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Review

Advancing Cosmetic Sustainability: Upcycling for a Circular Product Life Cycle

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Abstract

The cosmetics industry is undergoing a transformative shift toward sustainability due to growing consumer demand for eco-friendly products and the urgent need to reduce environmental impact. Challenges exist at every phase of a product's life cycle, requiring effective strategies to drive sustainability. Upcycling—the repurposing of byproduct waste materials or useless products—emerges as a powerful strategy to advance circularity, minimize waste, and conserve resources. Central to this process is sustainable ingredient sourcing, particularly the use of agro-food industry waste and byproducts, which often contain high-value bioactive compounds suitable for cosmetic applications. Beyond sourcing, other upcycling strategies can be applied across the cosmetic life cycle, such as optimizing production, valorizing post-consumer plastic waste, and reducing carbon footprint through innovative practices such as carbon dioxide capture and repurposing. This review explores the role of upcycling and other sustainable practices in reshaping the cosmetics industry, from product design to post-consumer use. It also underscores the importance of consumer education on sustainable consumption to promote responsible beauty practices. The findings highlight how upcycling and other sustainability approaches can significantly reduce the industry's environmental footprint. For long-term sustainability, the study recommends continued innovation in waste valorization, resource optimization, and consumer education, ensuring a holistic approach to reducing cosmetics' environmental footprint throughout their life cycle.

Keywords: sustainability; upcycling; cosmetics; circular economy

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1. Introduction

Cosmetics and the cosmetics industry play a central role in contemporary society. A 2022 study by Cosmetics Europe revealed that 72% of European consumers consider cosmetics and personal care products as important or very important in their daily lives, with 71% attributing significant quality of life benefits to these products [1]. According to Regulation (EC) No. 1223/2009 of the European Commission, a cosmetic product is "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 odors" [2].

The European cosmetics industry represents a vital economic sector, valued at EUR 104 billion in 2024, ranking second globally behind the United States [3] (Figure 1a).

Germany leads the European market, with an estimated value of EUR 16.9 billion in 2024, followed by France (EUR 14.2 billion), Italy (EUR 13.0 billion), the UK (EUR 12.2 billion), Spain (EUR 11.2 billion), and Poland (EUR 5.8 billion) [3] (Figure 1b). This thriving industry comprises thousands of companies, led by the French L'Oreal and the German Nivea (Beiersdorf AG), and supports over 3.5 million jobs through direct employment (259,244), indirect supply chain roles (2.68 million), and induced economic effects, highlighting its extensive socioeconomic impact [3,4].

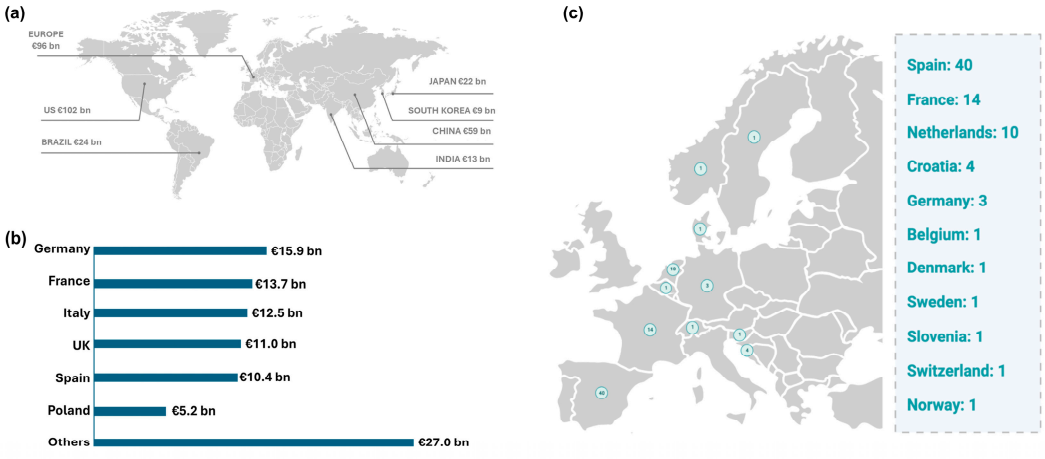

Figure 1. Cosmetic market statistics. (**a**) Global market in 2023 and (**b**) European market in 2024, (**c**) Location and number of European scientific innovation facilities conducting research in cosmetics as of 2018 [3,5].

Driven by scientific advancement and consumer demand for innovative formulations, the European cosmetics and personal care industry demonstrates a strong commitment to research and development (R&D) to create new and improved products. Leading companies typically reinvest 3–5% of their annual revenue into R&D, with total sector investment reaching EUR 2.35 billion in 2017 [5,6]. These investments fuel a continuous innovation pipeline that sees 25% of all products either upgraded or completely reformulated each year [5]. The development of a new product, from initial concept to market launch, typically spans five years of dedicated research, with ongoing refinements continuing after products reach consumers [5]. The industry's scientific capabilities are evidenced by several important metrics. In 2009 alone, cosmetic-related innovations accounted for 10% of all patents granted in the EU, highlighting the industry's substantial contribution to technological advancement. By securing patents for new formulations, ingredients, and technologies, companies can safeguard their innovations and sustain a competitive advantage in the market [5]. A skilled workforce of around 30,040 scientists across disciplines, e.g., physics, microbiology, biology, toxicology, nanoscience, analytical chemistry, and genetics, and more than 77 dedicated research facilities throughout Europe (as of 2018) underpin this progress [3] (Figure 1c).

Current research priorities reflect the following two major market trends: the growing demand for sustainable formulations and the potential of artificial intelligence (AI) and data-driven technologies to enable personalized beauty solutions [6]. Of these, sustainability has emerged as particularly critical, driving significant market transformation. The sustainable beauty and skincare sector is rapidly expanding and is projected to reach over USD 326 billion by 2031 [7], reflecting shifting consumer values. Recent studies reflect this paradigm shift—68% of consumers consider sustainability to be a crucial factor in their purchasing decisions, while 66% are willing to pay more for products with positive environmental and social impacts [8]. This need for sustainable products is mainly driven

by younger consumers who are more aware of ethical and environmental issues [7]. As this awareness rises, the industry faces increasing pressure to adopt more sustainable production and consumption practices [9]. This transition needs a comprehensive understanding of each phase of a cosmetic product's life cycle—from design and formulation to the post-consumer phase—to develop and implement effective sustainability strategies [10].

Building on the industry's sustainability imperative, upcycling has emerged as a transformative strategy that enhances industrial processes and promotes a circular economy. Upcycling, also known as creative reuse, converts waste materials into higher-value products, simultaneously reducing environmental impact while creating new market opportunities. For example, byproducts from the fruit and vegetable processing industry, often discarded, contain valuable bioactive compounds such as vitamins and phenolics that can be repurposed as cosmetic ingredients, offering both environmental and functional benefits [11]. This innovation aligns with broader circular economy principles that are reshaping the cosmetics sector. The circular model aims to reduce waste by reusing, repairing, refurbishing, and recycling materials and products, thereby extending their life cycle and maximizing their value. By keeping resources in use for as long as possible and recycling them at the end of their useful life, this approach conserves natural resources and reduces reliance on virgin materials, thus promoting sustainable growth. When applied to cosmetics, this framework manifests in multiple dimensions, including sourcing sustainable ingredients, optimizing manufacturing processes, and minimizing water and energy consumption [12,13]. Such systemic changes are proving essential for reconciling business growth with planetary boundaries.

This review provides a comprehensive analysis of key sustainability factors across the entire life cycle of cosmetic products, with a focus on upcycling as a transformative strategy for circularity. Unlike most existing studies—which often examine one or a few phases—we systematically explore each stage of the cycle, from design and raw material sourcing, through manufacturing, packaging, distribution, and use, to post-use phases. While upcycling is frequently discussed in the context of sustainable ingredients [14–23] or recycled packaging [24,25], this work consolidates its potential as a cross-cutting solution for enhancing circularity in the cosmetic industry. Building upon previous reviews from our group that addressed sustainability across the cosmetic life cycle without a dedicated focus on upcycling [9,26], this study evaluates current industry initiatives, identifies critical gaps, and explores potential strategies to accelerate the transition toward a circular economy. Although not all stages are explored in equal depth, the review synthesizes key insights and guides readers to specialized references for further investigation.

While this review provides a comprehensive analysis of upcycling in cosmetics, the several following limitations should be noted: (i) the focus on agro-industrial byproducts may overlook alternative sustainable sources, such as marine-based ingredients; (ii) while lab-scale upcycling is well-documented, data on large-scale industrial implementation remains limited, and is mainly addressed on company websites and in reports; (iii) most case studies come from developed markets in Europe and the United States, potentially underrepresenting challenges and opportunities in emerging markets; (iv) projections about market growth and premium pricing rely on surveys and stated preferences rather than long-term purchasing data; and (v) the rapidly evolving nature of sustainability innovations means that some recent advancements may not be captured in this review.

2. Methodology

This review adopts a hybrid methodology, blending a traditional narrative review with elements of a scoping review to comprehensively examine upcycling in the cosmetics industry. The traditional approach provides a broad synthesis of existing knowledge across

sustainability, the circular economy, and the cosmetic life cycle, while the scoping elements pay attention to gaps beyond the well-studied phases of upcycling in raw material sourcing.

The analysis draws on peer-reviewed scientific articles from PubMed, Scopus, Web of Science, and reputable online sources like the European Commission (https://ec.europa.eu/info/index_en), Cosmetics Europe (https://cosmeticseurope.eu), Cosmetics Design Europe (https://www.cosmeticsdesign-europe.com), Cosmetics Design North America (https://www.cosmeticsdesign.com), and Cosmetics & Toiletries (https://www.cosmeticsandtoiletries.com), as well as brand sustainability disclosures.

Given the timeliness and relevance of the topic, the focus centers on recent research (from 2018 to present), but select older sources were also consulted to provide historical context. Keyword searches guided the research, combining core concepts ("upcycling", "sustainability", and "circular economy") and cosmetic-specific terms ("cosmetic products", "cosmetic ingredients", "production", "packaging", and "product life cycle"), ensuring a focused and systematic exploration of the subject matter.

This approach aims to provide a holistic understanding of sustainability challenges and opportunities in the cosmetics industry, while highlighting the use of upcycling across all phases of the cosmetic life cycle as a pathway to greater circularity and environmental responsibility.

3. Sustainability in the Cosmetics Industry

3.1. Cosmetic Products

Cosmetics have been an integral part of human life for millennia, transitioning from ancient traditions to essential elements of contemporary daily routines. These products, ranging from fundamental hygiene items like toothpaste and soap for handwashing to makeup aesthetic enhancers, are all part of the vast cosmetics industry. Today, consumers use cosmetics and personal care products regularly to enhance their well-being, support their health, and boost their self-esteem [27]. According to Cosmetics Europe, these products can be classified into the following seven main categories: oral care, skin care, sun care, hair care, decorative cosmetics, body care, and perfumes [27] (Figure 2). Market analysis reveals skincare (EUR 27.7 billion) and toiletries (EUR 23 billion) to be the dominant categories in 2023, followed by hair care (EUR 16.8 billion), fragrances and perfumes (EUR 15.4 billion), and decorative cosmetics (EUR 12.7 billion) [3].

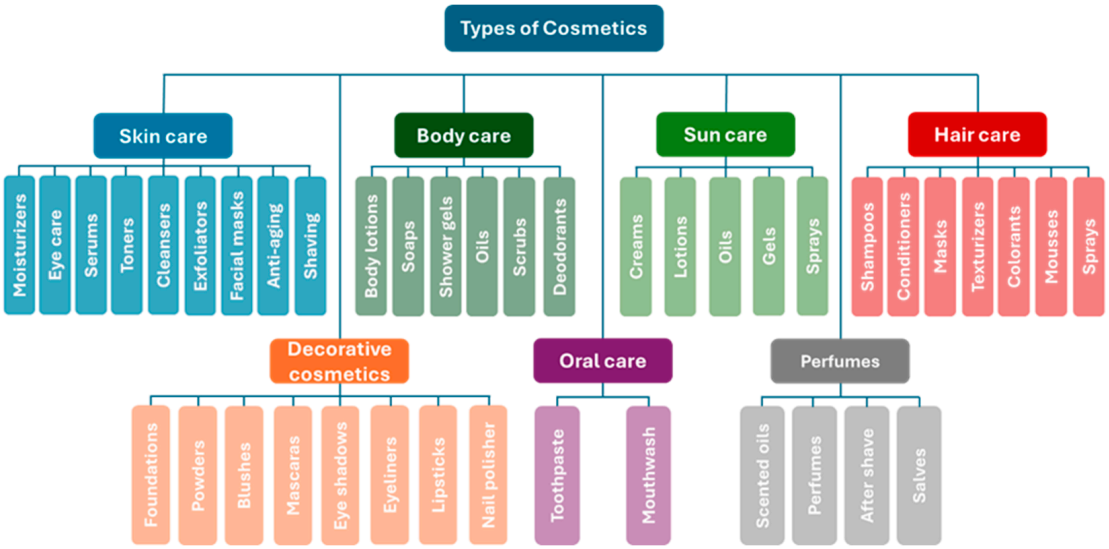

Figure 2. Types of cosmetics [27].

The 2022 European Consumer Perception study published by Cosmetics Europe revealed the profound integration of cosmetics in European lifestyles. The average consumer uses more than seven different cosmetic products daily and thirteen weekly, covering a variety of the categories shown in Figure 2. The study also revealed that women typically use nine cosmetics daily and fifteen weekly. Notably, male engagement with cosmetic products—including skincare, sun care, body care, perfume, and even makeup—has grown significantly, showing a 5.5% increase in perceived importance since 2017 [1]. This evolution reflects broader societal shifts in gender norms and self-care practices, demonstrating how cosmetics use has become universal.

3.1.1. Cosmetic Regulatory Framework

The European Union (EU)'s cosmetics market operates under the comprehensive Regulation (EC) No. 1223/2009, which harmonizes safety standards while ensuring the free circulation of products across member states [2]. This internationally recognized framework balances product safety with technological advances, such as the use of nanomaterials in cosmetic formulations [28]. At its core, the regulation establishes a rigorous mandatory pre-market evaluation, which includes the submission of relevant documentation (product identification, quality, safety, and claims) to the appropriate authorities. Manufacturers must provide a comprehensive safety assessment as part of a formal safety report prior to market placement [2,28].

The process is streamlined through the Cosmetic Products Notification Portal (CPNP), requiring a single notification for EU market access. To ensure compliance with the regulation, it is mandatory to designate a legal Responsible Person who oversees a product's entire life cycle [28]. This designated individual is accountable for ensuring adherence to Good Manufacturing Practice (GMP) standards and verifying ongoing product safety post-market placement [2].

Supporting this compliance structure, the Product Information File (PIF) serves as the comprehensive technical dossier for each cosmetic product. Containing critical details, including product description, safety report, manufacturing methods, GMP compliance, claim substantiation, and data from animal testing [2], the PIF is mandatory for all EU-marketed cosmetics and must be maintained for a decade after the last product batch enters the market. The Responsible Person must compile and regularly update the PIF, monitoring and reporting [2] serious undesirable effects (SUEs) to national authorities, who will share data with other EU countries. Reporting mechanisms are also accessible to both healthcare professionals and consumers [28].

The legislation demonstrates particular foresight in its treatment of nanomaterials, requiring explicit authorization for certain functional categories (colorants, preservatives, and UV filters), while mandating transparent labeling with the "nano" designation for all such ingredients [28].

By integrating pre-market safety evaluation, ongoing compliance monitoring, and post-market surveillance, the EU cosmetics regulation has established itself as a global benchmark for cosmetic product safety governance. This multilayered approach ensures consistent standards across the single market while accommodating scientific progress in cosmetic formulation and manufacturing [2,28].

3.1.2. Cosmetic Claims

Cosmetic product claims serve as marketing tools that companies use to differentiate their products from competitors, often reflecting their performance. The EU Regulation (EC) No. 655/2013 establishes a comprehensive system for governing cosmetic product claims, serving the dual purposes of consumer protection from misleading claims and providing

competent authorities in member states with a legal basis for market oversight [29]. The regulation outlines the following six equally weighed Common Criteria that manufacturers must satisfy when making product claims [30]: (i) Legal Compliance prohibits suggestions of endorsement from competent authorities and requires claims to demonstrate benefits beyond minimal legal requirements; (ii) Truthfulness demands precise alignment between formulations and claims, whether regarding ingredient presence, absence, or derived properties (i.e., when a formulation contains a specific ingredient, but fails to exhibit properties associated with that ingredient). It mandates a clear differentiation between subjective opinions and verified facts, with consideration for target audience comprehension; (iii) Evidential Support requires all claims, whether expressed or implied, to be substantiated by rigorous and verifiable evidence obtained using state-of-the-art methodologies. Referenced studies must demonstrate direct relevance to both the product and claimed benefits through valid, well-designed, reliable, and reproducible research designs that respect ethical standards; (iv) Honesty governs claim presentation, prohibiting exaggeration beyond available supporting evidence (e.g., avoiding digitally manipulated images) and mandating the clear disclosure of specific usage conditions (e.g., the simultaneous use of two products); (v) Fairness ensures objective comparisons and prohibits the denigration of competitors or legally permitted ingredients; and (vi) Informed Decision-Making obliges companies to present information clearly and understandably, enabling consumers to make educated choices based on precise, relevant claims.

3.2. Sustainability

While the concept of sustainability is not new, its complexity often leads to ambiguity. Sustainability has emerged as a multidimensional imperative for modern industries, with its foundations rooted in the landmark 1987 Brundtland Commission report "Our Common Future." The Commission defines sustainable development as "development that is able to meet the current needs of the population without compromising future generations to meet their own needs" [31]. This definition established the triple-bottom-line framework, often called the three key dimensions of sustainability (Figure 3), as follows: (i) Environmental: the preservation of natural capital while ensuring that the environment's source and sink functions remain intact; (ii) Social: maintaining societal cohesion and the capacity to work toward shared goals; and (iii) Economic: ensuring financial viability while fostering development that aligns with social and environmental sustainability.

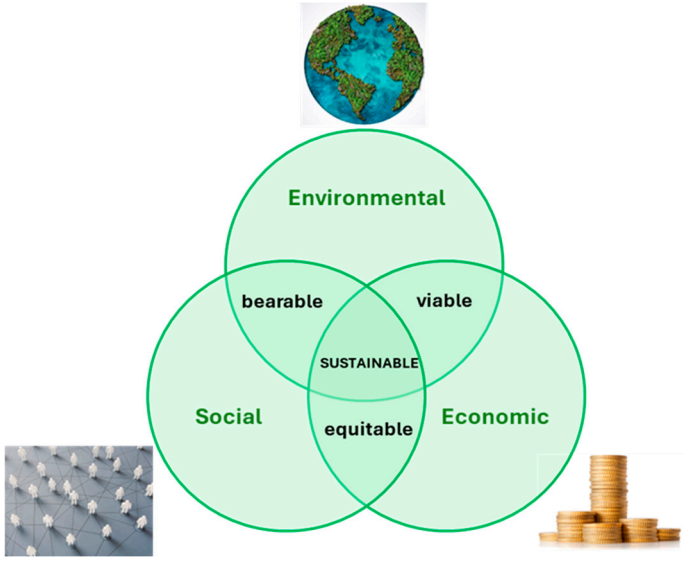

Figure 3. Dimensions of sustainability [9].

The document "Agenda 21", a comprehensive action plan adopted at the United Nations' Earth Summit conference held in Rio de Janeiro, Brazil, in 1992, marked a pivotal shift for identifying production and consumption patterns as the primary causes of environmental degradation. To address this issue, it advocated for the implementation of a new development model that replaced conventional production and consumption standards with sustainable alternatives [32]. For the cosmetics industry, this translated into growing pressure to transform linear models of production into circular systems that minimize waste and environmental harm. Today, amid heightened media focus on the importance of sustainability, aiming to raise consumer awareness about environmental and social issues, cosmetic companies are consistently striving to enhance the sustainability of their practices and products [9,26]. This manifests across the three dimensions of sustainability, as follows: environmental, by reformulating products with alternative ingredients (biodegradable, upcycled, etc.) and reducing water and energy footprints; social, by ensuring ethical sourcing, supporting fair labor practices, and promoting diversity and inclusion; and economic, by developing viable business models that align profitability with long-term ecological and social responsibility.

3.3. Sustainable Cosmetics

The cosmetics industry's evolving sustainability landscape has given rise to often confusing terminology, where marketing terms like "green", "natural", and "organic" are frequently misidentified as "sustainable." Terms like "green", "natural", and "organic" primarily refer to the origin and agricultural practices associated with the ingredients used in cosmetic products. For example, green cosmetics typically emphasize the use of natural, plant-based, and biologically sourced ingredients, rather than synthetic chemicals such as parabens, phthalates, or sodium lauryl sulfate. Thus, although these descriptors highlight certain product attributes, they represent narrow aspects of product composition rather than comprehensive environmental or social sustainability [9,26].

True sustainability encompasses a more comprehensive approach that considers environmental impacts throughout the entire life cycle of a product, from ethically sourced raw materials and energy-efficient manufacturing to distribution systems, consumer use patterns, and waste disposal. While there is no universally accepted definition of sustainable cosmetics, such products are generally characterized by environmentally favorable traits and a commitment to ethical, social, and economic responsibilities [9]. In essence, "sustainable" encompasses a broader commitment to reducing the overall environmental footprint of a product, going beyond ingredient sourcing. While "green", "natural", and "organic" labels may align with certain aspects of sustainability, they do not guarantee that a product is truly sustainable. The case of mica, a naturally occurring mineral plagued by child labor and unsafe mining practices, illustrates how "natural" origins alone cannot guarantee sustainability [26]. Similarly, organic ingredients may still carry heavy environmental footprints from water-intensive cultivation or long-distance transportation.

This terminology clarification empowers stakeholders to differentiate between marketing claims and verified sustainable practices, to recognize that natural ingredient sourcing is just one component of true sustainability, and to evaluate products based on comprehensive life cycle assessments rather than isolated attributes.

4. Upcycling Across the Cosmetic Life Cycle: Strategies and Opportunities

The cosmetics industry must embrace sustainability across the entire product life cycle to achieve sustainability—from the design and sourcing of raw materials and eco-conscious manufacturing to responsible packaging, distribution, use, and end-of-life management

(Figure 4). This transformation requires balancing the development of more sustainable products and processes with safety and regulatory compliance. By analyzing each life cycle phase, we can identify critical opportunities to promote sustainability in the cosmetics industry [9,26].

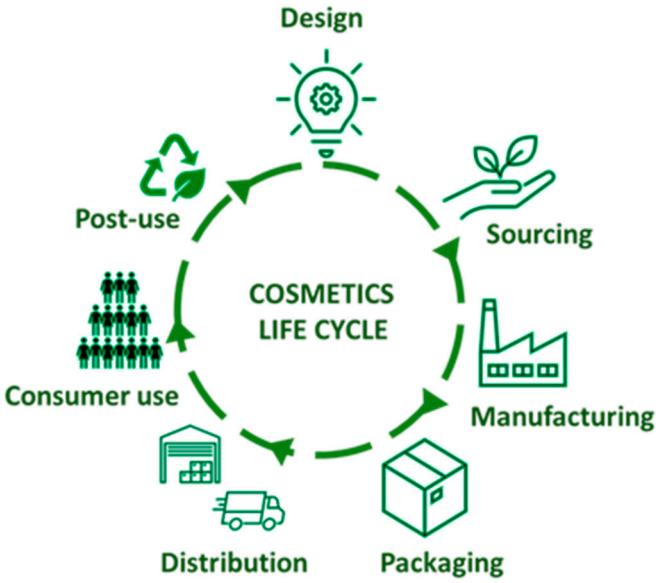

Figure 4. The life cycle of cosmetic products [9,26].

4.1. Design

The sustainability of a cosmetic product is shaped by decisions made throughout its entire life cycle, with the design phase being particularly influential. Early-stage decisions significantly impact all subsequent phases, playing a crucial role in the product's overall sustainability profile [26]. Research indicates that product design and raw material selection collectively contribute about 32% of a product's total sustainability impact. Subsequent phases—production, packaging, and post-use phases—each account for 14%, while distribution and consumer use each contribute 13% [9]. These findings emphasize how the strategic sustainability decisions made in the design stage affect all subsequent phases, although the exact impact percentages vary by product type.

4.2. Sourcing

The cosmetics industry is undergoing a profound transformation in its approach to ingredient sourcing, increasingly adopting strategies that prioritize the use of sustainable and natural ingredients over synthetic ones. This shift towards sustainable sourcing requires suppliers to continuously expand their product offerings and explore valuable ingredients derived from agricultural and food production byproducts [33].

The agro-food industry has been a significant contributor to the rise in industrial waste over recent decades, with approximately 1.3 billion tons, or one-third of the food produced globally, being wasted annually worldwide [34]. This waste includes food deemed aesthetically unappealing for supermarkets and byproducts generated during food processing, such as seeds, stems, leaves, and skins, which constitute from 3% to 60% of total plant food [26,35]. Discarding valuable nutrients like proteins, antioxidants, and dietary fibers is unsustainable, especially in the context of a growing global population. Repurposing these nutrients for use in cosmetics will not only reduce environmental strain, but also promote better resource management, contributing to the sustainability of both the food and cosmetic industries [26,36,37].

Leading this movement are innovative extraction technologies to achieve high yields without compromising the stability of the extracts and their components, and certification programs that validate the quality and sustainability of upcycled ingredients [35,37,38]. The market potential of these technologies is significant, projected to reach a staggering USD 483.4 million within the next decade, as demonstrated by the rapid adoption of Upcycled Certified™ products across industries. To date, the Upcycled Food Association (UFA) has certified 567 products and ingredients from 104 companies, diverting 2 million tons of food waste [37].

European initiatives have been particularly active in bridging the gap between agricultural waste streams and cosmetic applications, focusing on the upcycling of industrial byproducts containing valuable compounds. The Biowaste initiative, funded by the EC Department of Agriculture, includes programs like Transbio and Apropos. The first focuses on developing new ingredients from byproducts of the fruit and vegetable processing industry using environmentally friendly biotechnological solutions, while the second targets the reuse of agricultural residues rich in proteins and oils [35]. Another project financed by the EU is Olea4Value, coordinated by the Natac Group with its headquarters and factories in Spain, which aims at extracting bioactive compounds from olive leaf biomass [39].

The following case studies provide examples of upcycling agro-food industry byproducts into high-value cosmetic ingredients, now featured in commercial products (Table 1). A comprehensive catalog of upcycled ingredients is provided by the Upcycled Beauty Company's directory (available at: https://www.upcycledbeauty.com/upcycled-directory), along with their sources and applications.

Table 1. Ingredient upcycling as a pathway for developing sustainable cosmetic products [37,40–53].

Source	Company	Upcycled Ingredient	Properties	Applications
Spent coffee grounds	UpCircle Beauty	Coffee oil	Hydrates, nourishes, and repairs the skin barrier	Face and body care
	Givaudan and Kaffe Bueno	Koffee'Up™ (coffee oil)	Addresses early signs of aging, improves skin hydration, and strengthens the skin barrier against external aggressors	Face care
Coffee bean silverskin	Mibelle Biochemistry	SLVR'Coffee™	Increases skin hydration and protects the skin from stressors	Active ingredient for skin care cosmetics
Coffee cherry	Sanam and Flora Reserve	Naox® Derma	Antioxidant, anti-inflammatory, and anti-aging properties	Active ingredient for skin care products
Byproducts of olive oil industry	Circumference	Extracts of olive leaves	Skin regenerative effects	Facial cleansing products
	Roelmi-HPC	Olifeel® E-NAT W/O	Pleasant skin-feel, protects skin from water loss and environmental stress	Emulsifier for the formulation of W/O emulsions
Grape pomace	Caudalie	Resveratrol	Anti-aging, anti-wrinkle, and firming properties	Face care

Table 1. *Cont.*

Source	Company	Upcycled Ingredient	Properties	Applications
Bilberry seed	Givaudan	Omegablue®	Hydration and skin barrier restoration	Face and body care
	Pai Skincare	Billberry seed extract	Strengthens the skin barrier and soothes the skin	Face care
Downgraded avocados	Laboratoires Expanscience	Number 6 (avocado polyphenols concentrate)	Reduces dark circles and depuffs under-eye bags	Solid bar for eye contour
Damaged or misshapen bananas (yellow, pink, and green bananas)	Kadalys	Yellow banana bioactive Pink banana bioactive Green banana bioactive	Addresses early signs of aging, enhancing lifting, firming, and regenerating properties Boosts the skin's radiance and promotes a more unified complexion Purifies and balances, improving skin texture	Face, body and hair care
Tomato	Byroe's	Three different types of upcycled tomatoes	Anti-aging, improves deep wrinkles, firmness, and sagging	Face serum
Plum kernel	Le Prunier	Plum oil	Plumps, hydrates, and brightens the skin	Face, body, and hair care

4.2.1. Coffee Industry

Coffee (*Coffea arabica*) is one of the most widely consumed beverages globally, holding significant commercial importance. The International Coffee Organization (ICO) estimated that, in 2022–2023, global coffee consumption reached 173.0 million 60 kg bags, amounting to about 10 million tons [54]. Only 30% of the coffee bean mass is used in beverage production, leaving the remaining 70% as byproducts, such as spent coffee grounds (SCG), silverskin, and coffee cherry [41,55,56]. The brewing of around 9 million tons of ground coffee generates approximately 18 million tons of wet SCG annually. According to the 2022/23 IOC report, 11.14 million tons of SCG were produced globally from consumed coffee [56]. When disposed in landfills, this waste poses environmental hazards by emitting methane and other greenhouse gases during the composting process [19].

Recent advances in green chemistry have sparked growing interest in SCG valorization, with innovative technologies being used to transform this abundant waste stream into value-added cosmetic ingredients [56]. Several cosmetic companies are embracing upcycling by incorporating ingredients derived from SCG into their formulations. UpCircle Beauty, a London-based company, repurposes SCG from local cafés into a range of coffee-based products, including face and body scrubs [40]. Similarly, the French company Givaudan has partnered with the Danish start-up Kaffe Bueno to develop Koffee'Up™ oil from discarded SCG [41]. Kaffe Bueno's proprietary green extraction methods yield additional SCG-derived ingredients, such as Kaffoil®, a multifunctional lipophilic extract serving as both active and carrier oil in cosmetic formulations, and Kaffibre®, an eco-friendly exfoliant that replaces plastic microbeads in scrubs and cleansers [57].

The roasting process generates coffee silverskin, a thin, silver-colored membrane that detaches from coffee beans and is rich in bioactives, including chlorogenic acids (1–6%), caffeine (0.80–1.25%), and melanoidins (17–23%). These compounds offer significant skincare

benefits, from enhancing hydration and preventing skin aging to providing antimicrobial protection [55]. The Swiss company Mibelle Biochemistry pioneered its commercial application with SLVR'Coffee™, the first upcycled cosmetic ingredient derived from this byproduct. Research has shown that it reinforces the skin barrier, reduces transepidermal water loss (TEWL), and improves overall hydration [49].

In addition to SCG and coffee silverskin, the coffee industry discards about 60% of the coffee cherry (the fruit surrounding the beans) during processing. However, this discarded coffee fruit is rich in antioxidants, making it a prime candidate for upcycling in cosmetics [41]. The Colombian company Sanam's, partnering with Flora Reserve, developed Naox® Derma from coffee cherry pulp, demonstrating anti-aging, anti-inflammatory, and antioxidant properties [46].

The coffee upcycling model demonstrates how agricultural waste streams can become premium cosmetic ingredients when paired with scientific research and cross-industry collaboration. As technologies advance to improve extraction yields and compound stability, coffee byproducts are poised to play an expanding role in sustainable cosmetic formulation—turning an environmental liability into a source of cosmetic innovation and circular economic value.

4.2.2. Olive Oil Industry

The olive tree (*Olea europaea* L.) is a traditional plant whose fruits are used for olive oil production, playing a vital role in the economies of Mediterranean countries. However, the olive oil industry generates significant amounts of byproducts, which can pose environmental challenges. These byproducts include olive pomace (OP), olive stones, olive mill wastewater (OMWW), and leaves, all of which can accumulate in large quantities as olive oil demand grows. The disposal of some of these materials, especially those that are non-biodegradable, creates a pressing need for sustainable alternatives [58,59]. Paradoxically, these byproducts contain valuable bioactive compounds like antioxidants, fatty acids, and minerals, which show remarkable potential for the cosmetics industry. Olive leaves, for instance, contain high concentrations of antioxidants, such as flavones, flavonols, flavan-3-ols, substituted phenols, and secoiridoids, which have proven benefits for skin health and protection [58]. Innovative companies are already capitalizing on these opportunities. Circumference, a beauty brand established in 2018, partnered with Brightland Olive Oil through its "Waste-Not Sourcing Initiative" to develop a regenerative gel cleanser featuring upcycled olive leaf extract [40]. Similarly, Roelmi-HPC, an Italian company embracing sustainability, has innovated with Olifeel® E-NAT W/O, an emulsifier derived from olive oil byproducts for use in W/O emulsions [52].

4.2.3. Grape Industry

As the world's largest fruit crop, with over 70 million tons produced worldwide annually [60], grapes represent both an agricultural powerhouse and a significant source of valuable byproducts. While 80% of global production is used in wine production—generating substantial amounts of organic residues, wastewater, and greenhouse gases—about the remaining 20% yields grape pomace (GP), a nutrient-rich material with remarkable cosmetic potential [61]. This wine-making byproduct consists of the following two main fractions: seedless pomace (pulp, skins, and stems) and grapeseed (GS), both rich in bioactive phenolic compounds, including phenolic acids and flavonoids [62–64].

The cosmetics industry has harnessed these antioxidant-rich materials through innovative upcycling, and several products containing grape-derived ingredients have been commercialized worldwide, as recently reviewed by Castro et al. [65]. Probably the most famous is Caudalie's resveratrol, which is mainly extracted from grapevine stalks, being a

potent antioxidant known for its anti-aging, anti-wrinkle, and firming properties. Resveratrol helps to protect the skin from environmental damage, stimulates collagen production, and improves skin elasticity, making it a valuable ingredient in skincare products aimed at reducing visible signs of aging [43]. Several other byproducts from the grape industry are used in the cosmetics industry, including grape seed, grapevine shoot, grape flower, and grape skin, which are used in exfoliating scrubs, masks, anti-aging creams, hair treatments, and eyecare formulations [65]. These developments demonstrate how strategic valorization can transform viticulture waste into high-performance cosmetic ingredients, creating sustainable value from what was once considered a mere byproduct.

4.2.4. Fruit Industry

The food and beverage industry generates substantial amounts of fruit and vegetable waste, accounting for over 42% of total food waste [66]. Globally, the most harvested fruits are citrus fruits. The citrus industry alone, producing over 150 million tons annually [67], generates approximately 25 million tons of waste from juice production [68]. This abundance of organic byproducts presents both an environmental challenge and a remarkable opportunity for cosmetic innovation. Thus, innovative companies are transforming these waste streams into high-value cosmetic ingredients through cutting-edge upcycling technologies.

CP Kelco's KELCOSENS® Citrus Fiber, an ingredient derived from citrus peels, is used as an effective stabilizer in emulsifier-free formulations, enhancing product texture in facial creams, facial serums, and body lotions [37].

The bilberry industry has also yielded remarkable upcycling successes. Givaudan launched Omegablue®, an innovative ingredient sourced from upcycled bilberry seeds. While bilberries are predominantly utilized in the food industry for their juice and sugar, they also serve as a rich source of anthocyanidins extracted from the pulp and fruit skin, valued in the supplement and pharmaceutical sectors. The small seeds of bilberries contain up to 20% linoleic acid (omega-6) and α-linolenic acid (omega-3) in an optimal ratio, known for their skin benefits, including enhancing hydration and improving skin barrier function [48]. Pai Skincare, a company founded in 2007, also upcycles bilberry seeds discarded during the juicing process, producing an extract that has been incorporated into several of its products, including the C-2 Believe, a vitamin C moisturizer [50].

Laboratoires Expanscience's Number 6 active ingredient is upcycled from Peruvian avocados deemed unsuitable for the food industry. This aqueous concentrated polyphenol extract is used at 1–3% concentrations in eye contour products. Research studies demonstrate Number 6's multifunctional benefits for the delicate skin around the eyes, enhancing microcirculation, regulating pigmentation, reducing dark circles, and diminishing the fatty deposits responsible for eyebag appearance [44,47]. Number 6 is one more example of how cosmetic science can transform agricultural byproducts rejected by food quality standards into high-performance actives.

Kadalys, a French company founded in 2012, has pioneered banana upcycling in the cosmetics industry by transforming discarded misshapen or unsightly fruits into valuable bioactive ingredients for skincare products. Partnering with Caribbean banana growers, Kadalys uses a patented extraction method to obtain oily extracts from the peel and pulp of green, yellow, and pink bananas. These bioactives have several beneficial properties that nourish the skin and hair, making them versatile ingredients for cosmetic formulations. Kadalys' commitment to sustainability and innovative practices has garnered recognition within the industry, including by the 2021 Sustainable Beauty Awards [45,51].

Le Prunier is an exquisite luxury skincare brand founded by three sisters deeply committed to sustainable beauty practices. Le Prunier's century-old California plum farm

blends heritage with innovation. By harnessing the remarkable skin-enhancing properties of their organically grown plums, they have crafted a line of groundbreaking skincare products. Their signature product, Plum Beauty Oil, transforms discarded plum kernels into a multitasking oil rich in vitamins and antioxidants, designed to plump, hydrate, and brighten the skin, being suitable for face, hand, body, and hair application. Le Prunier's commitment to sustainability and high-quality ingredients has positioned this company as a noteworthy player in the beauty industry [53].

These case studies collectively demonstrate how the strategic upcycling of fruit byproducts simultaneously addresses waste management challenges, generates high-performance cosmetic ingredients, promotes agricultural sustainability, and meets the growing consumer demand for eco-conscious beauty solutions.

4.3. Manufacturing Process

Cosmetic product manufacturing is a vital stage in the life cycle of cosmetics, playing a significant role in the industry's overall sustainability. To align with environmental goals and commitments to sustainable development, manufacturers are increasingly adopting innovative approaches to minimize their ecological impact while maintaining production efficiency. Key strategies include reducing carbon emissions through energy-efficient processes, conserving water through recycling systems, optimizing resource use to minimize waste, and implementing circular approaches to material and energy flows [10]. Despite significant progress, substantial opportunities remain for industries to further decrease their environmental footprint. The following examples demonstrate how cosmetic companies are implementing these sustainable manufacturing practices to create both environmental and business value.

4.3.1. Water Reuse—"Waterloop" Factories

As a fundamental resource for both ecosystems and industrial processes, water faces increasing scarcity due to population growth and economic development. The cosmetics industry, where water serves as both a primary ingredient and essential production resource, faces mounting pressure to transform its water management practices [69]. With water constituting up to 80% of many cosmetic products, manufacturers are shifting from linear water consumption, characterized by increasing contamination and wastewater generation, toward circular systems that prioritize continuous reuse and recirculation [70]. This paradigm shift aligns with the 5Rs framework—reduce, reuse, recycle, restore, and recover [71] (Figure 5)—implementing the following three key water recovery strategies: (i) wastewater recycling for non-product applications like equipment cleaning and cooling and the irrigation of green areas within a factory; (ii) rainwater harvesting for industrial cooling or fire-suppressing systems; and (iii) advanced effluent filtration for closed-loop process water reuse [72,73].

L'Oréal's pioneering "waterloop factories" demonstrate the commercial viability of this approach. These facilities have redefined sustainable water management in industrial manufacturing since their 2017 debut in Burgos, Spain, and are positioned among the most sustainable industrial operations globally [74,75]. This innovative model employs an innovative closed-loop system that treats and recycles 100% of process water on-site through advanced purification technologies combining ultrafiltration and reverse osmosis (membrane filtration) with evapoconcentration (distillation) [69,74]. This comprehensive treatment enables the daily reuse of an average of 200 cubic meters of water (60 million litters annually)—comparable to the yearly consumption of approximately 600 households—while maintaining rigorous quality standards [74]. Thus, these factories minimize reliance on public or municipal water supplies for manufacturing processes,

reserving external water sources only for human consumption and specific product ingredients. Beyond its environmental benefits, this model provides significant financial advantages through reduced water procurement and treatment costs [74,75].

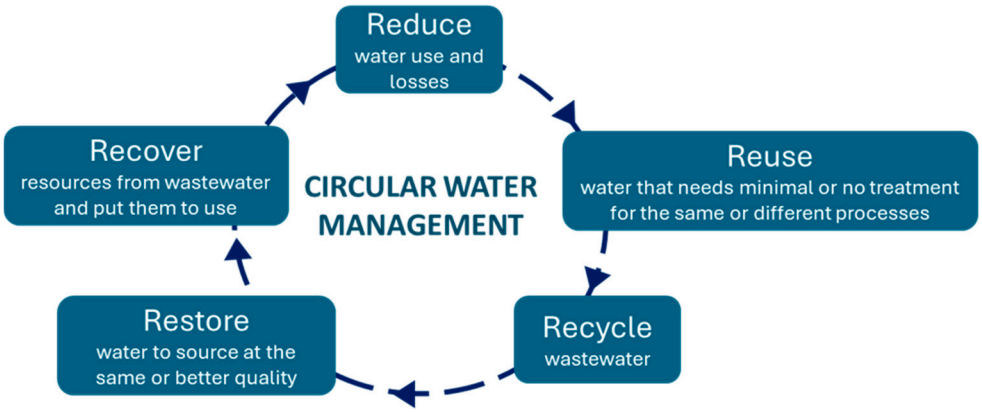

Figure 5. Circular water management [69,71].

As of 2021, L'Oréal operated six "waterloop factories" and planned to expand this approach to all 39 of its factories worldwide by 2030, particularly targeting water-stressed regions [75]. Overall, this scalable solution demonstrates how industrial operations can achieve both ecological sustainability and economic efficiency through innovative water management. These waterloop factories serve as a replicable blueprint for circular water management across manufacturing sectors.

4.3.2. Energy

Industrial facilities can achieve significant energy efficiency improvements through innovative reuse strategies. Residual heat generated by furnaces, boilers, or other processing equipment offers valuable potential—this thermal energy can be captured and reused to heat water for industrial processes, warm factory spaces, or generate steam to power machinery [76]. For moving equipment, kinetic energy recovery systems (KERSs) present another opportunity, capturing and repurposing energy from rotating components and conveyor systems to power secondary operations [77]. Complementing these approaches, on-site solar installations can sustainably power lighting networks and low-consumption equipment [78].

These principles are already being put into practice by industry leaders. L'Oréal, for instance, has established itself as a pioneer in sustainable manufacturing, not only through its waterloop factories [75], but also by driving comprehensive energy innovation [79]. The company announced that, as of December 2024, all its European operations—spanning factories, distribution centers, and offices—are fully powered by renewable energy [80]. A particularly compelling case is L'Oréal's Libramont Factory in Belgium, a sustainability frontrunner since its foundation in 2009 [81]. Developed in partnership with Eneco and Bio Energie Europa, this facility operates entirely on renewable methane gas. The biomethane center uses cutting-edge technology to upcycle agro-food industry biomass from local sources into methane via anaerobic fermentation. This biogas supplies 100% of the plant's electricity, with surplus energy distributed to nearby homes via the public grid. Beyond biogas, L'Oréal has expanded its renewable portfolio with large-scale solar installations, including a 1.2-megawatt array (3500 panels) in North Little Rock, Arkansas, and a 1.42-megawatt system (4100 panels) in Florence, Kentucky [82].

4.3.3. Other Strategies

Obsolete machines can be disassembled and adapted to create new equipment, out-of-service tanks or reactors can be converted to store reused rainwater, liquid waste, or raw materials, and discarded steel or iron structures can be used to build supports or storage racks [83]. Production lines with closed-loop systems can reuse working fluids, such as water, solvents, or oils after filtration and reconditioning [84].

Waste reuse is another sustainability strategy in industrial settings. An example of upcycling in infrastructure is the use of construction waste such as crushed concrete or bricks for paving or as bases for heavy equipment [85]. Manufacturing byproducts such as foams or fibers can also be reused as insulation or acoustic materials within factories [86]. Used machine oils and lubricants can be collected, filtered, and reused in compatible equipment [87]. Metal waste can be melted and transformed into new components within factories [88]. Finally, packaging materials such as cardboard boxes and plastics can be shredded and used as filling material or raw material for new packaging (see Section 4.4).

4.4. Packaging

Packaging plays a vital role in promoting economic, environmental, and social sustainability within the cosmetics industry. It safeguards products from damage or spoilage, streamlines business operations, and ensures that consumers receive products in the best condition. Beyond protection, packaging often serves to enhance a product's visual appeal and marketability, making it more desirable to consumers. As a result, sustainable packaging has become a key consideration for designers, who must carefully balance consumer appeal with environmental responsibility when creating attractive and eco-friendly designs [10].

While ensuring product integrity and enhancing marketability, conventional plastic packaging has substantial ecological consequences, with over 120 billion units of packaging produced annually [89]. The immense impact of plastics on the sustainability of cosmetic products has driven regulatory responses like the EU's Packaging and Packaging Waste Directive. First introduced in 1994, this Directive establishes common standards for packaging to facilitate trade while minimizing environmental impact [90]. There are several strategies that the cosmetics industry has been using to deal with this problem. Some will be approached here, while others will be discussed in Section 4.7 (post-consumer phase). Leading cosmetic brands are embracing sustainability by integrating upcycled materials into their packaging. Axiology demonstrates how environmental and social sustainability can intersect, employing packaging made from recycled trash, sourced through partnerships with Balinese women's cooperatives. Similarly, Clinique and Aveda have significantly increased the use of post-consumer recycled materials in their packaging [91]. The most technologically advanced innovation comes from a partnership between L'Oréal, LanzaTech, and Total, who developed the first sustainable packaging derived from captured and recycled industrial carbon emissions [92]. This innovative process involves LanzaTech's biological conversion of industrial emissions into ethanol, Total's polymerization of this ethanol into polyethylene, and L'Oréal's final packaging application of this upcycled polyethylene. The process is a closed-loop system that transforms pollution into viable packaging materials.

4.5. Distribution

The transportation of ingredients, materials, packaging, and final products is another crucial factor in the sustainability of cosmetic products. During the distribution phase, the primary concern is the emission of greenhouse gases (e.g., carbon dioxide, CO_2) from fossil fuel combustion, which significantly contributes to global warming [9,10,26]. To mitigate

this impact, cosmetics and other industries are implementing innovative logistics solutions that prioritize emission reduction during transportation/distribution. A key strategy involves optimizing transport modes, with several companies increasingly shifting from road to rail and from air to sea transport, while also integrating hybrid and electric vehicles into their fleets to reduce emissions. Many have optimized their distribution networks by consolidating operations, shortening distances between distribution centers and retailers, and utilizing mega-warehouses to minimize unnecessary transportation. Furthermore, the adoption of larger container trucks and compact products has significantly reduced the number of trips required. Notably, compact product designs have emerged as an effective solution, reducing both packaging waste and transportation frequency by allowing more units per shipment, leading to lower greenhouse gas emissions throughout distribution [93].

L'Oréal's Green Last Mile (GLAM) program exemplifies successful urban sustainability initiatives, implemented in selected regions based on delivery volume. In Brussels, L'Oréal partnered with Proximus, a Belgian telecom company, to deliver telecom products such as smartphones, accessories, and routers alongside hair salon products, using electric bicycles. This collaboration aimed to minimize CO_2 emissions while improving customer experience with fast and eco-friendly delivery options [94,95]. The program's success led to its expansion across three business divisions in 2020—L'Oréal Professional Products, Active Cosmetics, and Consumer Products—focusing on pharmacy deliveries in Antwerp and Brussels, where it completed around 2500 deliveries to over 270 retail locations within a year, marking a significant milestone in sustainable urban logistics [95]. While such electric vehicles offer a promising sustainable alternative to fossil fuels, their limited battery capacity has prompted the exploration of alternative solutions like bio-based fuels, although these raise concerns about land use competition with agriculture [96].

Upcycling is also possible during the distribution phase of a product's life cycle, using emergent carbon capture and utilization (CCU) technologies [97]. Sharma and Maréchal [96] proposed an interesting example of this type of upcycling that can be applied in the distribution phase of products. The authors propose a circular economy approach to fossil fuels, specifically focusing on reducing CO_2 emissions. The suggested system captures vehicle exhaust CO_2 through cooling and adsorption processes, converting it into liquid form for storage, then reconverting into usable fuel using renewable energy. This closed-loop system demonstrates how emissions can be transformed from waste into valuable resources [96].

These multifaceted strategies—from logistical optimizations to cutting-edge carbon recycling—highlight the cosmetics industry's evolving approach to sustainable distribution. While challenges remain in scaling these solutions, they collectively represent significant progress toward reducing the sector's transportation footprint through technological innovation and supply chain transformation.

Figure 6 summarizes the sustainability strategies involved in the transport and distribution phases of the cosmetics life cycle.

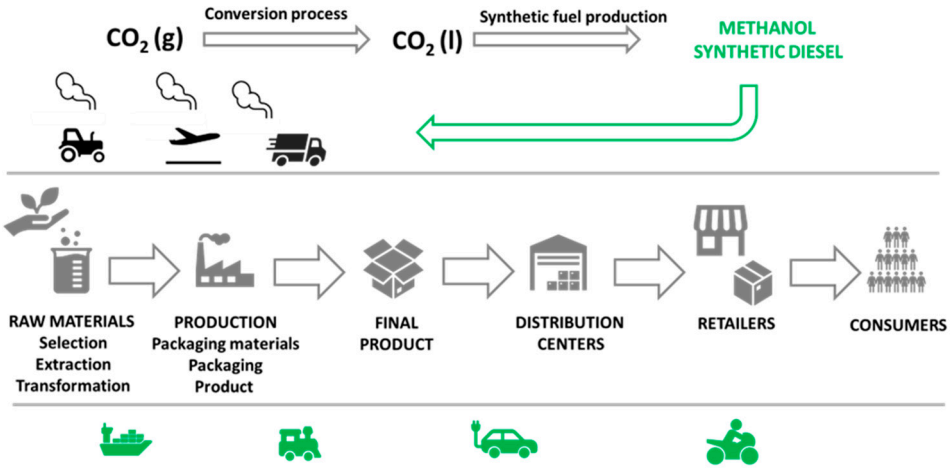

Figure 6. Sustainable strategies implemented during the transport and distribution phases of a cosmetics product's life cycle. Green indicates more sustainable transportation methods, including replacing air transport with trains and ships and using electric vehicles for shorter distances. The upper part of the figure illustrates an upcycling strategy, where CO_2 is captured and converted into synthetic fuels.

4.6. Consumer Use

The use phase of cosmetic products plays a pivotal role in their overall environmental footprint, particularly for rinse-off formulations like shampoos, conditioners, soaps, and hand washes. Key factors such as water consumed for rinsing, energy use for water heating, and product discharge collectively contribute to an adverse environmental impact. Therefore, considering the use phase is crucial when evaluating the overall sustainability of these products [93]. Notably, up to 90% of the total CO_2 emissions associated with a shampoo's life cycle stem from water heating and usage, underscoring the critical need for sustainable consumption practices [93].

Industry and consumer behavior jointly influence this environmental burden. Manufacturers are developing innovative, multi-functional formulations to reduce water dependency, such as 2-in-1 products combining shampoo and conditioner and waterless or low-rinse formulations [98,99]. By combining both functions in a single product, these formulations, exemplified by Head & Shoulders' 2-in-1 shampoo, eliminate the need for an additional rinse step, saving up to 30% water per use while minimizing packaging waste [99]. Such innovations highlight how the cosmetics industry can play a pivotal role in promoting environmental sustainability through resource-efficient product design [99].

Similarly, fast-rinse technologies that enhance product breakdown efficiency are emerging, exemplified by Love Beauty and Planet's conditioner that reduces shower time and water usage through optimized rinsing, offering a practical solution for eco-conscious consumers [98]. On the professional front, L'Oréal's Water Saver system, designed for beauty salons and launched at the Consumer Electronics Show (CES) 2021, represents a significant advancement in sustainable hair care. This innovative technology reduces salon water consumption by up to 80% by micronizing specially formulated products into a water steam, enhancing absorption while maintaining service quality [98]. This technology reflects L'Oréal's broader commitment to reducing its carbon footprint, evident in initiatives like the Water Saver, which is part of a broader strategy to promote sustainable practices across the beauty industry. While the device is currently deployed in professional settings, the company is developing an at-home version to extend these water-saving hair care routines to consumers [100].

Consumer education remains fundamental to amplifying these technological advances. Many companies have launched awareness campaigns to empower consumers with practi-

cal strategies to minimize household water and energy consumption. Practical strategies such as shorter showers, precise product dosing, and water-efficient fixtures can substantially decrease household impacts and also affect other phases of the product life cycle by decreasing the demand for manufacturing, packaging, and transportation [93]. Moreover, creative water repurposing can be employed, such as upcycling rinsing water for watering plants or for cleaning, maximizing resource efficiency. Another innovative approach is collecting leftover water from rinsing facial cleansers or toners in a spray bottle to create a refreshing facial mist. Thus, while sustainability in the consumer phase is largely achieved by reducing water and energy consumption, upcycling also offers consumers a meaningful opportunity to actively participate in waste reduction efforts.

In summary, while the complete elimination of water use remains impractical for rinse-off products, the combination of smarter formulations, innovative technologies, and conscious usage patterns presents a multifaceted approach to sustainability.

4.7. Post-Use Phase

The post-use phase of cosmetic products is crucial for managing packaging waste to minimize environmental impact [9,26]. Cosmetic companies possess a significant opportunity to lead consumers towards environmentally responsible disposal practices. This can be achieved through strategic decisions regarding packaging types, weights, sizes, and labels, coupled with initiatives that promote recycling and reuse [10]. Some such strategies are discussed.

4.7.1. Refillable and Reusable Packaging

Many cosmetics brands have embraced consumer-incentivized recycling and refill programs as a central strategy to advance sustainability. These initiatives effectively conserve raw materials, reduce waste, and allow companies to pass cost savings on to consumers. Understanding how consumers use and dispose of product packaging is vital, as educating them on sustainable practices can empower individuals to make a meaningful impact through responsible consumption [10].

Leading brands have pioneered diverse approaches to sustainable packaging. LUSH's "Bring It Back" program exemplifies closed-loop recycling, offering consumers financial incentives for returning empty containers—such as shampoo bottles, soap containers, or face mask pots—which are then repurposed into new products [101]. Similarly, M.A.C.'s Back-to-M.A.C initiative rewards consumers with free products when returning empty cosmetic containers [102]. This initiative has made a significant environmental impact; in 2022 alone, over 340,000 pounds of empty M.A.C containers were recycled in the United States, the equivalent to approximately 9.3 million lipsticks [103]. O Boticário's Boti Recicla program, now the largest packaging return program in Brazil's cosmetics sector, extends this impact by accepting packaging from any brand, regardless of material, and offering discounts to consumers. This versatile and inclusive initiative not only promotes proper waste disposal, but also encourages cross-brand participation, fostering a culture of sustainability in the beauty industry [104].

Collaborations with recycling specialists further enhance these efforts. Murad's partnership with TerraCycle launched the Murad Recycling Program to facilitate the recycling of empty packaging. Consumers send their empty Murad products to TerraCycle facilities and earn points redeemable for charitable donations. TerraCycle upcycles hard-to-recycle packaging, turning it into new products, such as park benches or playground equipment. This initiative combines environmental sustainability with social responsibility in the beauty industry [105]. Similarly, Mustela, known for its baby and maternity products, partnered with the eco-friendly packaging solutions company Jean Bouteille to create a

refillable system, Reviens glass bottles. Mustela offers its best-selling cleansing milk in these reusable glass bottles with pump dispensers. Customers first purchase the bottle, then return to participating pharmacies for refills. By 2021, this eco-friendly system had expanded to 21 pharmacies across France, offering consumers long-term savings and promoting sustainability in everyday skincare routines [106]. Major beauty brands, such as Giorgio Armani, Lancôme, and L'Occitane-en-Provence, have similarly implemented refillable options for select products in their collections [91].

4.7.2. Modular Packaging Systems

The cosmetics industry is increasingly embracing modular packaging systems as a sustainable strategy to reduce waste and minimize carbon emissions from production, while extending the life cycle of the packaging. These systems involve interchangeable or refillable components, allowing consumers to replace only specific parts rather than discarding entire containers. The brand Rituals, for example, sells eco-friendly refill pouches or inserts of several products that reduce the need for new containers, while maintaining the brand's premium look and feel.

4.7.3. Upcycling Packaging

The upcycling of post-consumer packaging, particularly plastics, into added-value products presents a transformative opportunity to address the global plastic crisis. Plastics remain indispensable in cosmetic packaging due to their versatility, durability, and cost-effectiveness, offering properties such as transparency, softness, heat sealability, and an optimal strength-to-weight ratio [107]. However, the improper disposal and mismanagement of plastic waste have led to significant environmental pollution, necessitating urgent innovative strategies for repurposing post-consumer plastic waste and transitioning toward a circular economy, where plastics are repurposed rather than discarded [108]. Cosmetic packaging predominantly relies on petrochemical-derived polymers like poly(ethylene terephthalate) (PET), poly(vinyl chloride) (PVC), poly(ethylene) (PE), poly(propylene) (PP), poly(styrene) (PS), and poly(amide) (PA). These materials are widely favored for their abundance, affordability, mechanical robustness, and barrier properties against gases and aroma compounds [107]. While significant progress has been made in PET recycling and degradation technologies, most current solutions focus on reconverting recycled monomers into PET or other second-generation materials, which are insufficient to mitigate the plastic waste crisis. Emerging innovative strategies now aim to upcycle plastics into higher-value products, redefining waste as a resource. Such advancements highlight the dual potential of plastic upcycling: reducing environmental harm while unlocking economic opportunities. By integrating scientific innovation with circular economy principles, industries like cosmetics can transform plastic waste into feedstocks for high-value applications, reducing reliance on single-use plastics. Notable breakthroughs are already demonstrating this potential—for example, Sadler and Wallace [108] pioneered a biological upcycling method using engineered Escherichia coli to convert PET-derived terephthalic acid into vanillin—the primary component of vanilla flavor and a key fragrance compound (Figure 7).

The microbial conversion of PET into vanillin offers several significant advantages, including the utilization of a low-cost and abundant raw material, a reduction in environmental pollution by transforming plastic waste into a valuable product, and alignment with the growing demand for sustainable ingredients in the cosmetics industry. While the study highlights the scalability of this process for industrial applications [108], several key challenges must be addressed to optimize its feasibility for large-scale implementation The current process faces limitations in vanillin yield, which impacts its economic feasibility. Optimizing key parameters, such as microbial strain engineering, reaction conditions, and

downstream processing, could significantly improve output efficiency. Additionally, the vanillin produced through this method must comply with stringent safety and quality standards for use in food, cosmetics, and pharmaceuticals [25]. Despite these challenges, this innovative approach represents a groundbreaking area of research with immense potential to revolutionize sustainable production methods for valuable compounds like vanillin. The success of such bio-upcycling technologies could establish new paradigms for waste valorization in the circular economy.

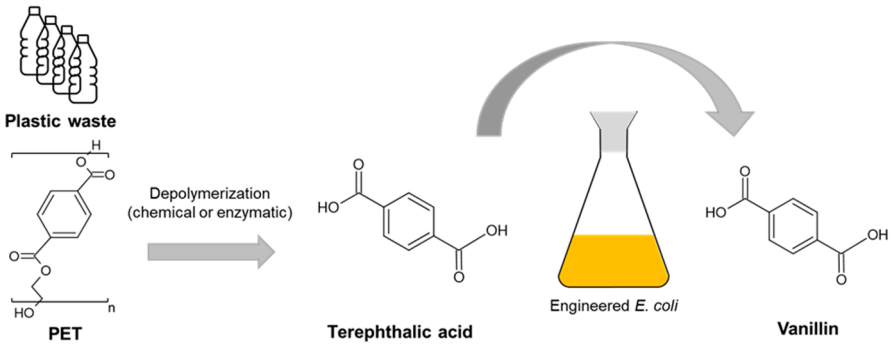

Figure 7. PET upcycling into the value-added compound vanillin [108].

4.7.4. DIY Packaging Upcycling

Empty cosmetic containers, such as lipstick tubes and powder compacts, can be used for DIY projects like creating decorative items or organizing small objects like buttons or beads. They can also be repurposed for artistic purposes and incorporated into creative projects, such as making artwork or jewelry holders. Additionally, attractive cosmetic packaging boxes or bags can be reused as gift packaging for other items, giving a second life to stylish and durable containers.

4.7.5. Upcycling Product Residues

Residual products in containers can be collected and reused in DYI formulations or donated to organizations that repurpose them for community use. An article published in Buzzfeed offers creative and practical ideas for repurposing old or leftover makeup, providing eco-conscious consumers with ways to minimize waste and extend the lives of their beauty products [109]. For example, remaining lipsticks can be melted together to create a new color, while residues of pressed powder can be mixed with facial moisturizer to make a tinted product.

5. Economic Challenges and Opportunities

The transition to sustainable cosmetics presents both significant hurdles and promising prospects for industry stakeholders. On the challenges front, the higher costs of natural and organic ingredients remain a persistent barrier, driven by constrained supply chains, rigorous certification processes, and intensive farming methods [110]. These cost considerations extend to packaging innovations, where eco-friendly solutions—including biodegradable materials, recyclable designs, and refill systems—often come with premium price tags, particularly when scaling production [111]. Supply chain transparency adds another layer of complexity, as ethical sourcing commitments require robust oversight systems (e.g., avoiding child labor in mica mining or ensuring sustainable palm oil) [112]. Furthermore, operational shifts toward circular business models demand substantial upfront investments in new technologies and infrastructure, from in-store refill stations to advanced recycling facilities [113]. Perhaps more crucially, companies face the dual challenge of edu-

cating consumers about legitimate sustainability while combating pervasive greenwashing, necessitating additional investments in clear, credible communication [112].

While the challenges are substantial, they are counterbalanced by compelling opportunities. The sustainable beauty sector is experiencing remarkable growth, with its market value projected to reach USD 326.8 billion by 2031, fueled by rising consumer demand for eco-conscious products [7]. Companies that effectively implement sustainable practices gain multiple competitive advantages in today's market. Research demonstrates that environmentally conscious consumers, particularly younger demographics, show greater brand loyalty and willingness to pay premium prices for verified sustainable products. These credentials also provide access to growing market segments where purchasing decisions are strongly influenced by environmental and social considerations [114]. Beyond direct revenue potential, adopting circular economy principles—such as using byproducts, optimizing supply chains, and reducing waste—can lower long-term costs and improve operational efficiency [7,115]. Perhaps most strategically, early adopters of genuine sustainability can help companies stay ahead of evolving regulations and differentiate themselves in a crowded marketplace [110].

While implementing sustainable practices in the cosmetics industry presents economic challenges—particularly in sourcing, production, and packaging —these are counterbalanced by significant market opportunities for growth, brand differentiation, and long-term cost savings. Companies that strategically invest in sustainability, optimize their supply chains, and communicate transparently with consumers can successfully balance costs with competitive pricing and market leadership.

6. Conclusions and Perspectives

The cosmetics industry plays a pivotal role in daily life, yet its environmental footprint requires the urgent adoption of sustainable practices. While significant strides have been made—adopting eco-friendly ingredients, sustainable packaging, and carbon reduction initiatives—achieving true sustainability demands a holistic approach across the entire product life cycle, from sourcing and manufacturing to distribution and end-of-life management. This work highlights upcycling as a transformative strategy, particularly in ingredient sourcing, by repurposing agro-industrial byproducts as ingredients in value-added cosmetic ingredients. These materials often contain valuable bioactive compounds (e.g., antioxidants and polyphenols) whose cosmetic efficiency has been scientifically validated. Through optimized extraction processes, these waste materials can be valorized into high-performance ingredients, simultaneously addressing waste reduction. Collaborative partnerships between the food and cosmetic industries can further streamline upcycling supply chains, fostering resource efficiency and innovation.

While upcycling is especially impactful in ingredient sourcing, sustainability efforts must extend to other life cycle phases, including production optimization, packaging solutions, and carbon footprint reduction during distribution. Implementing circular water management during production can significantly reduce the environmental impact of cosmetic production. Sustainable packaging remains a critical area in cosmetic sustainability. Rethinking post-consumer plastic as a valuable resource, rather than waste, can accelerate circular economy models. Additionally, improving distribution practices and exploring advancements in CO_2 capture and repurposing into fuel can help reduce the industry's carbon footprint. Sustainability efforts must also extend to consumers: educating and inspiring users on responsible consumption and disposal is essential for fostering sustainable consumption habits.

Figure 8 illustrates possible upcycling approaches applied across the life cycle of cosmetic products.

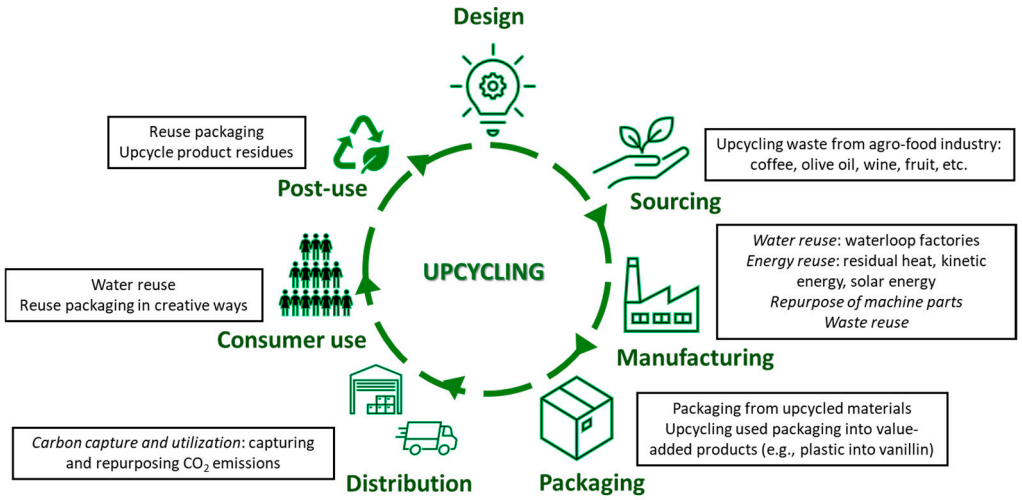

Figure 8. Upcycling strategies applied across the life cycle of cosmetic products.

To accelerate progress toward a truly sustainable cosmetics industry, the following recommendations are proposed:

For researchers, priority should be given to developing more efficient extraction methods, establishing standardized testing protocols for upcycled ingredients, and conducting comprehensive life cycle assessments to quantify environmental benefits. The application of emerging technologies such as AI for byproduct matching and process optimization represents a promising avenue for future investigation.

For policymakers, we recommend creating supportive regulatory frameworks that facilitate the approval of upcycled ingredients while ensuring consumer safety. Financial incentives such as tax credits for sustainable manufacturing practices and investments in regional upcycling infrastructure could significantly lower barriers to adoption.

For manufacturers, we suggest investing in pilot-scale facilities to bridge the gap between laboratory research and commercial production. Developing transparent sustainability metrics and reporting standards will be essential for building consumer trust and demonstrating the tangible benefits of upcycling initiatives.

For consumers, prioritizing products with recognized upcycling certifications (e.g., Cradle to Cradle or Upcycled Certified) ensures support for verified sustainable practices. Equally important is favoring brands that demonstrate full transparency about their ingredient sourcing and supply chains. Beyond purchasing choices, consumers can amplify their impact by participating in circular initiatives like container return programs that enable packaging reuse and by using their social media platforms to advocate for greater industry adoption of upcycled beauty solutions.

Looking ahead, the cosmetics industry must embrace a systems-thinking approach that considers the interconnectedness of ingredient sourcing, production processes, packaging design, distribution networks, and consumer behavior. Future research should explore innovative business models that fully capitalize on the circular economy potential of upcycling, while ongoing monitoring and evaluation will be crucial to assess the long-term sustainability impacts of these initiatives. By addressing these challenges through collaborative efforts across sectors, the cosmetics industry can transform itself from a contributor to environmental challenges to a leader in sustainable innovation.

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Abbreviations

The following abbreviations are used in this manuscript:

CES	Consumer Electronics Show
CPNP	Cosmetic Products Notification Portal
DIY	Do-It-Yourself
EU	European Union
GLAM	Green Last Mile
GMPs	Good Manufacturing Practices
GP	Grape pomace
GS	Grape seed
OMWW	Olive mill wastewater
OP	Olive pomace
PA	Poly(amide)
PE	Poly(ethylene)
PIF	Product information file
PP	Poly(propylene)
PS	Poly(styrene)
PVC	Poly(vinyl chloride)
R&D	Research and Development
SCG	Spent coffee grounds
TEWL	Transepidermal water loss

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