Environmental sustainability performance assessment tools in cosmetics industry: state of the art

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Abstract: The scientific literature confirmed that there is enough evidence of a trend of green consumerism in the cosmetics market. For this reason, it is no overstatement to say that sustainability innovation continually shapes the biological, environmental, social, and physical characteristics of cosmetics sector. What emerged also from the literature, is that there exist several drivers that push cosmetics organizations to become sustainable and that being fully sustainable means extending the green vision to the entire supply chain and to the entire product lifecycles. Cosmetics companies are required to shift toward sustainable manufacturing, integrating environmental and social objectives with the economics already considered. To support this transition, tools that allow companies to assess their current environmental sustainability level, set objectives, implement actions, and monitor the improvements are necessary. In this context, Life Cycle Assessment (LCA) is a well-known and standardized methodology for capturing the environmental impacts of a product, process, or human activity. The paper presents a systematic literature review aimed to identify the assessment tools that can be applied to evaluate environmental sustainability performances in the cosmetics industry. The analysis confirms that the most diffused methods are: (i) LCA, (ii) Carbon Footprint, (iii) Water Footprint and (iv) Environmental Risk Assessment. Secondly, the implementation degree of LCA in the cosmetics industry have been evaluated, identifying the main application area of LCA in cosmetics industry (i.e., cosmetics ingredients and their extraction process, cosmetics packaging, and skincare products).

Keywords: environmental sustainability; cosmetics industry; performance assessment tools; Life Cycle Assessment; systematic literature review.

I. Introduction

The organizations' interest in the implementation of sustainable practices is nowadays evident [1]. Thus, the current global focus is on supporting manufacturing industries to implement cleaner and more efficient production practices that enable the development of products and services with reduced negative environmental and societal impacts [2]. Companies are adopting different tools and instruments to assess the Triple Bottom Line (TBL) impacts (i.e., economic, social and environmental) of their products and their manufacturing chains [3]. [4] provide a categorization of sustainability assessment tools into three main clusters: (i) indicators and indices, (ii) product-related assessment tools and (iii) integrated assessment tools. Indicators are simple measures, most often quantitative, that represent a state of economic, social and/or environmental development. Product-related assessment tools are usually more focused on the environmental dimension of sustainability, and they are always based on the life cycle of the product, considering at times the eventuality of a Circular Economy approach [5]–[8]. The most established and well-developed tool in this category is Life Cycle Assessment (LCA). LCA is a structured, internationally standardized procedure for quantifying the emissions, consumed resources, as well as potential environmental and health impacts associated with a product [9]–[11]. Since LCA considers only the environmental dimension of the TBL concept, other two analogous approaches have been introduced: the Life Cycle Cost (LCC) and the Social Life Cycle Assessment (SLCA) [1], [12]. Finally, it's possible to talk about Life Cycle Sustainability Assessment (LCSA) that aims at a more comprehensive overview of sustainability issues [11], [13]. The third type of tools defined by Ness et al., are used for supporting decisions related to a policy or a project in a specific region. They usually have an ex-ante focus and often are carried out in the form of scenarios [4]. The Risk Analysis is an example of an integrated assessment tool [4]. Because of its heavy consumption of natural resources, cosmetics industry represents one of the sectors requiring a strategic vision to manage sustainability [14]. The need to guide the sector toward a sustainability transition is pushed by a strong emphasis on improving the environmental and social sustainability of its products and processes [15]. This contribution presents a systematic literature review aimed to identify the assessment tools that can be applied to evaluate environmental sustainability performances in cosmetics industry. Section 2 presents the research methodology underlies the work, while Section 3 shows the results of the literature review.

Finally, Section 4 ends the work with conclusions and final remarks.

II. RESEARCH METHODOLOGY

The research methodology of the work follows five steps, further described in the next sections: (i) definition of the research goals and research questions, (ii) literature review process; (iii) statistical analysis of the paper collected; (iv) critical review of the paper analysed; (v) literature review gaps identification.

A. Research goals and research questions

The overall goal of the work is to present a systematic literature review aimed to identify the assessment tools that can be applied to evaluate environmental sustainability performances in the cosmetics industry. The growth of the cosmetics sector involves high consumption of natural resources, emissions, and waste production. However, it seems not to be so clear what exactly means for a product, a company, and a supply chain in cosmetics industry to be sustainable [16], [17]. The first fundamental step is sustainability quantification and assessment, and several methodologies allow the measurement of the impacts. The research goal of the paper is twofold: (*a*) to identify the assessment tools that can be applied to evaluate environmental sustainability performances in cosmetics industry, and (*b*) understand the state of the art of LCA methodology application in cosmetics industry, being this one of the most widely used instruments [18]. The objective is the foundation for the research questions to be formulated. They are articulated as follows:

RQ1. What are the methodologies exploited in the cosmetics industry to measure environmental sustainability?

RQ2. What is the state of the art regarding the implementation of LCA in the cosmetics sector?

RQ1 is the most general question, and it aims to figure out how environmental sustainability is concretely measured in the cosmetics industry. The purpose of RQ2 is to investigate the LCA implementation in cosmetics.

B. Literature review process

This chapter describes in detail the literature review process conducted to answer to the two research questions. The review has been conducted following the PRISMA protocol [19] and it was mainly conducted analysing Scopus and Web of Science (WoS). To ensure comprehensive research, Google Scholar was also consulted. The additional papers found in the Google Scholar database were added to the papers resulting from all the filtering steps performed on Scopus and WoS. The papers resulting from this skimming process were then critically analyzed. In particular, the articles that could answer the RQ1 were classified according to the methodology described to assess environmental sustainability: (i) LCA, (ii) Carbon Footprint, (iii) Water Footprint, (iv) Environmental Risk Assessment (ERA), (v) others. Regarding RQ2, the articles focusing on the implementation of the LCA analysis were grouped based on the topics covered: (i) LCA of a cosmetic ingredient, (ii) LCA of a cosmetic product, (iii) LCA of a cosmetic process, (iv) LCA of cosmetic packaging, (v) LCA used to compare alternatives. The overall literature review process is outlined in Fig. 1. The keywords on Scopus and WoS used to narrow the research to the cosmetics industry are: "Cosmetic" and "Beauty". These two terms are usually employed to refer to cosmetics. The keywords exploited for underlining the sustainability concept are: "Sustainability" and "Green". Finally, the keywords for evaluating the papers dealing with the environmental sustainability assessment methods are: "Methodology", "Assessment", "Tool" and "LCA". Then, the literature search process continued following the 8 stages described below:

1. (Sustainability OR Green) AND (Cosmetic* OR Beauty).
2. Limit to (≥ year 2000). Only articles written in the time frame between 2000 and 2021 were considered for the analysis.
3. Limit to (English AND Italian). Articles in languages other than English or Italian were excluded.
4. (Sustainability OR Green) AND (Cosmetic* OR Beauty) AND (Assessment OR Methodology OR Tool OR LCA).
5. Limit to (Chemistry, Environmental Science, Chemical Engineering, Engineering, Materials Science, Business Management and Accounting, Energy, Pharmacology Toxicology and Pharmaceutics). Only the subjects that could potentially give relevant insights for the industrial and management fields were considered in the research process.
6. Filter by abstract. The abstracts of the articles resulting from stage 5 were read to understand whether they are dealing with out-of-scope topics.
7. Filter by content. Reading the remaining articles allowed to address only those papers that would help answer the research questions.
8. Snowballing. By consulting the reference section of the articles found at stage 7, it was possible to spot other relevant papers.

The 35 final papers that were critically analyzed, represent the output of the literature review process and were obtained by summing the articles of the three databases found after stage 8 without counting the duplicates.

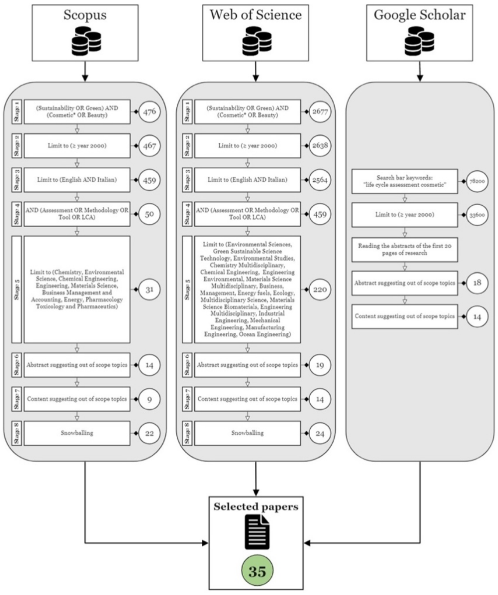

Fig. 1 Literature search process

The drastic reduction in the number of articles between stage 5 and stage 6 is mainly because: (i) many articles deal with alternative industrial processes to traditional ones or innovative raw materials that are considered more sustainable but without accompanying these reflections with an analysis of environmental impacts, (ii) other papers focus on the risk analysis of cosmetics ingredients on human health, leaving out the environmental aspect.

III. Results

In the next sections, the statistical analysis and the critical review of the paper analysed are reported.

A. *Statistical analysis of the paper collected*

The statistical description proposed regards the results obtained after stage 4 by examining both Scopus and WoS articles. The parameters considered for the statistical analysis are: (i) papers by year (only for WoS since the number of articles found after stage 4 in Scopus is too low to guarantee significant results); (ii) papers by country; papers by subject area (each article can belong to different subject areas). Starting from the number of papers by year, the following diagram summarizes the WoS results.

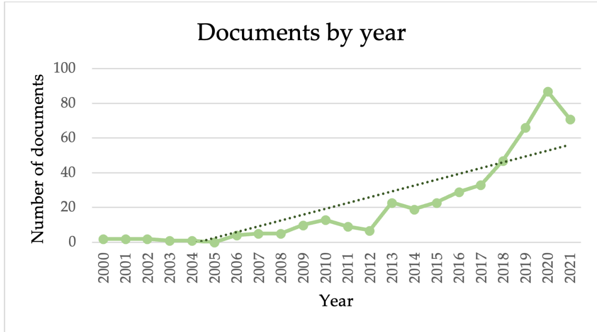

Fig. 2 Documents analysed by year

While between 2000 and 2010 the number of papers published annually remained almost unchanged, there has been an increasing trend in the last decade.

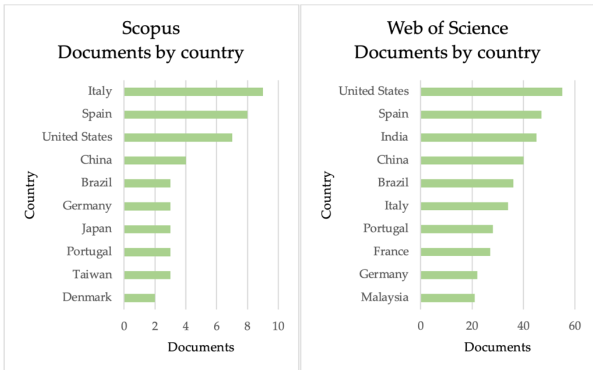

Fig. 3 Documents analysed by country

Italy ranks first if Scopus is used as a database. United States and Spain always occupy top positions.

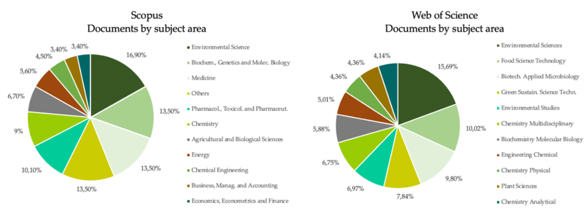

Fig. 4 Documents analysed by subject area

Papers discussing topics related to environmental science and chemistry are the majority in both databases. Interestingly, about 10% of the articles found with WoS belong to the “food science” category. The literature confirms that cosmetics and food industries are closely related in terms of raw materials, packaging, manufacturing processes and sustainability strategies.

B. Critical review of the paper analysed

In the last decades, with the increasing interest in environmental, economic and safety considerations, innovative alternatives with durable and green values have been hugely implemented in cosmetics industries. Following the twelve principles of green chemistry (2000) [20], and then the twelve principles of green engineering (2003) [21], researchers from academia and industry defined the term "green extraction" and established the six principles of green extraction (2012) [22], [23]. Green extraction is based on the discovery and design of extraction processes that will reduce energy consumption, allow the use of alternative solvents and renewable natural products, and ensure a safe and high quality extract/product [22]. Considering the last principle, a "green extract" or an "eco extract" must have a low environmental footprint. This parameter can be determined by using an LCA approach [22] or, in general, an environmental sustainability assessment methodology. Several assessment methods, indicators and tools exist, but they differ in goal and scope and are intended for different kinds of uses within companies, by consumers or by authorities to support policy planning and evaluation [24], [25]. The methods dealing with environmental issues that have been most found in the literature and used in the cosmetics industry are shown in Table I. Table I also proposes a classification of the 35 selected articles based on the tackled environmental impact assessment method.

TABLE I
CLASSIFICATION OF THE SELECTED ARTICLES BASED ON THE ENVIRONMENTAL IMPACT ASSESSMENT METHOD

Method	References
LCA	*(Civancik-Uslu,2019) (Jaccarini, 2017) (Jordan Gatt, 2021) (Muxika, 2017) (Guilbot, 2013) (Riazi, 2019) (Pérez-López, 2014) (Kyriakopoulou, 2015) (Secchi, 2016) (Martinez, 2017) (Koehler, 2009) (Kröhnert, 2021) (Chemat, 2019) (Monteiro, 2018) (Venkata Mohan, 2019) (Golsteijn, 2018) (Vauchel, 2018) (Kyriakopoulou, 2013) (Chakravarty, 2021) (Kulke, 2015) (Vargas-Gonzalez, 2019) (Campion, 2018) (Bom, 2019) (Pihkola, 2017) (Pihkola, 2017) (Clarke, 2018) (Cosmetics Europe, 2012) (Ness, 2007)*
Carbon Footprint	*(Glew, 2004) (Silalertruksa, 2017) (Francke, 2013) (Campion, 2018) (Pihkola, 2017) (Pihkola, 2017)*
Water Footprint	*(Silalertruksa, 2017) (Francke, 2013) (Pihkola, 2017) (Pihkola, 2017)*
Environmental Risk Assessment	*(Sadutto, 2021) (Sánchez-Quiles, 2015) (L'Haridon, 2018) (Bom, 2019)*
Others	*(Vargas-Gonzalez, 2019) (Pihkola, 2017) (Pihkola, 2017)*

The key findings of the literature review regarding the papers highlighted in Table I are illustrated in the following bulleted list.

- LCA, Carbon Footprint, Water Footprint and ERA are the main environmental impact assessment methods.

Observing Table I, the most often cited methods in the literature for assessing the environmental sustainability of cosmetics are four: LCA, Carbon Footprint, Water Footprint and ERA. Among them, the LCA methodology is the most used. In some cases, also extensions of the methodology are provided. For example, [26] aim to provide a new list of weighting factors covering all impact categories in the International Reference Life Cycle Data System (ILCD) impact assessment methodology and based on the Planetary Boundary concept. Carbon footprint is used to measure the greenhouse gas emissions (GHG) of products and processes [27]. Water Footprint (WF) is a consumption indicator of freshwater use that quantifies direct and indirect volumes. The indicator has three components [28]: (i) green water footprint; (ii) blue water footprint; (iii) grey water footprint. Finally, the ERA is a method that evaluates the likelihood or probability that adverse effects may occur to environmental values, as a result of human activities (i.e., a formal procedure for identifying and estimating the risk of environmental damage) [29].

- The implementation of ERA to assess the impacts of PPCPs.

The ERA is frequently used to evaluate the concentration of Pharmaceuticals and Personal Care Products (PPCPs) in the aquatic environment and the damage they may cause to the marine ecosystem. For instance, [30] focuses on a comprehensive monitoring of wastewater, surface water, sediment and soil in order to: (i) analyse the occurrence and spatial distribution of PPCPs in a Mediterranean coastal wetland affected by several land uses and increasing water scarcity; (ii) assess anthropic effects in different areas of the coastal wetland through the concentration of PPCPs; (iii) compare these results with those from a previous study made nine years ago; and (iv) estimate the environmental risks from PPCPs to the aquatic biota.

- Few tools to measure cosmetics products sustainability level.

Regarding the tools and methodology available to assess the level of sustainability of a product, very few articles were found in the literature and none of them are based on LCA. The "Sustainability calculator tool" proposed by [31] is created on the opinion of experts working in the different branches of the cosmetics industry. In 2014, L'Oréal Group developed an ecodesign methodology to reduce the aquatic environmental impact of new formulas [17]. Three environmental indicators have been selected to cover all possible impacts of ingredients upon the aquatic environment: (i) biodegradability, (ii) grey water footprint, and (iii) a complementary indicator, highlighting a possible alert on formula ingredients with an unfavourable environmental profile. The last indicator can fall in the category of "measuring the level of sustainability" of a cosmetic formula since it results in four possible colours corresponding to four possible global statements on the environmental profile of an ingredient. Even in this methodology, an LCA is not considered and the calculation of the three indicators is based on mathematical expressions. Concerning the papers found in the literature addressing the LCA topic, the table below summarizes whether the topic is tackled only in a theoretical way or if a real implementation and quantification of the results are described in the paper.

TABLE II
CLASSIFICATION OF THE SELECTED ARTICLES ADDRESSING LCA TOPIC

Method	References
LCA theory	*(Chemat, 2019) (Bom, 2019) (Pihkola, 2017) (Pihkola, 2017) (Clarke, 2018) (Cosmetics Europe, 2012) (Ness, 2007) (Campion, 2018)*
LCA of a cosmetic ingredient	*(Muxika, 2017) (Guilbot, 2013) (Riazi, 2019) (Pérez-López, 2014) (Kyriakopoulou, 2015) (Chakravarty, 2021) (Kulke, 2015)*
LCA of a cosmetic product	*(Secchi, 2016) (Martinez, 2017) (Koehler, 2009) (Kröhnert, 2021) (Golsteijn, 2018) (Vargas-Gonzalez, 2019)*
LCA of a cosmetic process	*(Monteiro, 2018) (Venkata Mohan, 2019) (Vauchel, 2018) (Kyriakopoulou, 2013) (Chakravarty, 2021)*
LCA of a cosmetic packaging	*(Civancik-Uslu,2019) (Jaccarini, 2017) (Jordan Gatt, 2021)*
LCA used to compare alternatives	*(Civancik-Uslu,2019) (Jaccarini, 2017) (Jordan Gatt, 2021) (Guilbot, 2013) (Riazi, 2019) (Pérez-López, 2014) (Kyriakopoulou, 2015) (Secchi, 2016) (Martinez, 2017) (Koehler, 2009) (Kröhnert, 2021) (Venkata Mohan, 2019) (Vauchel, 2018) (Kyriakopoulou, 2013)*

- Ingredients, packaging, processes and products as objects of the LCA.

The implementation of the LCA usually concerns an ingredient of the cosmetic formula, the packaging of cosmetic product, a production process for the extraction of raw materials, a cosmetic product itself. Regarding the raw materials, LCA is often used to assess the environmental impacts of ingredients and/or raw materials that will be included in the formula of a cosmetic, as in the case of microalgae [32], [33], shea butter [34], and Isostearic Acid (IA) [35]. Regarding makeup packaging, [36] describe an LCA analysis based on a small blush powder makeup compact, intended for portable everyday use. The main objective is the quantification and comparison of the different environmental life cycle impacts resulting from recycling and reusing plastic cosmetic packages. Regarding the cases of LCA implementation on processes, usually, the focus is on methods for extracting ingredients that can then be used as inputs in cosmetics manufacturing or other industries. In the field of extraction processes, different innovative technologies have emerged in the last decades, such as microwave, ultrasound, pulse electric field assisted extractions and extractions using pressurized fluids. Those technologies are commonly considered green extraction processes, as they generally permit reductions in time, energy, water and organic solvent consumption [37]. The few LCA analyses found in the literature and conducted on cosmetic products have skincare items as the objects of the analysis and not makeup ones [18].

- LCA used to compare alternative solutions.

The LCA is usually implemented to compare the sustainability of alternative solutions in terms of packaging materials and raw materials extraction methods. An example is represented by [38] where a cradle-to-gate LCA is conducted on three different cosmetics tubes which differ in terms of weight and material composition. In [39] a comparative life cycle analysis of different carotenoid extraction techniques is presented, while [40] analyse the use of alternative physical-chemical and biological-chemical methods for the extraction of ω3-rich lipids from liquid by-products. Also *what-if* analyses find space in the literature to understand how the environmental impacts change if the location of a supplier changes, if the use phase is not taken into account in the analysis, and if the operating conditions of a process are different. [41] conducted a LCA on cosmetic packaging focusing on the Global Warming Potential (GWP) and energy consumption. The case study proposed in [37] concerns a potential valorization of antioxidant polyphenols from chicory grounds, which are a by-product of chicory beverage industrial production.

- Raw material and use stage as main environmental impacts contributors.

The most impacting stages of the life cycle vary depending on the object of the analysis and on the system boundaries considered. When it comes to assessing the environmental impacts of packaging, the raw materials stage is frequently the main contributor. For instance, considering the LCA on the three different cosmetics tubes by [38], the raw materials extraction for the first tube contributes to more than 50% of the total impact for most of the impact categories. Also in [41] the raw material extraction phase results also as the most energy consuming phase of the lifecycle. [42] presents a recapitulation of LCAs of chitosan-based films performed by many authors. It was found that the most polluting stage for Chitosan films is raw material extraction followed by film manufacturing. [34] describes the most impacting stages on GHG of the shea butter life cycle: post-harvest processing and the raw materials extraction in Ghana cause over 75% of the entire GHG supply chain emissions. [43] stresses instead the connection between the impacts of raw materials and packaging when the objects of the analysis are household-cleaning agents, toilet care products and liquid soap. Indeed, as the final product water content increases, the raw chemical supply chain becomes less influential, and the packaging value-chain becomes more important. In the case of a cradle-to-grave analysis of a cosmetic product, the use phase plays a relevant role in terms of negative environmental impact. The study conducted by [43] shows that in a cradle-to-grave analysis, all the carbon, energy, and environmental footprints are heavily affected by the use phase with average contributions of 50-75% to the overall GWP. For soaps and detergents, environmental impacts caused by consumer use are mainly driven by warm-water supply, which accounts for 90-99% of the use phase associated GWP. In their study, [44] four scenarios are compared regarding the packaging of a shampoo including also refill options. Considering the baseline scenario, again the use phase is the most relevant life stage for all impact categories, except for land use, followed by the manufacturing stage. The work conducted by [45] investigates the role of the fragrance industry in the global sustainability debate and the impact of a fragrance in a consumer product life cycle. In the report, the data for water use and global warming CO2 equivalents per kg of fragrance material, surprisingly results that naturally sourced patchouli oil has a high carbon and water footprint. The results of the analysis concerning the cosmetic cream described in paper [18] show that sometimes an alleged "eco-friendly" ingredient (such as a natural by-product derived one) could result in a less preferable environmental profile if assessed from a life cycle perspective. Actually, the environmental performance of the bio-based ingredient taken into account as a potential alternative raw material by [18] is mainly affected by the treatments needed to make it suitable for use as a cosmetic ingredient. Nevertheless, with the accurate design of formulations and ingredients dosages, the bio-based compound could bring positive contributions. Some papers emphasize also the importance of using an ecodesign approach to reduce the environmental impacts of products [18], [46].

- Link between food and cosmetics ingredients.

Among the raw materials that can have commonalities between food and cosmetics sectors, the literature confirms that β-carotene is widely used in the food, cosmetics and pharmaceutical industry as a natural colouring, antioxidant and anti-inflammatory agent. The main sources of natural β-carotene include extraction from vegetable resources (i.e., carrots) and microbial fermentation (i.e., microalga Dunaliella salina) [47].

IV. Discussion

Frequently, a cradle-to-gate analysis is conducted with the main objective of comparing alternative solutions to identify the most sustainable options in terms of materials, extraction processes and suppliers' location. Thus, the two main gaps that have been observed in the literature are reported below:

- The implementation of the LCA methodology in the cosmetics industry does not cover makeup products. In fact, although case studies have been found in the literature applied to makeup packaging, LCA analyses covering the life cycle of a makeup product are not present.
- No tool that relies on the results of the LCA analysis of a cosmetic product exists in the literature for understanding the level of sustainability.

V. Conclusions

The literature review conducted allowed for some questions to be answered and gaps to be pointed out. Regarding RQ1, the environmental impact assessment methods most found in the literature are four: LCA, Carbon Footprint, Water Footprint and Environmental Risk Assessment. Answering to RQ2, in literature the LCA is applied to quantify the environmental impacts of cosmetics ingredients and their extraction process, cosmetics packaging and skincare products. Usually, the critical phase of the life cycle that negatively affects the most the environment is the raw materials extraction process. In the case of rinse-off products or products that can be carried around by consumers, the use phase can be critical in terms of sustainability.

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