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Use of Life Cycle Assessment on cosmetic products

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Abstract
This thesis is a literature review on the use of Life Cycle Assessment (LCA) on cosmetic products. Based on the review, the effectiveness of the method for the sustainability assessment of cosmetics is evaluated. The focus of the thesis is on cosmetic products and ingredients, rather than cosmetic packaging.

In this thesis, an extensive search for existing LCA studies on cosmetics was performed. 14 studies were collected as the result of the search. The studies meeting the full search criteria were critically examined. The findings from these prove the method to be functional, although it has notable limitations. The results show that LCA is an effective tool for assessing the environmental impacts of cosmetic products, particularly when comparing different production processes and ingredients. The method enables comprehensive evaluation of sustainability across multiple different environmental categories. The main limitations of the method are deficient data availability, difficult result reporting, problematic research reproducibility and comparability between different studies.

Based on the results, it is evident that LCA should be more widely applied in the sustainability assessment of cosmetic products. As the amount of data grows, the accuracy of the method will also increase. The results from individual studies are better interpreted and utilized, if the study includes comparative analysis. In general, reporting practices should be improved to make results more accessible and understandable, especially for non-expert audiences. Furthermore, efforts should be made to enhance the comparability of results across studies. Tools and novel approaches developed based on LCA may help address existing challenges and provide new perspectives.

Keywords Life Cycle Assessment, LCA, cosmetics, sustainability

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Tiivistelmä

Kosmetiikkateollisuus on kasvanut viime vuosikymmenen aikana huomattavasti, mikä korostaa alan tarvetta kestävän kehityksen mukaisille käytännöille. Vahvasti tieteeseen perustuva kosmetiikka-ala kehittyy nopeasti ja uusia ekoinnovaatioratkaisuja kehitetään jatkuvasti. Alan kehitys kestävämpään suuntaan edellyttää olemassa olevien ja uusien menetelmien ympäristövaikutusten luotettavaa arviointia. Yksi tämän hetken lupaavimmista menetelmistä tähän on elinkaariarviointi (*Life Cycle Assessment*, LCA). Kosmetiikan pakkausten kestävyyttä on kuvattu elinkaariarvioinnin avulla laajasti hyvin tuloksin, mutta itse kosmetiikan tuotteiden tutkimus on laajalti puutteellista.

Elinkaariarviointi on tieteellisissä piireissä yleisesti luotettavana ja toimivana pidetty menetelmä. Myös Euroopan unioni on tunnustanut menetelmän tehokkaaksi tuotteiden ja palvelujen ympäristövaikutusten arvioinnissa. Kansainvälinen standardisoimisjärjestö International Organization for Standardization eli ISO on standardisoinut menetelmän standardien ISO 14040:2006 ja ISO 14044:2006 avulla. Tästäkin huolimatta menetelmän toteutus sallii paljon vapautta. Esimerkiksi tästä syystä menetelmässä on vielä paljon heikkouksia ja puutteita.

Tämä kandidaatintyö on kirjallisuuskatsaus, jossa tarkastellaan elinkaariarvioinnin käyttöä kosmetiikkatuotteille. Työ keskittyy itse kosmetiikan tuotteisiin ja raaka-aineisiin, joten kosmetiikan pakkauksia tutkivat työt ovat suljettu pois. Tarkastelun pohjalta arvioidaan menetelmän toimivuutta. Työ toteutettiin suorittamalla systemaattinen tiedonhaku olemassa olevista LCA tutkimuksista, jotka tutkivat kosmetiikkaa. Tiedonhaussa hyödynnettiin eri tietokantoja ja hakukoneita. Hakukriteerejä vastaavat tutkimukset tarkasteltiin kriittisesti.

Aineistoksi kerättiin 14 LCA-tutkimusta kosmetiikkatuotteista. Näiden perusteella menetelmä osoittautui toimivaksi, mutta siinä on silti huomattavia puutteita. Tulokset osoittavat, että LCA on tehokas työkalu kosmetiikkatuotteiden ympäristövaikutusten arvioinnissa, erityisesti kun sitä hyödynnetään eri tuotantomenetelmien ja ainesosien ympäristövaikutusten vertailuun. Menetelmä mahdollistaa kestävyyden tarkastelun hyvin laajasti eri osa-alueita hyödyntäen. Merkittävimmiksi puutteiksi nousivat heikko datan saatavuus, tulosten vaikea raportointi, tutkimuksen toistettavuuden ongelmallisuus ja eri tutkimusten vertailukelpoisuus.

Tulosten perusteella on selvää, että LCA:ta tulisi hyödyntää laajemmin kosmetiikkatuotteiden ympäristövaikutusten arvioinnissa. Tiedon määrän kasvaessa menetelmän tarkkuus ja käytettävyys kasvaa. Yksittäisten tutkimusten tulosten tulkintaa ja hyödyntämistä helpottaa, jos tutkimuksessa on suoritettu vertailua. Yleisesti tulosten raportointimenetelmiä olisi kehitettävä, jotta ne olisivat helpommin ymmärrettäviä myös ei-asiantuntijoille sekä sidosryhmille. Tulosten vertailukelpoisuutta tutkimusten välillä olisi myös edistettävä. LCA:n pohjalta kehitetyt työkalut ja uudet menetelmät voivat auttaa vastaamaan LCA:n haasteisiin ja tarjota uusia näkökulmia.

Avainsanat Elinkaariarviointi, kosmetiikka, LCA, kestävyys

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1 Introduction

Over the past decade, the cosmetics industry has been one of the fastest growing industries globally, with around 7% annual growth rate in market value from 2017 to 2023 (Liu, 2022). Despite global recession, the growth is expected to continue at an annual rate of 3,37% between 2025-2030, which is shown in figure 1 (Statista, 2025). Therefore, the industry has a strong need to put emphasis on sustainable practices.

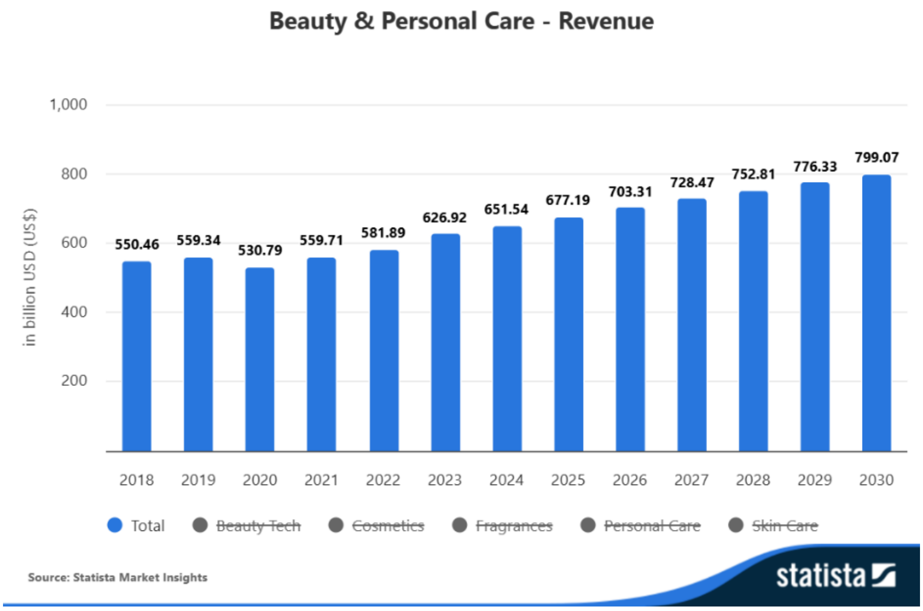

Figure 1. Annual revenue change of the global beauty and personal care market from 2018 to 2030 in US$ (Statista, 2025).

Sustainable development is defined and interpreted in various ways. It often refers specifically to the sustainable use of natural resources. However, this perspective is neither sufficiently comprehensive nor fully adequate, as the term encompasses a much broader set of needs and considerations. One of the most widely known definitions of sustainability is from the Brundtland report in 1987, which defines sustainable development to be development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987).

For companies and policymakers to act sustainably they require reliable information regarding sustainability. One of the most promising tools for evaluating sustainability is Life cycle assessment (LCA). LCA has been developed to consider several impact types in all the stages of a product's or a service's life cycle (Damiani et al., 2022). It is widely used in the sustainability assessment for many products, processes and services (Guinée et al., 2011). It has been proven a great tool for assessing the sustainability of packaging, including cosmetics packaging (Vassallo & Refalo, 2024). However, there are limited studies focused on applying LCA to the cosmetic products themselves, rather than their packaging.

This thesis is done in collaboration with Lumene Oy. Lumene strives to be a leader in circular beauty practices (*Lumene Group Annual Report 2024*, 2024). They have previously conducted an LCA study for their moisturiser jars, which are used on some of their most sold products (*Product carbon footprint pre-study*, 2025). As they work to make their practices and products more sustainable, they are investigating ways to further assess the sustainability of their products.

This thesis investigates and reviews the use of Life Cycle Assessment on cosmetic products. The used methodology is described in the second chapter. The concept and key components of LCA are explained in the third chapter. The fourth chapter presents the LCA studies included in the literature review. The thesis examines the trends, methodologies, achievements, and limitations of existing LCA studies. Chapter 5 discusses the findings and results of the literature review in detail. Based on this analysis, conclusions are drawn regarding the potential of Life Cycle Assessment as a tool for assessing the sustainability of cosmetic products. The aim of this thesis is to review the potential of LCA as a tool for assessing the sustainability of cosmetic products.

2 Methodology

In this literature review an extensive search was performed to collect data on existing Life Cycle assessments (LCA) of cosmetic products. For data collection, Google scholar, Web of Science, Scopus and ProQuest were used. Sources from found material were evaluated if they could be further used as sources on their own. However, no new results were obtained this way.

The selection of relevant studies was based on the following inclusion and exclusion criteria:

- Inclusion of studies regardless of their publication date.
- Inclusion of studies of any geographical scope.
- Inclusion of studies stating that LCA methodologies were implemented according to ISO 14040:2006 or 14044:2006 standards.
- Exclusion of studies where the main goal is the sustainability assessment of cosmetic packaging.
- Exclusion of studies not mentioning cosmetics, cosmetic products, personal care products or personal-hygiene products in the title.
- Exclusion of studies made on the development of an LCA based tool.
- Exclusion of studies written in other languages than English.
- Exclusion of studies, that could not be fully accessed using licenses provided for students at Aalto University.

Studies on singular ingredients were not included in the thesis, if there was no mentioning of it specifically being used in cosmetics. This would have been out of the scope of the thesis.

Data collection was made by using specific search keywords throughout the databases. Commonly used synonyms for cosmetics were incorporated in the searches. Keywords also included some specific product types. Finnish Safety and Chemicals Agency (Tukes) lists common cosmetic products on their website, which specifies what is meant by cosmetics (Tukes, 2025). Products picked for the search were: soap, cream, lotion, deodorant, nail, sunscreen. Phrases used for the search are presented in table 1.

Table 1. Keywords for the search.

"LCA" OR "Life Cycle Assessment"	AND "cosmetic" OR "cosmetics"
	AND “personal care” OR “hygiene”
	AND "makeup" OR “beauty”
	AND "hair care"
	AND "fragrance"
	AND "soap"
	AND "cream"
	AND "lotion"
	AND "deodorant"
	AND "nail"
	AND "sunscreen"

Before the data collection was done, it was not certain that a sufficient number of studies could be found on the subject. Had this been the case, the scope of the literature review would have been extended to include LCAs on cosmetic ingredients or pharmaceutical products. However, as data collection began, it became apparent that there were enough studies that met the specified requirements to draw meaningful conclusions.

Each study was reviewed to evaluate if they were performed by ISO standards. If the study did not explicitly state compliance with ISO 14040 or 14044, it was carefully reviewed to assess whether it still followed the standard. This was done by checking if the study followed the four phases of ISO 14040:2006 and that it defined a scope and a functional unit.

3 Overview of Life Cycle Assessment

Life Cycle Assessment is a systematic and quantitative methodology developed for assessing the potential environmental impacts of a product (Vieira et al., 2016). LCA calculates the impacts and resources used in the whole life cycle of a product (Damiani et al., 2022). The calculations can implement multiple environmental impact categories. This ensures that there is no burden shifting in the evaluation of sustainability. It also enables identifying potential trade-offs between different environmental impacts.

A theory and practice book on Life Cycle Assessment (Hauschild et al., 2018) summarises where LCA methodology originated from and how it has developed over the years. As the public awareness of environmental issues started growing in the late 1960s and early 1970s, research on the topic also started to develop. The first uses of life-cycle-oriented thinking can be dated back to this time. The term LCA became widely used only in the 1990s. Before that, the terms Resource and Environmental Profile Analysis (REPA) or Ecobalance were used in similar contexts, and they can be interpreted as precursors of LCA. Early uses focused mainly on material and energy accounting. The focus of which environmental concerns were addressed in the studies shifted a lot based on the main public concerns. Since then, the methodology has undergone significant development, and considerable efforts have been made towards its standardization.

3.1 LCA definition by ISO standards

The principles and framework of Life cycle assessment were first standardized by the International Organization for Standardization (ISO) in 1997-2000 (ISO, 2006). In 2006 they were revised into ISO 14040 and ISO 14044, which now define LCA.
The general methodological framework in ISO 14040 consists of four main phases. The descriptions of the phases are based on ISO 14040 and the terminology provided in a PEF (Product environmental footprint) report published on the European Union’s website (Damiani et al., 2022).

i.) Goal and Scope Definition: The first phase states the reasons and applications for the study. Functional unit, system boundaries, assessed impact categories and allocations are determined. Data requirements, level of detail as well as assumptions and limitations of the study are stated.

ii.) Life Cycle Inventory Analysis (LCI): An inventory of primary and secondary data is formed. This data may include energy input, raw material usage, other physical inputs, output of products and possible co-products, waste and emissions. Data from unit processes, functional unit and allocations are calculated.

iii.) Life Cycle Impact assessment (LCIA): The purpose of this phase is to provide additional information to help understand the inventory of data collected in the LCI phase. The potential impact associated with the predetermined impact categories is calculated. Grouping, normalisation and weighting of the data is done if deemed necessary.

iv.) Interpretation: Data from previous phases is summarized and discussed. Hotspot analysis to find the most relevant processes and resource flows is performed. Used modelling choices are evaluated using sensitivity analysis. The previous phases are revised, if necessary, given the iterative nature of the methodology.

It is stated in ISO 14040 that the framework does not describe the methodologies for the phases (ISO, 2006). It is also emphasized that LCAs are comparable only if the assumptions and context of both studies are equivalent.

The general framework of Life Cycle Assessment is depicted in figure 2 below. It demonstrates the iterative nature applied in the study methodology.

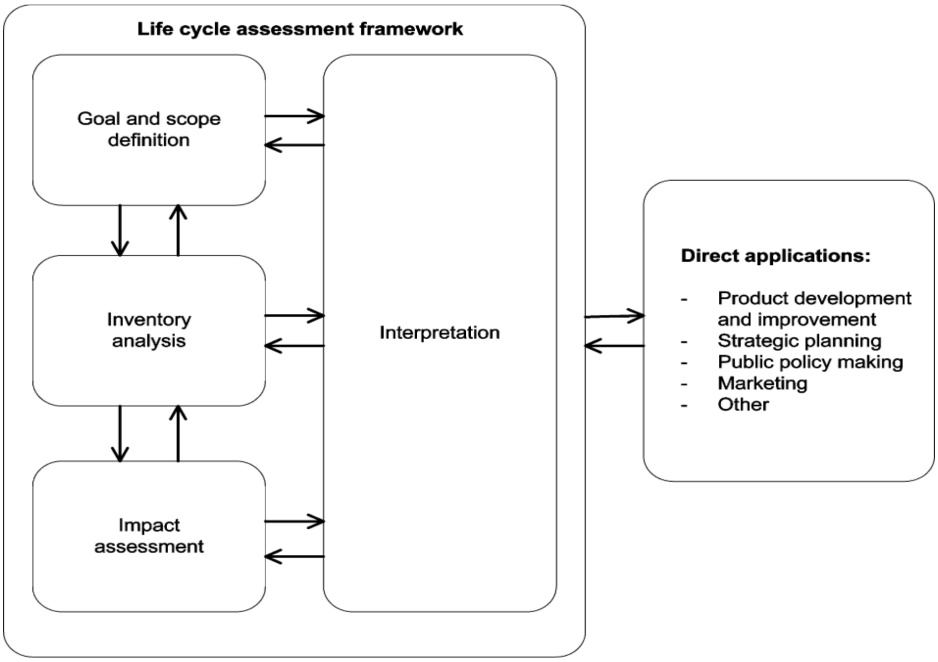

Figure 2. General methodological framework for LCA (Guinée et al., 2011)

In the first phase of any LCA study a functional unit must be determined. ISO 14040 defines it as quantified performance of a product system for use as a reference unit (ISO, 2006). It also points that the potential environmental impacts calculated in LCAs are related to the functional unit, making them relative expressions. As each study defines the functional unit separately, comparing them often becomes quite challenging. Furberg et al. discuss the challenges of defining and using functional units in an article about developing a framework for defining functional units (Furberg et al., 2022). There is a conflict between defining the functional unit as precisely in accordance with the standards as possible and defining it in a way that allows for easy comparability. Defining the functional unit in the case of studying novel materials is especially difficult, due to the unknown future applications of the material.

Another crucial step in the initial phase of the LCA is boundary setting and level of detail i.e. the scope. Boundary setting refers to the life cycle stages considered in the investigation (Kokare et al., 2023) and it has a significant impact on the results. The most used boundary scopes are cradle-to-gate and cradle-to-grave (Pohl et al., 2019). Cradle-to-grave analyses all the life cycle stages of a product, from raw material extraction to end-of-life, while cradle-to-gate excludes the use phase and end-of-life (Kokare et al., 2023). These are shown in figure 3.

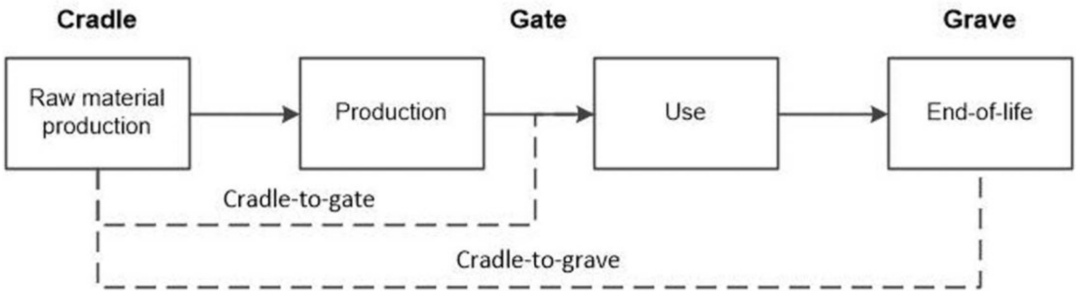

Figure 3. Cradle-to-gate and cradle-to-grave system boundaries of LCA (Kokare et al., 2023).

Life Cycle Assessment can be used to assess several different types of impact categories. It can be utilized to analyse environmental, economic, and social impacts, but most LCA's still focus on just environmental aspects of sustainability (Guinée et al., 2011). Commonly used impact categories are listed on the European Commission's website (*Life Cycle Assessment & the EF methods*, 2025) as shown here in table 2.

Table 2. Environmental Impact categories

1	Climate change
2	Ozone depletion
3	Human toxicity, cancer
4	Human Toxicity, non-cancer
5	Particulate matter
6	Ionising radiation
7	Photochemical ozone formation
8	Acidification
9	Eutrophication, marine
10	Eutrophication, terrestrial
11	Eutrophication, freshwater
12	Ecotoxicity, freshwater
13	Land use
14	Water use
15	Resource use, fossils
16	Resource use, minerals and metals

Impact categories can be further divided into midpoint and endpoint categories (Koch et al., 2023). Midpoint categories describe the environmental impact of the actual process. Endpoint categories describe the damage done to human health, natural resources or the natural environment. Usually, fewer assumptions are required when calculating midpoint categories, making them more accurate.

The impacts for the chosen impact categories are calculated in the LCIA phase. Each impact category has several different LCIA calculation methods (Koch et al., 2023). It has been shown that the selection of a method can make a difference in the results (Bueno et al., 2016). The possible inconsistencies and variability highlight the importance of method selection.

3.2 LCA limitations

Despite large efforts to standardize LCA, the method still has several limitations that must be noted (Damiani et al., 2022). So much specific data about the energy and material flows is required through all the life cycle stages of a product or system, much of it ends up being assumptions or average data. Data about every stage is just not available.

As explained in the previous section, although the steps are standardized, the method offers much freedom. Due to numerous decisions done in the Goal and scope definition phase of every LCA, the results may vary almost indefinitely. The comparability and reproducibility of the studies is thus negatively affected. The freedom of the method also makes reporting the results transparently and accurately difficult (Haverkamp et al., 2025). It is considered especially challenging when communicating to non-expert audiences.

4 Life Cycle Assessment on cosmetic products

Using the methods and applied limitations described in the methodology section, a total of 14 studies were found. In addition to these 14 that met the full criteria, four were first collected but later left out from the results due to not fully meeting the criteria. Two of these were studies made on the development of an LCA based tool (L'Haridon et al., 2023; Rocca et al., 2023). One was focused on implementing new factors for Life cycle assessment, rather than performing an LCA (Vargas-Gonzalez et al., 2019). One article left out was an LCA study, that did not follow ISO 14040 or 14044 standards(Trindade Filho et al., 2025).

Identifying the keywords used in the included studies was done by performing bibliographic coupling of these documents with VOSviewer. Two of the studies (Lambert, 2019; Pacheco & Huston, 2018) could not be included in the coupling due to their file format. The clusters formed by VOSviewer are not further used in reviewing the articles due to the relatively small number of total studies. The figure illustrates that all the keywords are connected by "life cycle assessment", "life-cycle assessment" or "lca". The cluster network is shown in figure 4.

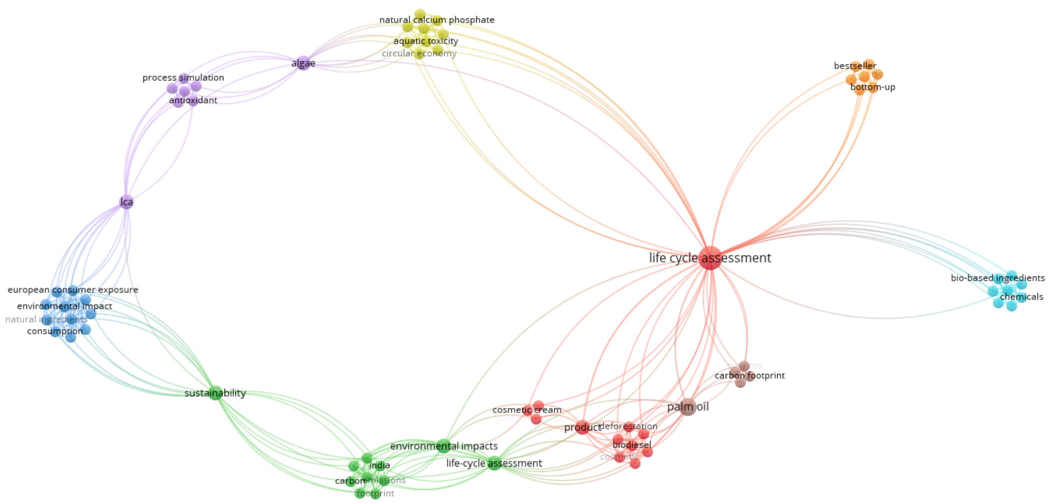

Figure 4. Keyword cluster network from VOSviewer.

Each included study is presented in order of publication date in table 3. Study type, scope of the study, functional units and publication date are listed for each study.

Table 3. Literature review studies in order of publication date.

Study	Study type	Scope	Functional units	Publication date
(Koehler & Wildbolz, 2009)	Journal article	Cradle-to-gate and Cradle-to-grave	(1) 1kg of finished product (2) One application of nine different products	21.10.2009
(Guilbot et al., 2013)	Journal article	Cradle-to-gate and Cradle-to-grave	(1) Preparation of emulsion (2) Production of 1t of packaged APG in a plant	4.10.2013
(Glew & Lovett, 2014)	Journal article	Cradle-to-gate	1 kg of shea butter formulated and packaged in a finished cosmetic product	1.4.2014
(Secchi et al., 2016)	Journal article	Cradle-to-gate	Three options in the production of a day face cream	15.8.2016
(Martinez et al., 2017)	Journal article	Cradle-to-grave	Preparation and use of one 30 g jar of cosmetic cream	1.3.2017
(de Camargo et al., 2019)	Journal article	Cradle-to-grave	(1) Corporate activities of the company in 2013 (2) One use of representative 10 products	30.7.2018
(Pacheco & Huston, 2018)	Journal article	Cradle-to-gate	(1) Traditional 1,3-Butylene Glycol production (2) Natural alternative production	15.11.2018
(Lambert, 2019)	Master's thesis	Cradle-to-gate	1l of raw ylang-ylang complete (III) oil	2019
(Kröhnert & Stucki, 2021)	Journal article	Cradle-to-grave	One hair wash of the investigated shampoo	29.7.2021
(Pagels et al., 2022)	Journal article	Cradle-to-gate	(1) 1 kg of a cosmetic product (2) minimum antioxidant concentration for 1 kg of cosmetic product	30.10.2022
(Righi et al., 2023)	Journal article	Cradle-to-gate	The amount of UV-filters necessary to obtain 100,0 g of sunscreen	1.3.2023
(Gaurav et al., 2023)	Journal article	Cradle-to-grave	1kg of soap	8.6.2023
(Martz et al., 2023)	Journal article	Cradle-to-gate	Production of 1 kg of a fragrance ingredient	28.7.2023
(Rudolf et al., 2024)	Journal article	Cradle-to-gate	100kg of cosmetic cream	12.12.2024

Apart from one master's thesis, all the studies are from scientific journals. While articles from scientific journals are usually peer reviewed, making them more credible, the thesis was reviewed to be done very thoroughly and thus it is included in the results. A master's thesis is generally a large enough work, that a comprehensive LCA can be conducted for it.

The publication dates of the studies are set between the years 2009-2024. There is no trend on the scopes over time, other than only the first two conducting both cradle-to-gate and cradle-to grave at once. Out of the 14 studies, eight studies carried out cradle-to-gate LCA studies. Four performed cradle-to-grave, while two studies included both cradle-to-gate and cradle-to-grave.

Examining the used functional units reveals much about the achievements of the study. The functional unit of all the studies carried out cradle-to-gate is either a certain amount of a finished product or a certain amount of an ingredient in a finished product. The studies carried out cradle-to-grave assess the entire life cycle of products with most of them focusing on the use phase. The following sections go more into detail about the findings of each study. They are divided into two sections based on the used scope and presented in the order of publication date.

4.1 Cradle-to-gate

Koehler & Wildbolz compare the environmental footprints of home-care and personal-hygiene products (Koehler & Wildbolz, 2009). For the purposes of this thesis, only the parts about the cosmetic products (a bar soap and a liquid soap) are reviewed. The bar soap consists mainly of palm oil, coconut oil and sodium hydroxide. The liquid soap is represented by an antibacterial foaming hand-wash fluid, consisting mostly of synthetic ingredients. In this study, packaging is included in the results. Both cradle-to-gate and cradle-to-grave studies were carried out. For now, the cradle-to-gate part of the study is reviewed. For this, 1kg of final product was assessed. Chemicals representing under 1% of total product mass were excluded and production conditions were assumed to be the average conditions. Liquid soap was found to have 1.5-4.6 higher cumulative fossil energy demand than bar soap. However, the carbon footprint of raw chemical production and supply, as well as process waste disposal of bar soap was higher than the liquid alternative. Bar soap's environmental profile was found to be highly driven by land-use impacts of vegetable oil production, which is bar soap's main ingredient.

Guilbot et al. assess the environmental impacts of an alkyl polyglucoside composition (APG) in a cosmetic cream (Guilbot et al., 2013). APG is widely considered environmentally friendly due to its vegetable origin and its manufacturing process complying with the 12 rules of Green chemistry. It can be used as a self-emulsifier in cosmetics. The study aimed to provide quantifiable measurements and assess several potential improvements to decrease

APG's global impacts. Both cradle-to-gate and cradle-to-grave studies were carried out. Seven impact categories were selected for both. For now, the cradle-to-gate part of the study is reviewed. The cultivation of raw materials to the production of APG was first assessed. This was done by studying the preparation of 1 t of packaged APG in a plant located in the South of France. LCI data was collected from direct industrial data as well as from literature. This part of the study found that cetearyl alcohol manufacturing conditions have a major impact on the environmental profile of APG, as APG's weight is over 80% contributed to cetearyl alcohol. The carbon footprint of APG was calculated to be between 1.9 and 49.8 t CO_2 eq. per t of APG. The cultivation of palm trees and the resulting land use directly impact APG's carbon footprint.

Glew & Lovett conducted LCA to study Greenhouse gas emissions across the shea butter supply chain (Glew & Lovett, 2014). The used functional unit is determined as 1 kg of shea butter formulated and packaged in a finished cosmetic product, but only the emissions relating to shea butter are considered. This makes the results comparable to other vegetable oils in possible future studies. Cosmetic packaging is included in calculations. Alternative low carbon opportunities for the supply chain were assessed and compared to traditional processing. Post-harvest processing and extraction were found to cause more than 75% of the total GHG emissions. Refining and formulation were responsible for less than 2%. Plastic packaging of the product was found to have major effect, causing almost fifth of total GHG emissions. The low carbon opportunities were found to greatly reduce shea butter emissions, but also possibly reduce the positive effects current methods bring to local economies. Several limitations are mentioned. The comparisons are based on studies with unknown scopes. The occurrence of co-products in the refining stages and their carbon footprint is not considered. The accuracy of data on specific processes supplied from the shea cosmetics formulation factory and shea butter mechanical extraction factory was stated unknown.

Secchi et al. study, if the chosen ingredients for a cosmetic significantly contribute to the environmental impact of the final product (Secchi et al., 2016). They perform the study by examining three possible cosmetic cream formulations, one benchmark product with fossil-based ingredients and two alternatives, both with two ingredients replaced to different bio-based alternatives. The bio-based raw materials were sourced from olive oil production side-streams. The motive of the study is to ensure that these natural ingredients do not cause burden shifting in their life cycle i.e. making them actually less sustainable. The study showed that with accurate formulation design, the bio-based compound could bring positive contributions. But also, that the presumed eco-friendly options could result in a worse environmental profile. They found that the main environmental impacts caused by bio-based ingredient compared to benchmark came from treatments to the ingredient to make it suitable to cosmetic use. In addition to data limitations, the authors note ignoring the impact of the mixtures of chemicals. Due to the obtained results, the authors point out the relevance of adopting LCA for green chemistry options.

Pacheco & Huston carry out a comparative LCA between petroleum-based and naturally-sourced glycols (Pacheco & Huston, 2018). This LCA is conducted by Genomatica, the same company that has developed the naturally-sourced glycol 1,3BG called Brontide. The study found petroleum-based glycol production to have 103% greater global warming potential (GWP) and 85% greater energy demand from non-renewable resources, compared to Brontide. However, the biobased alternative was found to perform worse on all other examined impact categories: Eutrophication Potential, Blue Water Consumption and Smog Formation Potential. Despite this, the study concludes these to be less significant than GWP and energy demand, making Brontide the more sustainable option.

Lambert studies the environmental impact of ylang-ylang essential oil, a widely used fragrance in cosmetics that is marketed as natural (Lambert, 2019). The study found ylang-ylang to perform mostly similarly compared to other essential oils, especially lemon and orange oils. However, a notable difference in water consumption was noted, caused by extraction via steam distillation. In addition to water use, a significant amount of the oil's impact turned out to come from fertilizers and the capital goods used in production. The cultivation of the studied ylang-ylang flowers seemed to have a relatively positive effect on the surrounding area's biodiversity. Although, this is noted to depend on production techniques a lot. The study concludes that the chosen ingredients of a cosmetic product may have greater weight in the impact than the production processes of the product itself. The choice of production techniques significantly determines ylang-ylang essential oil's environmental footprint. Lambert states the list of limitations of the study to be long and thus, no conclusive statement is made regarding the sustainability of the oil. They also note the dire need for an increase in database information especially for African products, as notable amounts of cosmetic ingredients are sourced from the continent.

Pagels et al. evaluate the environmental impact of seaweed extracts in comparison to commonly used ingredients with antioxidant properties; green tea extract and ascorbic acid (Pagels et al., 2022). All 16 environmental impact categories were assessed. The study also aims to propose improvements to seaweed processing after identifying the hotspots in processing. Seaweed was found to have lower environmental impact compared to both green tea extract and ascorbic acid. Seaweed performed better than green tea in all impact categories and had a similar or lower impact than ascorbic acid. In addition, seaweed's cultivation at sea compared to terrestrial plants and the ingredient's natural origin are considered advantageous characteristics. With the use of renewable energy in processing, repurposing the residue from seaweed extraction and using an alternative drying method the environmental impacts could be minimized.

Righi et al. investigate the environmental impacts of natural calcium phosphate (Cap-N) from fisheries as UV-filters in sunscreen (Righi et al., 2023). They did this by partially substituting UV-filters of a sunscreen with Cap-N and comparing them to zinc oxide nanoparticles (ZnO NPs). ZnO NPs are used in sunscreens, but they have been reported to possibly penetrate damaged skin into the body as well as cause harm in marine ecosystems. The study found Cap-N to be neither toxic nor ecotoxic. Cap-N's environmental performance was also found to be better in the majority of the 16 examined impact categories. Significantly higher impact (140%) was only found in the use of fossil resources. The study does not consider the end-of-life, but a conservative assumption is made that end-life is the same in the alternatives, as Caps are less toxic than Zno NPs.

Martz et al. use LCA to study the environmental impacts of fragrance ingredients (Martz et al., 2023). The study assesses 27 fragrance ingredients, which were selected from fragrances used by L'Oréal. The hundreds of ingredients were categorized and the most used were selected from each category. Also, the ingredients with the worst and best environmental profiles were included for better diversity. The results reveal significant variations between different ingredients. They found, that using renewable ingredients does not automatically lead to lower environmental impacts. The production of raw materials is shown to cause the biggest environmental impact, followed by their transformation process. Solvents used in some ingredient's extraction are also mentioned as significant pollutants. Because specific fragrance compositions are kept confidential by producers, LCAs of products containing fragrances must often rely on simplified representative ingredients. Martz et al. propose that the results from this study could be used to help develop a clustering method for conducting LCA for fragrances.

Rudolf et al. evaluate the environmental impacts of producing a cosmetic cream with Gold nanoparticles (AuNPs) also containing Hyper-Harmonized Hydroxylated Fullerene Water Complex (3HFWC) (Rudolf et al., 2024). Both these nanoparticles provide skin benefits, including anti-aging properties when applied to cosmetics. However, as they have gained popularity as innovative ingredients, questions about their sustainability and toxicity have risen. In addition to evaluating the product's environmental footprint the study aims to identify opportunities for reducing its environmental impacts. The study revealed several critical areas of environmental impact, most significant being AuNP synthesis with its high energy and water use. AuNP synthesis contributes to freshwater eutrophication, which is one of the biggest concerns usually associated with using nanoparticles. Resource depletion of precious metals for cosmetic use is noted as problematic. Results on toxicity had such high variability, that more data and investigation is suggested. Rudolf et al. include several options for mitigating the environmental impacts of the process. Optimizing the AuNP synthesis or even exploring alternative materials with lower environmental impacts are mentioned.

4.2 Cradle-to-grave

In addition to a cradle-to-gate study, Koehler & Wildbolz also performed a cradle-to-grave study on comparing the environmental footprints of home-care and personal-hygiene products (Koehler & Wildbolz, 2009). This part of their study focused on the entire life cycle of the products. The used functional unit was determined as “one typical application”. Typical and alternative consumer practices were modelled to describe the typical use of products as accurately as possible. Home transport from stores was also included in the calculations for use phase, based on mobility studies and Swiss consumer-price index. Wastewater treatment from consumer use containing the specific chemicals from the products was computed. Disposal of the packaging materials was also included in the end-of-life LCI data. The use phase of the products was found to contribute heavily to the product’s carbon, energy and environmental footprints. For the soaps, 90-99% of this is due to warm-water supply use. Overall, bar soap’s environmental and carbon footprint is 88% caused by consumer-use stage. For liquid soap, production plays a bigger role (28-52%) with use phase contributing less (42-49%). When assessing both study scopes, the alternative soaps show notable trade-offs. Although the cradle-to-gate showed the environmental footprint of producing bar soap to be bigger, cradle-to-grave showed that washing hands with bar soap is better compared to liquid soap considering all studied indicators.

In addition to a cradle-to-gate study, Guilbot et al. also performed a cradle-to-grave study assessing the environmental impacts of an alkyl polyglucoside composition (APG) in a cosmetic cream (Guilbot et al., 2013). Now the life cycle from raw materials to the end-of-life is assessed. This was done by studying the preparation of an oil in water emulsion. The results show the formulation processes and the use phase having the biggest impact on the overall impact of the cream. Emulsion oil and cosmetic packaging contribute most to formulation processes. The study proved APG to have a relatively small impact (4 to 24%) to the overall impact of a cream containing 5% of the ingredient. To confirm the green status of the assessed biosurfactant, the authors suggest future studies to compare the found results to other surfactants.

Martinez et al. study the environmental impacts of a bio-sourced cosmetic cream containing an alkyl polyglucoside (APG) surfactant based on refined palm kernel oil (RPKO) (Martinez et al., 2017). Used baseline scenario was the best oil palm agricultural practices in Malaysia. Transport and packaging were found to be most impactful life cycle stages of the cream. RPKO's contribution to the creams impact was found to be on average 20%. Deforestation and peat soil occupation had major impacts on climate change and land use impacts. The contribution of RPKO was not found critical regarding other processes along the entire life cycle of the cosmetic cream.

de Camargo et al. study the annual corporate activities of a representative cosmetic company and use of 10 cosmetic products by implementing organizational LCA (de Camargo et al., 2019). The study was conducted to act as a proof of concept for an even broader product portfolio of NATURA's 2600 products. The ten representative products were bestsellers chosen from different product categories. The study assessed the entire life cycle of products. The end-of-life fate of ingredients was excluded due to lack of data. Corporate activities were modelled separately to cover the impacts of transport and distribution as well as distribution and commercialization materials, which do not directly relate to individual products. The model portraying NATURA's annual product's portfolio is defined as impacts of corporate activities in addition to product life cycle of each representative product, multiplied by the total number of products sold in the corresponding product category. The study found that the products' production life cycle stages and especially the use phase contribute most to the company's overall impact. Corporate activities represented less than 10% in 12 out of the 18 assessed impact categories. The choice of suppliers was seen as a significant factor to potentially mitigate the company's global impacts. Out of the ten assessed products, a soap bar was found to have the biggest impact, with palm oil plant origin, raw material transport and warm water for use phase contributing most to it. The authors found this pilot study successful and NATURA plans to include more LCI product data to carry out future studies.

Kröhnert & Stucki analyze the environmental impact of a plant-based shampoo produced and marketed in Zurich (Kröhnert & Stucki, 2021). The aim of the study was to identify the hotspots during the life cycle, consider better possibilities based on identified hotspots and analyse different refill options. The packaging is included in this LCA. The study assessed "one hair wash" which was approximated using average German consumers shampoo application data. The study found that the use phase caused the biggest impact in all included categories, except for land use. The production of ingredients of the purely plant-based shampoo contributed most to land use. The impacts of the use phase were found to be heavily dependent on the consumers showering habits. The impact of packaging and its disposal had little effect on overall impacts. They could be further lowered with refill options.

Gaurav et al. research the environmental effects caused by the production and use of 1kg of bar soap (Gaurav et al., 2023). Packaging is included in the study. LCI data was partly provided by the soap manufacturer based on a questionnaire designed to get high quality data for the purposes of this study. Lack of information on part-level data or materials is mentioned as one notable limitation of the study. However, the overall quality of the data is stated to be high. The results of the study show eutrophication to have the biggest impact compared to other categories. Consumer behaviour was found to have major influence on the environmental impact of bar soap, as the use phase significantly affects most assessed categories.

5 Discussion

Several conclusions can be drawn from the existing LCA studies on cosmetics. The studies included in this review have evident achievements, but undoubtedly, there is still a dire need for further investigation to be done. This section discusses the achievements, trends, limitations and advantages of the reviewed studies. Also, opportunities for improvement are discussed.

5.1 Trends and achievements

Most of the studies are carried out cradle-to-gate, rather than cradle-to-grave. The appropriate scope depends on the aims of the study. When the life cycle of a single product is examined, a broader scope provides more comprehensive results. Cradle-to-grave model should also be used in comparative studies with differing or unexplored gate-to-grave situations. However, in comparative studies when the use and end-of-life phases do not differ significantly, the use of cradle-to-gate is appropriate. Also, if the goal is to focus especially on the production process and possibly explore alternative production processes the cut-off at gate is justified. The aims and the scopes of the reviewed studies mostly correspond with one another. Secchi et al., (2016) note that the cut-off at the gate possibly causes uncertainty at the results in the study about alternative bio-based cosmetic ingredients. The use of cradle-to-grave is appropriate in all the studies that used the broader scope. Most cradle-to-grave studies focus on the use phase or finding the hotspots across the entire life cycle.

Most studies include a comprehensive set of impact categories. All but one calculate most of the impact categories corresponding to table 2. Individual categories have been omitted in certain studies, for example due to insufficient data on them. LCA study by Glew & Lovett, (2014) about shea butter use in cosmetics calculates only greenhouse gas emissions.

The studies show some mixed results in comparisons between synthetic and alternative ingredients. Most studies assessing biobased ingredients or novel ingredients found them to perform better than their traditional counterparts. However, three studies found that incorporating biobased raw materials might have negative impacts to a cosmetic's overall sustainability (Martz et al., 2023; Pacheco & Huston, 2018; Secchi et al., 2016). Martz et al. (2023) found that using biobased materials in fragrances did not necessarily lead to a lower environmental impact. In addition, Pacheco & Huston, (2018) found biobased glycol to perform worse than petroleum-based glycol in all assessed impact categories, except for GWP and energy demand. Secchi et al., (2016) found that using biobased ingredients in a cosmetic cream can make it less preferable than its fossil-based alternative. For example, human toxicity, radiation, acidification and freshwater eutrophication were found to possibly perform worse with a biobased ingredient. The importance of reliable sustainability assessment is highlighted by the fact that incorporating some biobased ingredients might have negative effects to a cosmetic's environmental impact.

Most of the studies are comparative. In some, the primary aim of the study is the comparison of different alternatives. In addition to these, as a part of the assessment of a single research subject, comparisons—such as between production methods—are incorporated into the analysis. Incorporating comparisons in any way to LCA is very effective. As many LCA studies are not directly or possibly at all comparable with each other, this makes the results immediately more applicable. The utilization of previous studies is possible to some extent. For instance, Martinez et al., (2017) draw upon the previous study about APGs in cosmetics from Guilbot et al., (2013) in their study about an APG surfactant based on palm oil.

LCA always assesses a very specifically defined situation, but by examining the results, some general conclusions can nevertheless be drawn. The use phase is shown to cause major impacts in most products assessed cradle-to-grave. Four studies examined wash-off products, where water consumption in the use phase accounts for the largest impacts. In addition, Guilbot et al., (2013) found the use phase of a cream containing APG to notably contribute to its overall impact, but this was caused by the transport of product from retailer to customer. Even tough packaging is outside the scope of this thesis, several LCAs included packaging in the life cycle assessments. In many instances, packaging was mentioned as a notable contributor to the overall impacts of a cosmetic product.

The products assessed thus far are mostly soaps, shampoos and creams. This leaves many knowledge gaps for future research, as the number of product types in cosmetics is high. LCA studies on popular products like serums, toners and nail polishes could prove insightful.

Looking at how the studies have evolved over time; it is possible to point out some trends. First, the studies have been published with increasing frequency over the years, with six of them published in the 2020s. It makes sense, since sustainable development is getting increasingly topical and significant in cosmetics. Second, a trend on the types of studied products can be noticed. Many of the earlier LCAs focused on widely used products and materials. More recent studies are shifting the focus to novel materials like seaweed, fish bones and gold nanoparticles.

Nearly all the studies state the need for more research to be done on the sustainability of cosmetics. Most state the results of their studies could be further investigated in further research. The uncertainty of the LCA method is likely to decrease with more research. European commission has developed Product Environmental Footprint (PEF) to improve the comparability of environmental assessments and the communication of the environmental performance of products to consumers (Haverkamp et al., 2025). PEF is based on LCA, and it could be a promising improvement to the method.

5.2 Limitations

All the studies state limitations. The list of limitations is more comprehensive in some studies than in others. All report relying on estimated data from databases like Ecoinvent to compensate for missing data. For instance, collecting background inventories often needs estimates. The infrastructure needed for processes in not considered in most studies. Chronologically the first two (Guilbot et al., 2013; Koehler & Wildbolz, 2009) do not specifically acknowledge their uncertainties. The used estimations are mentioned in sections describing the used methodology, but effects from them are not discussed. In addition, the study on organizational LCA (de Camargo et al., 2019) does not discuss the uncertainties. Most studies have a chapter dedicated to discussing the limitations. Only one study included uncertainty analysis. Secchi et al., (2016) implemented Monte Carlo simulation for uncertainty analysis of the model outcome. Gaurav et al., (2023) note that uncertainty analysis should be conducted to make their study results more reliable. Most studies performed sensitivity analysis on used parameters or the results to test their robustness.

It is evident that reporting the results in an effective way is difficult to do. The results are often not straightforward, and the calculations produce a large amount of data. The results are frequently presented in tables, and while this shows some of the results clearly and effectively, a proper understanding of them requires extensive background knowledge of the study methods. This issue should be considered, as the limitation significantly affects the applicability of the method. Effectively presenting results to non-expert audiences, like stakeholders, is crucial not only for companies but also in the research community.

The consistency of the method is also a problem. If two researchers were to carry out an LCA with the same purpose, using the same functional unit and the same scope, the freedom of the method would most likely lead them to have entirely different results, even if both would use the method correctly by the standards. Reproducibility is one of the key characteristics of scientific research. Even if all the choices and calculation methods could be documented in the research report, this level of variability in the results is undesirable.

5.3 Advantages

Despite LCA's limitations, the method has many advantages and appropriate applications. It is very versatile, and practically, it can be applied to almost infinite scenarios, though this is somewhat limited by data availability. The method is great for comparisons of alternative production methods or materials. It can be used to assess very targeted situations in detail and identify hotspots along the value chain. Despite the variability in data quality, properly carried out LCA studies can produce very high-quality results.

LCA can be utilized to investigate environmental aspects very extensively, instead of just focusing on one aspect of it. The 16 most used impact categories allow for the exploration of multiple aspects of sustainability. By examining the impacts of a process in multiple categories, it is possible to analyse the trade-offs between alternatives and avoid unintended burden shifting.

Although comparing the studies with one another is challenging and some of the data show considerable geographical variability, examining different cosmetic value chains always provides valuable new data. New information enhances the understanding of other value chains as well, enabling process developments. In addition, examining the whole value chain can further contribute to a transition toward more sustainable practices, as it shows the relevance of, for instance, the suppliers' practices.

Like mentioned earlier, LCA has shown that not all materials from renewable sources can be considered sustainable. An example like this underlines, that data-driven decisions are always better, than decisions based on assumptions. Through its ability to model various scenarios, LCA helps reduce the risk of investing on new technology that might be detrimental in the end.

6 Conclusion

This bachelor's thesis studied the use of Life Cycle Assessment on cosmetic products. The potential of the method for use in specifically cosmetics was reviewed. The motive for the thesis came from the knowledge gap caused by insufficient quantitative studies on the sustainability of cosmetics. The focus of the thesis was on cosmetic products themselves and cosmetic ingredients, excluding their packaging. Cosmetic packaging is already more extensively studied.

The usability of the method was examined by reviewing existing LCA studies on cosmetics. The thesis was carried out as a systematic literature review. The search resulted in 14 studies. As a general conclusion from the literature review, it can be stated that assessing the sustainability of cosmetics is a complex and challenging topic. The existing research on the subject is limited, and there is a considerable need for future studies.

The aim of this thesis was to examine the potential of LCA as a method for assessing the sustainability of cosmetic products. The results are not entirely unambiguous. LCA has many limitations, but also many advantages. Both should be thoroughly noted, when considering if carrying out the study would be beneficial. The main limitations of the method are deficient data availability, difficult result reporting, problematic research reproducibility and comparability between different studies. The main advantages of the method are comprehensive analysis of different aspects of sustainability, identifying hotspots along the value chain and high data quality to help with important decisions. In addition, the method proves particularly suitable for conducting comprehensive comparisons between alternatives.

In the future we are likely to see more LCA done on various cosmetic products and ingredients. This would be a highly desirable direction. LCA based tools and new methods like PEF might help address the challenges of LCA and provide new perspectives. As cosmetics are studied more, more data is likely to become available.

References

Brundtland, G. H. (1987). *Our common future world commission on environment and developement*. http://www.un-documents.net/ocf-02.htm

Bueno, C., Hauschild, M. Z., Rossignolo, J. A., Ometto, A. R., & Mendes, N. C. (2016). Sensitivity analysis of the use of Life Cycle Impact Assessment methods: a case study on building materials. *Journal of Cleaner Production*, *112*, 2208-2220. https://doi.org/https://doi.org/10.1016/j.jclepro.2015.10.006

Damiani, M., Ferrara, N., & Ardente, F. (2022). *Understanding Product Environmental Footprint and Organisation Environmental Footprint methods*. Publications Office of the European Union. https://doi.org/doi/10.2760/11564

de Camargo, A. M., Forin, S., Macedo, K., Finkbeiner, M., & Martínez-Blanco, J. (2019). The implementation of organizational LCA to internally manage the environmental impacts of a broad product portfolio: an example for a cosmetics, fragrances, and toiletry provider. *The International Journal of Life Cycle Assessment*, *24*(1), 104-116. https://doi.org/10.1007/s11367-018-1502-4

Furberg, A., Arvidsson, R., & Molander, S. (2022). A practice-based framework for defining functional units in comparative life cycle assessments of materials. *Journal of Industrial Ecology*, *26*(3), 718-730. https://doi.org/https://doi.org/10.1111/jiec.13218

Gaurav, G., Dangayach, G. S., Meena, M. L., Chaudhary, V., Gupta, S., & Jagtap, S. (2023). The Environmental Impacts of Bar Soap Production: Uncovering Sustainability Risks with LCA Analysis. *Sustainability*, *15*(12), 9287. https://www.mdpi.com/2071-1050/15/12/9287

Glew, D., & Lovett, P. N. (2014). Life cycle analysis of shea butter use in cosmetics: from parklands to product, low carbon opportunities. *Journal of Cleaner Production*, *68*, 73-80. https://doi.org/https://doi.org/10.1016/j.jclepro.2013.12.085

Guilbot, J., Kerverdo, S., Milius, A., Escola, R., & Pomrehn, F. (2013). Life cycle assessment of surfactants: the case of an alkyl polyglucoside used as a self emulsifier in cosmetics [10.1039/C3GC41338A]. *Green Chemistry*, *15*(12), 3337-3354. https://doi.org/10.1039/C3GC41338A

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., & Rydberg, T. (2011). Life Cycle Assessment: Past, Present, and Future. *Environmental Science & Technology*, *45*(1), 90-96. https://doi.org/10.1021/es101316v

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (2018). *Life Cycle Assessment: Theory and Practice*. Springer Cham. https://doi.org/https://doi.org/10.1007/978-3-319-56475-3

Haverkamp, P., Schmidt, L., Backes, J. G., & Traverso, M. (2025). Product Environmental Footprint in the construction sector – Proposal and assessment of a representative product for carbon-reinforced concrete. *Journal of CO2 Utilization*, *95*, 103078. https://doi.org/https://doi.org/10.1016/j.jcou.2025.103078

ISO. (2006). ISO 14040:2006(en) Environmental management — Life cycle assessment — Principles and framework. In.

Koch, D., Friedl, A., & Mihalyi, B. (2023). Influence of different LCIA methods on an exemplary scenario analysis from a process development LCA case study. *Environment, Development and Sustainability*, *25*(7), 6269-6293. https://doi.org/10.1007/s10668-022-02302-w

Koehler, A., & Wildbolz, C. (2009). Comparing the Environmental Footprints of Home-Care and Personal-Hygiene Products: The Relevance of Different Life-Cycle Phases. *Environmental Science & Technology*, *43*(22), 8643-8651. https://doi.org/10.1021/es901236f

Kokare, S., Oliveira, J. P., & Godina, R. (2023). Life cycle assessment of additive manufacturing processes: A review. *Journal of Manufacturing Systems*, *68*, 536-559. https://doi.org/https://doi.org/10.1016/j.jmsy.2023.05.007

Kröhnert, H., & Stucki, M. (2021). Life Cycle Assessment of a Plant-Based, Regionally Marketed Shampoo and Analysis of Refill Options. *Sustainability*, *13*(15), 8478. https://www.mdpi.com/2071-1050/13/15/8478

L'Haridon, J., Patouillard, L., Pedneault, J., Boulay, A.-M., Witte, F., Vargas-Gonzalez, M., Bonningue, P., Rollat, I., Blanchard, T., Goncalves, G., Hervio, A., & Gilbert, L. (2023). SPOT: A Strategic Life-Cycle-Assessment-Based Methodology and Tool for Cosmetic Product Eco-Design. *Sustainability*, *15*(19), 14321. https://www.mdpi.com/2071-1050/15/19/14321

Lambert, M. (2019). *Cradle-to-Gate Life Cycle Analysis (LCA) of Ylang-Ylang Complete Essential Oil Destined for Cosmetic Use from Central Region, Ghana Using the Software SimaPro* [Master's thesis, Université Libre de Bruxelles]. https://mem-envi.ulb.be/Memoires_en_pdf/MFE_18_19/MFE_Lambert_18_19.pdf

Life Cycle Assessment & the EF methods. (2025). European Commission. https://green-forum.ec.europa.eu/green-business/environmental-footprint-methods/life-cycle-assessment-ef-methods_en

Liu, J.-K. (2022). Natural products in cosmetics. *Natural Products and Bioprospecting*, *12*(1), 40. https://doi.org/10.1007/s13659-022-00363-y

Lumene Group Annual Report 2024. (2024). https://www.lumenegroup.com/wp-content/uploads/2025/05/Lumene-Group-Annual-Report-2024.pdf

Martinez, S., Bessou, C., Hure, L., Guilbot, J., & Hélias, A. (2017). The impact of palm oil feedstock within the LCA of a bio-sourced cosmetic cream. *Journal of Cleaner Production*, *145*, 348-360. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.01.042

Martz, P., Phan, T. V. T., L'Haridon, J., Beausoleil, M.-H., Lafaye, K., Gérand, Y., & Gallardo, C. (2023). Environmental profile of the production of fragrance ingredients used in cosmetic products: comparative analysis of results obtained by life cycle assessment and the green chemistry-based eco-design tool GREEN MOTION™ [10.1039/D2GC04860D]. *Green Chemistry*, *25*(16), 6365-6382. https://doi.org/10.1039/D2GC04860D

Pacheco, R., & Huston, K. (2018). Life Cycle Assessment (LCA) of Naturally-Sourced and Petroleum-Based Glycols Commonly Used in Personal Care Products. *SOFW Journal*, *144*(11), 12-15. https://www.brontidebg.com/wp-content/uploads/2020/09/SOFW-LCA-Article.pdf

Pagels, F., Arias, A., Guerreiro, A., Guedes, A. C., & Moreira, M. T. (2022). Seaweed Cosmetics under the Spotlight of Sustainability. *Phycology*, *2*(4), 374-383. https://www.mdpi.com/2673-9410/2/4/21

Pohl, J., Suski, P., Haucke, F., Piontek, F. M., & Jäger, M. (2019). Beyond Production—the Relevance of User Decision and Behaviour in LCA. In F. Teuteberg, M. Hempel, & L. Schebek (Eds.), *Progress in Life Cycle Assessment 2018* (pp. 3-19). Springer International Publishing. https://doi.org/10.1007/978-3-030-12266-9_1

Product carbon footprint pre-study. (2025). Lumene Oy. Retrieved 20/7/2025/ from https://uk.lumene.com/pages/life-cycle-assesment-study-and-product-carbon-footprint-pre-study

Righi, S., Prato, E., Magnani, G., Lama, V., Biandolino, F., Parlapiano, I., Carella, F., Iafisco, M., & Adamiano, A. (2023). Calcium phosphates from fish bones in sunscreen: An LCA and toxicity study of an emerging material for circular economy. *Science of The Total Environment*, *862*, 160751. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.160751

Rocca, R., Acerbi, F., Fumagalli, L., & Taisch, M. (2023). Development of an LCA-based tool to assess the environmental sustainability level of cosmetics products. *The International Journal of Life Cycle Assessment*, *28*(10), 1261-1285. https://doi.org/10.1007/s11367-023-02219-0

Rudolf, R., Majerič, P., Pintarič, Z. N., Horvat, A., & Krajnc, D. (2024). Life Cycle Assessment (LCA) of the Impact on the Environment of a Cosmetic Cream with Gold Nanoparticles and Hydroxylated Fullerene Ingredients. *Applied Sciences*, *14*(24), 11625. https://www.mdpi.com/2076-3417/14/24/11625

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. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.04.073

Statista. (2025). *Beauty & Personal Care - Worldwide* (https://www.statista.com/outlook/cmo/beauty-personal-care/worldwide

Trindade Filho, W. J., Borges, T. d. M. D., Silva, B. C. d., & Correia, V. M. S. (2025). The use of Life Cycle Assessment and the Leopold Matrix to analyze environmental aspects and impacts in a handmade soap production industry. *Gestão & Produção*, *32*.

Tukes. (2025). *Which products are 'cosmetic products'?* Finnish Safety and Chemicals Agency (Tukes). https://tukes.fi/en/chemicals/cosmetics/which-products-are-cosmetic-products-

Vargas-Gonzalez, M., Witte, F., Martz, P., Gilbert, L., Humbert, S., Jolliet, O., van Zelm, R., & L'Haridon, J. (2019). Operational Life Cycle Impact Assessment weighting factors based on Planetary Boundaries: Applied to cosmetic products. *Ecological Indicators*, *107*, 105498. https://doi.org/https://doi.org/10.1016/j.ecolind.2019.105498

Vassallo, N., & Refalo, P. (2024). Reducing the Environmental Impacts of Plastic Cosmetic Packaging: A Multi-Attribute Life Cycle Assessment. *Cosmetics*, *11*(2), 34. https://www.mdpi.com/2079-9284/11/2/34

Vieira, D. R., Calmon, J. L., & Coelho, F. Z. (2016). Life cycle assessment (LCA) applied to the manufacturing of common and ecological concrete: A review. *Construction and Building Materials*, *124*, 656-666. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2016.07.125