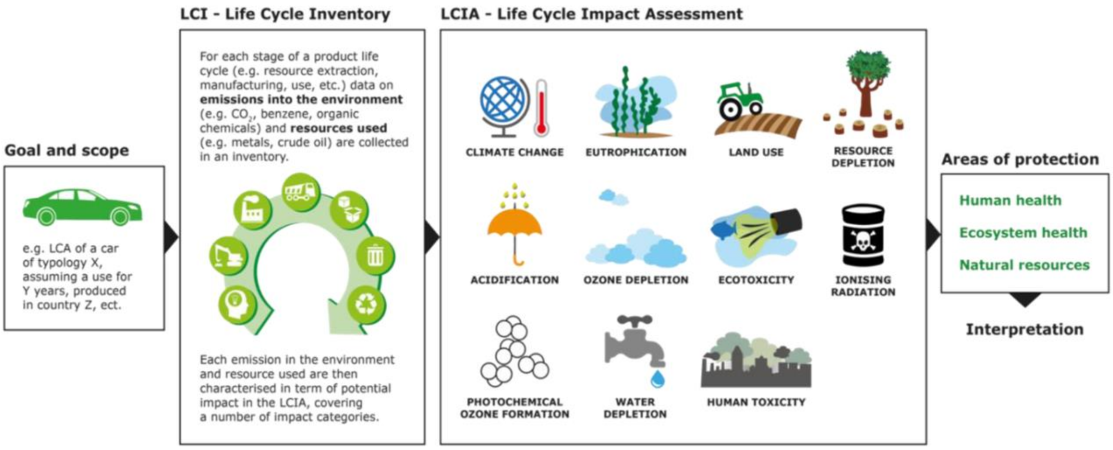
A product's entire life cycle is considered in a life cycle assessment, starting with resource extraction and continuing through production, consumption, recycling, and final waste disposal. Importantly, LCA research consequently assists in preventing the solution of one environmental issue while causing another to arise: When you reduce the environmental impact at one stage of the life cycle and then raising it at another, this unwanted "shifting of burdens" occurs.

LCA helps prevent increased land use or acid rain and reduces greenhouse gas emissions. It also avoids creating waste-related problems during manufacturing upgrades or shifting emissions from one nation to another. Therefore, life cycle assessment is a vital tool for decision support. It works together with other important techniques to achieve sustainable production and consumption effectively and efficiently (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010).

Also, there key standards related to life cycle assessment (LCA) such as ISO 14040 and ISO 14044. ISO 14040 outlines the principles and framework for conducting an LCA (ISO 14040:2006), while ISO 14044 provides specific requirements and guidelines for conducting an LCA study (ISO 14044:2006). These standards ensure that environmental impacts are systematically evaluated throughout the life cycle of a product or service, helping organizations make informed decisions to minimize their environmental footprint.

2.5.1. LCA phases

The framework of Life Cycle Assessment (LCA) is structured around four principal phases, as depicted in Figure 2.2 Life Cycle Assessment steps: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation (European Commission, 2023).



e.g. LCA of a car of typology X, assuming a use for Y years, produced in country Z, ect.

For each stage of a product life cycle (e.g. resource extraction, manufacturing, use, etc.) data on **emissions into the environment** (e.g. CO_2, benzene, organic chemicals) and **resources used** (e.g. metals, crude oil) are collected in an inventory.

Each emission in the environment and resource used are then characterised in term of potential impact in the LCIA, covering a number of impact categories.

Figure 2.2 Life Cycle Assessment steps: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation (Sala et al., 2016).

In the **goal and scope phase**, the aims of the study are defined, namely the intended application, the reasons for carrying out the study and the intended audience. This step involves making the most significant methodological decisions, including precisely defining the functional unit, identifying system boundaries, allocating procedures, analyzing impact categories, selecting Life Cycle Impact Assessment (LCIA) models, and determining data quality requirements.

The **Life Cycle Inventory (LCI) phase** entails the data gathering and the calculation process for quantifying the inputs and outputs of the analyzed system. Energy, raw materials and other physical inputs, waste, goods and byproducts, emissions into the air, water, and soil, and other environmental factors are all considered inputs and outputs. The collected data pertains to both front-end processes (such as product manufacturing and packing for consumer goods manufacturers) and back-end activities (such as purchasing electricity and materials for consumer goods manufacturers). The data are verified and correlated with the functional and process components (European Commission, Joint Research Centre, 2023).

The **impact assessment phase of LCA** is designed to evaluate the significance of potential environmental impacts utilizing the LCI results. Typically, this process involves linking inventory data with specific environmental impact categories and category indicators, thus attempting to comprehend these impacts. The LCIA phase also supplies information for the life cycle interpretation phase.

The impact assessment may involve the repetitive process of reviewing the goal and scope of the LCA study to ascertain if the objectives of the study have been met or to adjust the goal and scope if the assessment suggests they cannot be achieved.

Factors such as selection, modeling, and evaluation of impact categories can introduce subjectivity into the LCIA phase shown in Figure 2.3. Hence, transparency is essential to the impact assessment to ensure that assumptions are clearly articulated and documented (British Standards Institution, 2006).

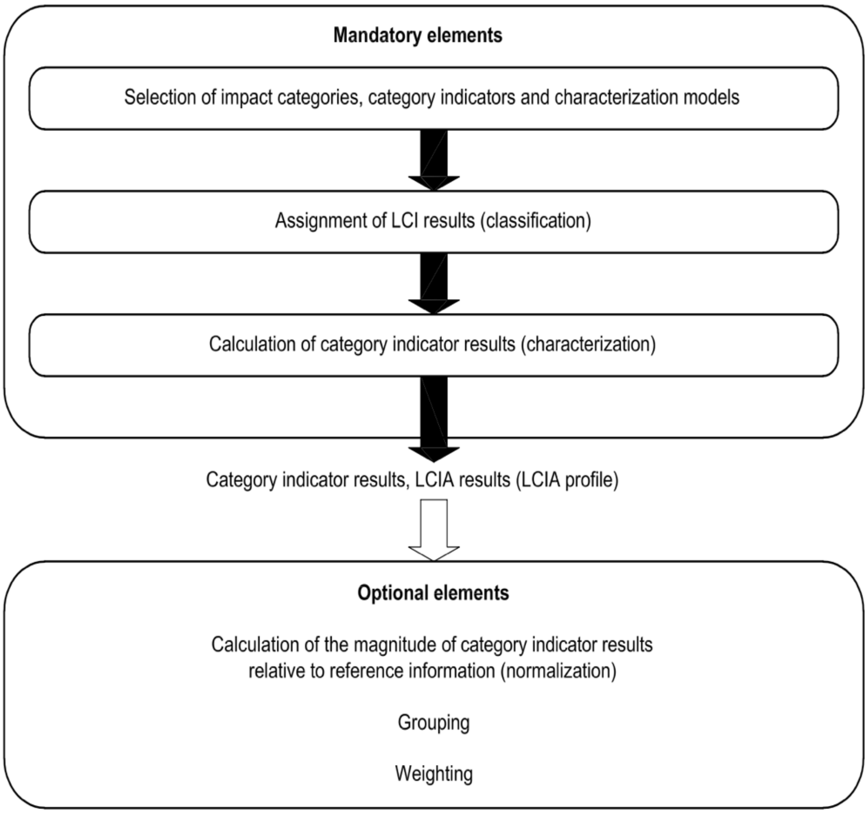


Figure 2.3 Elements of the LCIA phase (British Standards Institution, 2006).

Limitations of LCIA

The LCIA addresses only the environmental issues that are delineated in the goal and scope. Thus, LCIA does not constitute a comprehensive evaluation of all environmental issues of the product system under analysis.

LCIA may not consistently reveal significant distinctions between impact categories and the corresponding indicator results of alternative product systems. This inconsistency could be attributed to:

- inadequate development of the characterization models, sensitivity analysis, and uncertainty analysis for the LCIA phase,
- constraints of the LCI phase, such as establishing the system boundary, which might not cover all potential unit processes for a product system or fail to account for all inputs and outputs of each unit process due to truncations and data gaps,

- shortcomings of the LCI phase, such as poor LCI data quality which could stem from uncertainties or discrepancies in allocation and aggregation procedures, and
- limitations in gathering inventory data that is accurate and representative for each impact category.

Interpretation is the stage in a Life Cycle Assessment where outcomes from the inventory analysis and impact assessment are integrated, or in the case of LCI studies, only the results of the inventory analysis are used. This phase aims to provide results that align with the established goals and scope, drawing conclusions, outlining limitations, and offering recommendations.

The interpretation phase acknowledges that LCIA outcomes are comparative, indicating potential environmental impacts. These outcomes do not predict precise effects on specific environmental endpoints, surpass thresholds, or assess risks. The outcomes from this phase typically offer conclusions and recommendations for policymakers, aligning with the study's objectives and scope. Life cycle interpretation also aims to clearly, comprehensively, and consistently present the LCA results, following the study's defined goal and scope. This phase may include an iterative review and refinement of the LCA scope, as well as adjustments to the data quality and type used, ensuring consistency with the specified objectives.

Cradle-to-gate approach

"Life Cycle Assessments (LCA) following the 'Cradle-to-Gate' approach focus on measuring a product's environmental impact up to the point where it leaves the factory gate. This methodology excludes the environmental footprint associated with the product's use by customers and its end-of-life processes such as waste management, recycling, or upcycling.

The Cradle-to-Gate approach simplifies and expedites the LCA process, which is particularly advantageous when data on post-factory processes is limited. For instance, certain materials like chemicals or textiles may have multiple applications beyond the factory's premises.

In the context of LCA, Cradle-to-Gate is considered a 'Life Cycle Model,' which determines the scope of the assessment by specifying which phases of the product's life cycle are included.

Life Cycle Models serve as guidelines for focusing the LCA on particular stages of the product's life.

Typically, products undergo various life cycle phases, including raw material extraction (referred to as the 'cradle'), manufacturing and processing, transportation, usage and retail, and waste disposal (referred to as the 'grave').

LCAs conducted using the Cradle-to-Gate approach evaluate the environmental impacts associated with one or more of these stages, depending on the specific scope defined for the assessment. This involves determining the system boundaries or scope of the LCA, which dictates which phases of the product's life cycle are considered." (Ecohain, 2022).

Carbon footprint analysis

The entire amount of greenhouse gases, mostly carbon dioxide (CO2), released either directly or indirectly by human activity is referred to as the "carbon footprint." It is a measurement of these activities' environmental impact and is typically given in CO2 equivalents. The practice of measuring and evaluating the carbon emissions connected to a good, service, company, or person across the course of their life cycle is known as carbon footprint analysis.

Carbon footprint analysis is used to assess the environmental effects of different stages of production, such as sourcing raw materials, manufacturing processes, packaging, transportation, consumption, and disposal, in the context of cosmetic products. This analysis helps identify possibilities for reducing the environmental impact of cosmetic products by eco-friendly practices, such as using renewable resources, streamlining production procedures, and minimizing packaging waste. It also offers insightful information about the carbon emissions generated by cosmetic products.

The ISO 14067 standard, which provides guidelines for quantifying and communicating the carbon footprint of products, forms the basis for carbon footprint analysis. It outlines the principles and requirements for calculating a product’s greenhouse gas emissions across its life cycle, ensuring consistency and transparency in carbon footprint reporting (ISO, 2018).

Natural Origin Index (NOI)

The Natural Origin Index (NOI) is a metric used to quantify the percentage of natural ingredients in a product, typically in the cosmetics industry. The NOI is calculated based on the proportion of ingredients that are derived from natural sources, such as plants, minerals, or marine resources, relative to the total formulation.

The NOI of each ingredient is determined by its origin:

- Ingredients of synthetic or mineral origin are assigned an NOI of 0%.
- Natural ingredients, such as plant-based components and water, boast an NOI of 100%.
- Derived natural ingredients fall between 0% and 100%, representing modifications to natural ingredients. For instance, acetylated hyaluronic acid, derived from 100% biotechnologically produced hyaluronic acid, carries an NOI of 76%.

The NOI is often determined by considering both the origin of the raw materials and the processes used to derive them, with higher indices indicating a greater reliance on natural sources. Various standards, such as ISO 16128, provide guidelines for calculating the NOI, ensuring consistency and transparency across the industry (ISO 16128-1:2017).

3. Case Study: Reformulated Body Butter Product

The case study focused on a single product, a body butter which is skin moisturizer that uses fats as raw materials. Starting from original formulation, the producing company developed two re-formulated options in which some ingredients were replaced as follows:

- Green formulation 1: synthetic ingredients and/or classified as microplastics (acrylic polymers, PMMA) replaced by naturally derived ingredients, i.e., polysaccharides (carrageenan, sclerotium gum) and an inorganic powder (silica).
- Green formulation 2: acrylic polymers have been replaced with polysaccharides (a derivative of starch and sclerotium gum), the PMMA with an inorganic silica-based texturizer, the synthetic emollients with naturally derived esters (caprylyl-caprylate/caprate and coco-caprylate) and isopentyldiol with pentylene glycole which has NOI 1. In this last formula we also had to modify the concentrations of some waxes and butters to maintain the same consistency of the original starting product. All changes are highlighted in green.

In the table 3.1 provided, ingredients of the original product on the market is presented in the first column. The most problematic ingredients in terms of Natural Origin Index (NOI) and sustainability are underlined in red. The second column illustrates the same product reformulated by replacing some synthetic ingredients and/or classified as microplastics (such as acrylic polymers, PMMA) with naturally derived ingredients, including polysaccharides (carrageenan, sclerotium gum) and an inorganic powder (silica).

The third column demonstrates another variant of the same product reformulated in ecodesign. In this version, the acrylic polymers have been substituted with polysaccharides (a derivative of starch and sclerotium gum), PMMA with an inorganic silica-based texturizer, synthetic emollients with naturally derived esters (caprylyl-caprylate/caprate and coco-caprylate), and isopentyldiol with pentylene glycole, which has a NOI of 1. Additionally, adjustments to the concentrations of some waxes and butters were made to maintain the same consistency as the original product. All modifications are highlighted in green.

Through these substitutions, the company was able to reduce the carbon footprint linked to raw materials, resulting in an increase in the formula's NOI from 75/100 to 98/100, signifying that 98% of the ingredients are of natural origin.

Due to the company's confidentiality policies, only the names of the ingredients that have been modified are provided in the tables, while all other ingredients are described using general terms, and the brand name is kept confidential.

Table 3.1 Comparison of Original and Reformulated Products Ingredients

Original Product	**Green Formulation 1**	**Green Formulation 2**
water	water	water
synthetic chemical	synthetic chemical	synthetic chemical
synthetic chemical	natural ingredient	natural ingredient
natural ingredient	pH regulator	pH regulator
natural ingredient	natural ingredient	natural ingredient
natural ingredient	Preservative	Preservative
Preservative	**Magnesium Sulfate**	**Sclerotium gum**
pH regulator	**Carrageenan Iota**	synthetic chemical
Emulsifier	**Sclerotium gum**	natural ingredient
Emollient	synthetic chemical	Emulsifier
UV filter	natural ingredient	Emollient
Emollient	Emulsifier	UV filter
Emollient	Emollient	Emollient
Moisturizer	UV filter	Emollient
Emollient	Emollient	Moisturizer
"Moisturizer	Emollient	Emollient
Emollient	Moisturizer	Moisturizer
Isononyl isonanoate	Emollient	Emollient
2-propylheptyl caprylate	Moisturizer	**Caprylyl-caprylate/caprate**
Synthetic chemical	Emollient	**Coco-caprylate**
Natural ingredient	DUB ININ	synthetic chemical
Vegetable oil	CETIOL SENSOFT	**Hydroxypropyl starch phosphate**
Anti-aging agent	synthetic chemical	Natural ingredient
Sodium polyacrilate	Natural ingredient	Vegetable oil
PMMA	Vegetable oil	Anti-aging agent
Colorant	Anti-aging agent	**Sodium Potassium Aluminum Silicate, Titanium Dioxide (CI 77891), Silica**
ISOPENTYLDIOL	**Sodium Potassium Aluminum Silicate, Titanium Dioxide (CI 77891), Silica**	Colorant
Natural ingredient	Colorant	**Pentylene glycol**
Parfum	ISOPENTYLDIOL	Natural ingredient
Acqua, Acrylates/Beheneth-25 methacrylate copolymer	Natural ingredient	Parfum
	Parfum	

3.1 Production Phases of the Products

This section provides general production steps of the body butter product. These places are the same for all three products except some ingredients. the differences in the production process of the products are indicated in the text.

The ingredients, masses and CO2 values of the product are shown in the table below. Content marked in red is the most problematic content according to the NOI index. The production process of the product is as follows;

A Phase:

- Heat water to 75°C and solubilize various ingredients including emulsifiers, moisturizers, acids, preservatives, and pH adjusters. To aid solubilization, keep the stirrer activated at 500 rpm. Pre-solubilize a gelling agent in glycerin before adding it to A Phase.

B Phase:

- Weigh together all the ingredients of the oil phase and melt them at 80°C, mixing with the stirrer at 200/300 rpm. B phase will be completely liquid after 15/20 minutes.

Emulsifying:

- Transfer the phases to the turboemulsifier. Immerse the head of the turboemulsifier in the beaker containing A phase and, under rapid mixing (4500 rpm), add the B phase little by little until the emulsion is homogeneous (at least 5 minutes). After emulsification, add a specific emulsifier under rapid mixing (2500 rpm).
- After emulsification, add PHASE D under rapid mixing (2500 rpm) (only for green formulation 2 production process).

- Allow the emulsion to cool down to below 40°C.
- Mixing at max 2000 rpm, add a mixture of natural oil and vegetable oil.
- Add specific emollients little by little.
- Add specific fillers little by little.
- Premix a pigment with a solubilizer and add the dispersion to the emulsion.
- Add a preservative.
- Add fragrance.

4. Methodology

This study was conducted using life cycle assessment (LCA) methodology based on relevant ISO standards to compare the environmental impacts of the original cosmetic product (body butter) and two reformulated products which are green formulation 1 and green formulation 2. The methodology section of this study outlines the detailed steps and procedures followed to assess and compare the carbon footprints of the three cream formulations using the cradle-to-gate approach. This section is structured to provide a comprehensive overview of the goal and scope definition, data collection methods, inventory analysis, impact assessment, and interpretation processes. By systematically addressing each of these components, the methodology ensures a transparent and reproducible evaluation of the environmental impacts associated with the production of the cream formulations.

4.1 Goal and Scope Definition

4.1.1 LCA Framework (ISO 14040/14044)

This study adopts the Life Cycle Assessment (LCA) framework as outlined in the ISO 14040 and ISO 14044 standards to evaluate the environmental impacts of a cosmetic body butter product before and after reformulations. The LCA methodology is divided into four main phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation (ISO, 2006a; ISO, 2006b).

4.1.2 System Boundaries and Functional Unit

The system boundaries for this LCA include the stages from cradle to gate, encompassing raw material extraction, processing, manufacturing of the single raw materials in the cosmetic cream. The functional unit, which is essential for comparing the original and reformulated products, is defined as 'the provision of moisturizing effects for 300 g of body butter over a typical product lifespan'.

4.2 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. Data obtained from sectoral areas, literature and databases documented in this section.

4.2.1. Data Collection and Key Assumptions

Due to confidentiality principles, only the emission factors of the replaced ingredients are provided along with their data sources. The following tables summarizes the sources of emission factors for the replaced ingredients used in the cream formulations.

The following details have been organized into separate tables (Table 4.1-4.2-4.3) for original and green formulations to provide clarity on the data collection methods and sources:

Table 4.1 Selected Databases and details of original product

Ingredients of Original Product	Selected DataBase	Details
Isononyl isonanoate	ECOINVENT	isononanoic acid(A)>>>Fatty acids, from vegetarian oil, at plant/kg/RER
2-propylheptyl caprylate	ECOINVENT	Glycerine {FR}| treatment of used vegetable cooking oil, purified, esterification | Cut-off, U
	ECOINVENT	Fatty acid {RER}| fatty acid production, from palm oil | Cut-off, U
Sodium polyacrilate	ECOINVENT	Acrylic acid {RER}| acrylic acid production | Cut-off, U
	LITERATURE	Sodium hydroxide, without water, in 50% solution state {RER}| chlor-alkali electrolysis, average production | Cut-off, U
PMMA	ECOINVENT	polymethyl methacrylate production, beads
Isopentyldiol	ECOINVENT	isononanoic acid(A)>>>Fatty acids, from vegetarian oil, at plant/kg/RER
Acqua, Acrylates/Beheneth-25 methacrylate copolymer	COMPANY-PROVIDED	Emission values were provided from the company data

Table 4.2 Selected Databases and details of Green Formulation 1

Ingredients of Green Formulation 1	**Selected DataBase**	**Details**
Magnesium Sulfate	ECOINVENT	magnesium sulfate {RER}|magnesium sulfate production|Cut-off, U
Carrageenan Iota	COMPANY-PROVIDED	Emission values were provided from the company data
Sclerotium gum	COMPANY-PROVIDED	Emission values were provided from the company data
Sodium Potassium Aluminum Silicate, Titanium Dioxide (CI 77891), Silica	ECOINVENT	Sodium Potassium Aluminum Silicate |sodium silicate production, spray powder, 80% production|Cut-off, U
	ECOINVENT	Titanium Dioxide {RER}|titanium dioxide production, chloride process|Cut-off, U
	ECOINVENT	Silica{RER}|silicone product production|Cut-off, U

Table 4.3 Selected Databases and details of Green Formulation 2

Ingredients of Green Formulation 2	**Selected Database**	**Details**
Caprylyl-caprylate/caprate	ECOINVENT	Caprylic acid| Fatty acids, from vegetarian oil, at plant/kg/RER
	ECOINVENT	Glycerin, from vegetable oil, at esterification plant/kg/FR
Coco-caprylate	ECOINVENT	Capric acid |Fatty acid {RER}| fatty acid production, from palm oil | Cut-off, U
	ECOINVENT	Coconut oil, crude {RoW}| coconut oil production, crude | Cut-off, U
Hydroxypropyl starch phosphate	ECOINVENT	Hydroxypropyl starch phosphate, maize starch production
Pentylene glycol	ECOINVENT	Propylene glycol production, liquid {RER}| Cut-off, U

These tables ensure transparency in the data collection process for the environmental impact assessment while maintaining the confidentiality of the overall cream formulations. The emission factors for the modified ingredients are sourced from reputable databases, literatue and company-provided data to ensure accuracy and reliability in the life cycle assessment.

4.2.2 Emission Data of the Formulations

To calculate the emissions for each ingredient in the cream formulations, we follow a method that uses the emission factors of the precursor chemicals based on their molecular weights. This approach ensures that the emissions are proportionately distributed based on the actual amounts of materials used in the chemical synthesis. Here is a step-by-step explanation of the methodology:

Step-by-Step Calculation:

1. Identify Molecular Weights:
    - Determine the molecular weights of the target compound and its precursors
2. Stoichiometry:
    - Identify the stoichiometric relationship between the target compound and its precursors. This includes understanding the chemical reaction and molar ratios involved.
3. Convert Mass to Moles:
    - Calculate the number of moles of the target compound using its mass and molecular weight.

$$\text{Moles of target compound} = \frac{\text{Mass of target compound}}{\text{Molecular weight of target compound}}$$

4. Calculate Mass of Precursors:
    - Use the moles of the target compound and the stoichiometric ratios to calculate the required mass of each precursor.

Mass of precursor = Moles of target compound × Molecular weight of precursor

5. Emission Factor Application:

   - The mass of each precursor was converted to kilograms and multiplied by its respective emission factor (kg CO_2-eq per kg) to obtain the emissions.

$$\text{Emissions} = \text{Mass of Precursor in kg} \times \text{Emission Factor}$$

6. Total Emissions Calculation:

   - The emissions from all precursors were summed to get the total emissions for the production of each target compound.

$$\text{Total Emissions} = \sum \text{Emissions from Precursors}$$

Modelling and Assumptions

Due to the unavailability of precise emission factors for some ingredients, we employed modeling and assumption approaches:

1. Building Block Approach:

   - For some compounds, the emissions were calculated based on their chemical building blocks. The emission factors of the precursor chemicals were used to approximate the emissions of the final compound.

2. Analogue Substitution:

   - For certain ingredients, where direct emission factors were unavailable, we used the emission factors of structurally similar or functionally equivalent compounds. This approach involved identifying chemicals with similar properties and using their emission data as a proxy.

These methodologies ensured a robust and transparent calculation process, providing accurate emission data while maintaining consistency across all ingredients.

Below are the tables (Table 4.4-4.5-4.6) showing the detailed emission values and masses for the three cream formulations. These tables are designed to offer a clear and concise view of the environmental impact of each formulation, aiding in the overall life cycle assessment.

Table 4.4 Emission values and masses of the Original Product

FASE	**NAME**	**Mass (g)**	**Emission Factor (kg CO_2-eq per kg)**	**Emission Value (kg CO_2-eq)**
A	ACQUA	134,01	0	0
B	synthetic chemical 1	0,3	4,43	0,0013
B	synthetic chemical 2	1,5	3,96	0,0059
B	natural ingredient 1	0,9	3,49	0,0031
B	natural ingredient 2	1,5	1,69	0,0025
B	natural ingredient 3	9	5,15	0,046
B	Preservative	0,3	4,20	0,0013
B	pH regulator	0,09	2,70	0,00024
C	Emulsifier	12	0,34	0,0041
C	Emollient 1	9	2,58	0,023
C	UV filter	0,3	5,28	0,0016
C	Emollient 2	9	10,37	0,093
C	Emollient 3	1,5	3,44	0,0052
C	Moisturizer	1,5	2,17	0,0033
C	Emollient 4	10,5	4,81	0,050
C	Moisturizer 2	6	2,82	0,017
C	Emollient 4	9	2,60	0,023
C	Isononyl isonanoate	21	2,98	0,063
C	2-propylheptyl caprylate	24	4,43	0,11
C	Synthetic chemical 3	16,5	3,78	0,062
D	Natural ingredient 4	0,3	3,37	0,0010
D	Vegetable oil	3	9,89	0,030
E	Anti-aging agent	1,5	6,12	0,0092
F	Sodium polyacrilate	0,9	1,45	0,0013
G	PMMA	9	7,35	0,066
H	Colorant	3	0	0
H	ISOPENTYLDIOL	9	3,61	0,032
I	Natural ingredient 5	0,3	0,73	0
L	Parfum	2,1	0	0
M	Acqua, Acrylates/Beheneth-25 methacrylate copolymer	3	1,85	0,0055

Table 4.5 Emission values and masses of the Green Formulation 1

FASE	NAME	Mass (g)	Emission Factor (kg CO_2-eq per kg)	Emission Value (kg CO_2-eq)
A	ACQUA	134,16	0	0
B	synthetic chemical 1	0,3	4,43	0,0013
B	natural ingredient 1	0,9	3,49	0,0031
B	pH regulator	0,09	2,70	0,0002
B	natural ingredient 3	9	5,15	0,0463
B	Preservative	0,3	4,20	0,0013
B	Magnesium Sulfate	2,25	1,86	0,0042
B	Carrageenan Iota	4,5	30,29	0,1363
B	Sclerotium gum	1,5	9,25	0,0139
B	synthetic chemical 2	1,5	3,96	0,0059
B	natural ingredient 2	1,5	1,69	0,0025
C	Emulsifier	12	0,34	0,0041
C	Emollient 1	9	2,58	0,0232
C	UV filter	0,3	5,28	0,0016
C	Emollient 2	9	10,37	0,0934
C	Emollient 3	1,5	3,44	0,0052
C	Moisturizer 1	1,5	2,17	0,0033
C	Emollient 4	10,5	4,81	0,0505
C	Moisturizer 2	6	2,82	0,0169
C	Emollient 5	9	2,60	0,0234
C	Isononyl isonanoate	21	2,98	0,0626
C	2-propylheptyl caprylate	24	4,43	0,1063
C	synthetic chemical 3	16,5	3,78	0,0624
D	Natural ingredient 4	0,3	3,37	0,0010
D	Vegetable oil	3	9,89	0,0297
E	Anti-aging agent	1,5	6,12	0,0092
F	Sodium Potassium Aluminum Silicate, Titanium Dioxide (CI 77891), Silica	4,5	2,35	0,0106
G	Colorant	3	0	0,0000
G	ISOPENTYLDIOL	9	3,61	0,0325
H	Natural ingredient 5	0,3	0,73	0,0002
I	Parfum	2,1	0	0,0000

Table 4.6 Emission values and masses of the Green Formulation 2

FASE	NAME	Mass (g)	Emission Factor (kg CO_2-eq per kg)	Emission Value (kg CO_2-eq)
A	ACQUA	137,91	0	0
B	synthetic chemical 1	0,3	4,43	0,00133
B	natural ingredient 1	0,9	3,49	0,00314
B	pH regulator	0,09	2,7002	0,00024
B	natural ingredient 3	9	5,1463	0,04632
B	Preservative	0,3	4,2003	0,00126
B	Sclerotium gum	3	9,246417	0,02774
B	synthetic chemical 2	1,5	4,224028	0,00634
B	natural ingredient 2	1,5	3,23343	0,00485
C	Emulsifier	12	0,34206	0,00410
C	Emollient 1	9	2,58	0,02322
C	UV filter	0,3	5,277479	0,00158
C	Emollient 2	4,5	10,374	0,04668
C	Emollient 3	4,5	3,4354134	0,01546
C	Moisturizer 1	6	2,1699848	0,01302
C	Emollient 4	6	4,8060549	0,02884
C	Moisturizer 2	6	2,82	0,01692
C	Emollient 5	9	2,5998	0,02340
C	Caprylyl-caprylate/caprate	21	2,09	0,04389
C	Coco-caprylate	24	2,88	0,06900
C	synthetic chemical 3	16,5	3,78	0,06237
D	Hydroxypropyl starch phosphate	3	1,0517	0,00316
E	Natural ingredient 4	0,3	3,37	0,00101
E	Vegetable oil	3	9,89	0,02967
F	Anti-aging agent	1,5	6,115154	0,00917
F	Sodium Potassium Aluminum Silicate, Titanium Dioxide (CI 77891), Silica	4,5	2,35	0,01058
G	Colorant	3	0	0,00000
G	Pentylene glycol	9	3,6071	0,03246
H	Natural ingredient 5	0,3	0,72568566	0,00022
I	Parfum	2,1	0	0,00000

4.3 Impact Assessment Methods

4.3.1 Classification

The classification of carbon dioxide (CO2) emissions is a crucial stage in the analysis of the reformulated body butter product's environmental impact. Using a cradle-to-gate methodology, the Life Cycle Inventory (LCI) phase was solely concerned with the CO2 emissions produced during the course of the product's life cycle. This method covers every step of the process, starting with the extraction of raw materials and continuing through transportation, manufacturing, and product delivery from the factory.

Because CO2 plays a major role in contributing to global warming, it is the main greenhouse gas taken into consideration in this study. Since CO2 has the ability to intensify the greenhouse effect by trapping heat in the Earth's atmosphere, the identified emissions were systematically classified under the "Climate Change" impact category.

Key sources of CO2 emissions in the product’s life cycle include:

- Raw Material Extraction: CO2 emissions generated during the extraction and processing of key ingredients such as oils, emulsifiers, and preservatives.
- Transportation: CO2 emissions resulting from the transportation of raw materials to the manufacturing facility, primarily due to the combustion of fossil fuels in vehicles.
- Manufacturing Processes: The energy used during the manufacturing processes, including heating, mixing, and packaging, contributes to CO2 emissions.

The study focuses a clear emphasis on the product's connection to global warming by classifying these emissions under the "Climate Change" category. This classification process is necessary to determine which phases of the product's life cycle are the most carbon-intensive, which is important for creating plans to lower the body product's overall carbon footprint.

4.3.2 Characterization

Using environmental models, characterization measures each elementary flow's capacity that is allocated to an impact category indicator. The impact scores, derived from characterisation data, are expressed as a single measure for each impact category. This makes it possible to aggregate all of the contributions into a single score that shows the overall effect of the product system on that category. Aggregated indicator ratings for the various effect categories make up the product system's defined impact profile (Zampori et al., 2016).

Process of Characterization:

- **Calculation of Total CO2 Emissions:** The total CO2 emissions for each formulation were calculated by summing the CO2 emissions of all individual ingredients within that formulation. This provides a single, comparable metric (in kg CO2-eq) for each product.

Example of Characterization:

- **Original Product:** The total CO2 emissions from all ingredients in the Original Product formulation were summed to provide the total impact.
- **Green Formulation 1:** Similarly, the total CO2 emissions for Green Formulation 1 were calculated by adding up the emissions from its ingredients.
- **Green Formulation 2:** The total CO2 emissions for Green Formulation 2 were determined in the same manner.

Characterization Results:

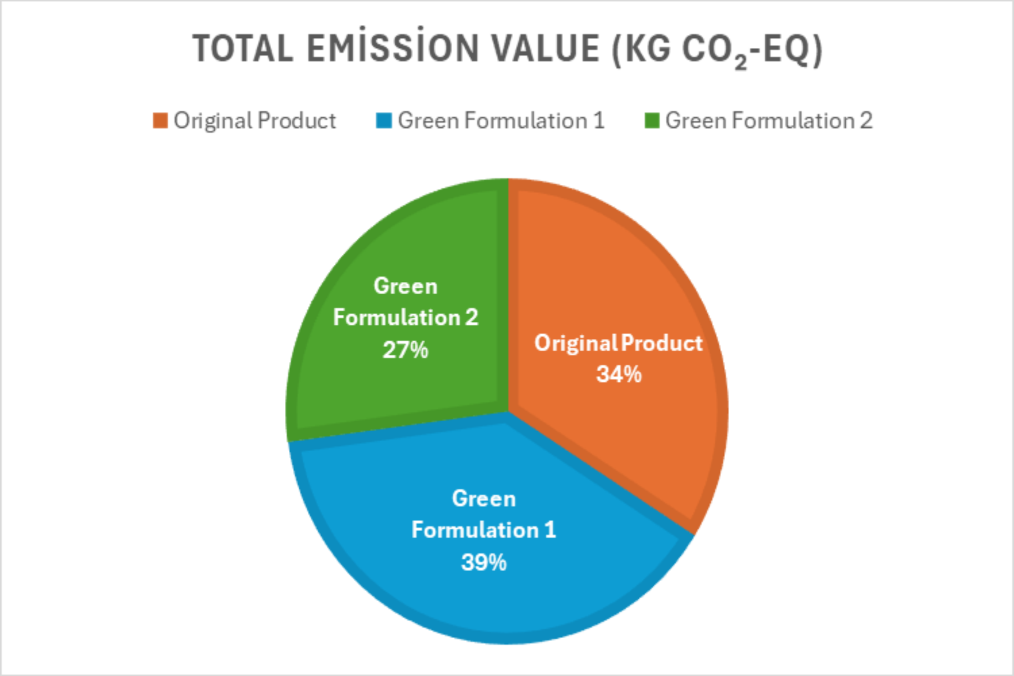


Figure 4.1 Total emission values of the formulations

Figure 4.1 illustrates the total greenhouse gas (GHG) emissions associated with each formulation of the body butter product. The emissions are calculated using a cradle-to-gate approach, which includes all stages of production from raw material extraction to the final product ready for distribution. The original formulation is compared against the two reformulated versions that incorporate more natural and sustainable ingredients. A detailed interpretation and discussion of these results will be provided in the Results and Discussion section.

4.4 Interpretations of Findings

The carbon footprint comparison of the three body butter formulations—Original, Green Formulation 1, and Green Formulation 2—reveals interesting insights into the environmental impacts of ingredient choices. Contrary to the common assumption that natural ingredients invariably result in lower emissions, the analysis shows that Green Formulation 1 exhibits a higher total emission value than the Original Product.

This unexpected outcome can be attributed to the inclusion of certain natural ingredients that, while perceived as environmentally friendly, possess high emission factors. A prime example of this is the use of carrageenan iota in Green Formulation 1. Carrageenan iota, derived from red seaweed, is often chosen as a natural alternative to synthetic chemicals for its gelling properties. However, the production and processing of carrageenan are associated with significantly high greenhouse gas emissions. As a result, substituting synthetic ingredients with carrageenan iota in Green Formulation 1 has inadvertently increased the product's overall carbon footprint.

This finding highlights the complexity of formulating truly sustainable cosmetic products. It underscores the necessity of not only focusing on the natural or organic origin of ingredients but also considering the full life cycle emissions associated with them. While the transition to natural ingredients is generally positive, it is crucial to carefully evaluate each ingredient's environmental impact to avoid unintended consequences that could undermine the sustainability goals.

In contrast, Green Formulation 2, which incorporates a more balanced selection of natural ingredients with lower emission factors, demonstrates a reduction in total emissions compared to both the Original and Green Formulation 1. Specifically, in Green Formulation 2, acrylic polymers have been replaced with polysaccharides (a derivative of starch and sclerotium gum), PMMA with an inorganic silica-based texturizer, synthetic emollients with naturally derived esters (caprylyl-caprylate/caprate and coco-caprylate), and isopentyldiol with pentylene glycol, which has a Natural Origin Index (NOI) of 1. This strategic approach to ingredient selection, informed by a thorough understanding of each component's carbon footprint, is essential for achieving genuinely sustainable cosmetic products.

Overall, this comparison of the carbon footprints of the three formulations provides valuable insights into the environmental trade-offs involved in the reformulation of cosmetic products.

The results emphasize the need for a holistic approach to sustainability that takes into account the complex interactions between ingredient sourcing, production processes, and the resultant environmental impacts.

The findings also have implications for certification standards and consumer perception. While certifications like COSMOS aim to guide consumers towards more sustainable choices, the higher emissions seen in Green Formulation 1 indicate that these certifications alone may not be sufficient to ensure true sustainability. Consumers and manufacturers alike must be educated about the complexities of sustainability, including the fact that natural or organic labels do not necessarily equate to lower carbon footprints. This understanding is essential for making informed decisions that align with sustainability goals.

These comments suggest several avenues for future research and industry applications. First, more comprehensive databases are needed that provide accurate emission factors for a broader list of natural ingredients. Second, that industry should consider developing more robust sustainability certifications that take into account the full lifecycle impacts of ingredients, rather than focusing solely on natural or organic ingredients.

5. Conclusion

This thesis explored the sustainability of the cosmetic industry by evaluating the environmental impacts of reformulated body butter products. Through a detailed carbon footprint analysis, it became evident that not all natural ingredients are inherently better for the environment. For example, the use of carrageenan iota, though natural, led to higher emissions compared to synthetic alternatives in one of the reformulations.

The study highlights the importance of carefully selecting ingredients, considering not just their origin but their entire life cycle impact. Green Formulation 2 demonstrated that a strategic approach, with well-chosen natural ingredients, can lead to a more sustainable product with lower overall emissions.

This research underscores the need for a nuanced understanding of sustainability in cosmetics. Certification standards and consumer perceptions must evolve to reflect the complexities of ingredient sourcing and environmental impact. While natural and organic labels are important, they do not always equate to sustainability.

In conclusion, to achieve a true sustainability approach, it is not enough to replace synthetic ingredients with natural ones, but rather more. It involves a comprehensive evaluation of each ingredient's environmental footprint, from sourcing to production. This thesis provides valuable insights and recommendations that can guide future product development in the cosmetic industry towards more sustainable practices.

REFERENCES

1. Amberg, N., Fogarassy, C. (2019). Green consumer behavior in the cosmetics market resources. Resources, 8(3), 137.
2. Anderson, A. G., Grose, J., Pahl, S., Thompson, R. C., & Wyles, K. J. (2016). Microplastics in personal care products: Exploring perceptions of environmentalists, beauticians and students. *Marine Pollution Bulletin, 113*(1-2), 454-460. https://doi.org/10.1016/j.marpolbul.2016.10.048
3. BDIH. Certified Natural Cosmetics. Guidelines for Certified Natural Cosmetics. n.d. https://www.kontrollierte-naturkosmetik.de/e/guideline_natural_cosmetics.htm
4. BDIH. (2021). BDIH Certification.
5. Beerling, J. (2014). Chapher 9: Green Formulations and Ingredients. In A. Sahota (Ed.), Sustainability: How the Cosmetics Industry is Greening up, (pp. 197-215.) London: Wiley.
6. British Standards Institution. (2006). Environmental management — Life cycle assessment — Principles and framework (BS EN ISO 14040:2006, Incorporating Corrigendum No. 1). https://www.iso.org/standard/37456.html
7. Cheung, P. K., & Fok, L. (2017). Characterisation of plastic microbeads in facial scrubs and their estimated emissions in Mainland China. *Marine Pollution Bulletin, 114*(1), 108-116.
8. Chang, M. (2018). Reducing microplastics from personal care products: A new standard. *Water Science and Technology, 77*(3), 984-989.
9. Cosmetics Europe- The Personal Care Association, 2018a. Over 97% of plastic microbeads already phased out from cosmetics [WWW Document].
10. Cosmetics Europe- The Personal Care Association, 2012a. Ten steps to sustainability

11. Cosmos-standard, 2013. Cosmetics Organic and Natural Standard.
12. COSMOS. (2021). COSMOS-standard.
13. Ecochain. (2022, May 25). Cradle-to-Gate in LCA. Retrieved from https://ecochain.com/blog/cradle-to-gate-in-lca/
14. ECOCERT. (2021). ECOCERT Certification.
15. Ecocert Greenlife. Natural and organic cosmetics. n.d, 2012. http://www.ecocert.com/en/natural-and-organic-cosmetics/
16. European Commission, 2015. Glossary and Acronyms Related to Cosmetics Legislation.
17. European Commission - Joint Research Centre - Institute for Environment and Sustainability. (2010). International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition.
18. European Commission, Joint Research Centre. (2023). European Platform on Life Cycle Assessment https://eplca.jrc.ec.europa.eu/lifecycleassessment.html
19. European Food Safety Authority (EFSA). (2016). Presence of microplastics and nano plastics in food, with particular focus on seafood. *EFSA Journal, 14*(6), e04501.
20. Fendall, L. S., & Sewell, M. A. (2009). Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Marine Pollution Bulletin, 58*(8), 1225-1228.
21. Guerranti, C.; Martellini, T.; Perra, G.; Scopetani, C.; Cincinelli, A. (2019). Microplastics in cosmetics: environmental issues and needs for global bans. Environmental Toxicology and Pharmacology, (), S1382668918305635–. doi:10.1016/j.etap.2019.03.007

22. Griskevicius, V., Tybur, J. M., & Van den Bergh, B. (2010). Going green to be seen: Status, reputation, and conspicuous conservation. Journal of Personality and Social Psychology, 98(3), 392-404.
23. Guerrero, M., Roda, I., & Castells, F. (2018). Cosmetics as a source of xenobiotic substances: A systematic review. Environmental Science and Pollution Research, 25(7), 6021-6034.
24. ISO 14040:2006(en), Environmental management - Life cycle assessment - Principles and framework.
25. ISO 14040:2006(en), Environmental management - Life cycle assessment - Principles and framework.
26. ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication. Geneva, Switzerland: ISO.
27. Isobe, A. (2016). Percentage of microbeads in pelagic microplastics within Japanese coastal waters. *Marine Pollution Bulletin, 110*(1), 432-437.
28. International Organization for Standardization. (2017). ISO 16128-1:2017 Guidelines on technical definitions and criteria for natural and organic cosmetic ingredients and products — Part 1: Definitions for ingredients. Geneva, Switzerland: ISO.
29. Kalčíková, G., Alič, B., & Demirak, A. (2017). Uptake and effects of microplastics on freshwater fish. *Environmental Science and Pollution Research, 24*(5), 4587-4597.
30. Lee, S., & Grebitus, C. (2021). Do information provision strategies affect consumers' choice of certified eco-friendly products? Evidence from a choice experiment. Journal of Cleaner Production, 287, 125490.
31. Liobikienė, G., & Bernatonienė, J. (2017). Why determinants of green purchase cannot be treated equally? The case of green cosmetics: Literature review. *Journal of Cleaner Production, 162*, 109–120

32. Lwin, M. O., Phau, I., & Ong, D. (2018). Sustainable consumption and production in the cosmetics industry: A systematic review. Journal of Cleaner Production, 198, 1296-1316.
33. Martins, A. M., & Marto, J. M. (2023). A sustainable life cycle for cosmetics: From design and development to post-use phase. Research Institute for Medicines (iMed.ULisboa), Faculty of Pharmacy, Universidade de Lisboa, Av. Professor Gama Pinto, 1649-003, Lisboa, Portugal.
34. Natrue, 2017. Natrue Label Requirements to Be Met by Natural and Organic Cosmetics. http://www.natrue.org
35. NATRUE. (2021). NATRUE Label.
36. Šniepienė, G., Jankauskienė, R. (2021). Organic personal care cosmetics: behavior of choice and consumption. International Conference on Innovatıons in Science and Education (Medicine and Pharmacy), Prague, Czech Republic www.iseic.cz proceedings of CBU in Medicine and Pharmacy Vol.2.
37. Sala, S., Reale, F., Cristobal-Garcia, J., Marelli, L., & Pant, R. (2016). Life cycle assessment for the impact assessment of policies. *Life thinking and assessment in the European policies and for evaluating policy options*, *28380*.
38. Secchi, M., Castellani, V., Collina, E., Mirabella, N., & Sala, S. (2016). Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient. *Journal of cleaner production*, *129*, 269-281.
39. Syberg, K., Hansen, S. F., Christensen, T. B., & Foss Hansen, S. (2018). Microplastics: Occurrence, effects, and sources of releases to the environment in Denmark. *Danish Environmental Protection Agency.*

40. Xanthos, D., & Walker, T. R. (2017). International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. *Marine Pollution Bulletin, 118*(1-2), 17-26.