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Integrating Sustainability into Cosmetic Manufacturing and Consumption: Challenges and Innovations

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ABSTRAK

Industri kosmetik global terus mengalami pertumbuhan pesat, dengan pendapatan yang diperkirakan melampaui USD 800 miliar pada tahun 2030. Peningkatan omset dari kosmetik ini berdampak positif bagi perekonomian. Namun, peningkatan ini juga menimbulkan dampak lingkungan akibat penggunaan bahan sintetis, kemasan plastik, serta proses produksi. Kajian ini bertujuan meninjau dampak lingkungan dari industri kosmetik melalui empat aspek utama: bahan baku kosmetik, kemasan, proses manufaktur, dan perilaku konsumen. Metode yang digunakan adalah telaah pustaka terhadap publikasi tahun 2000–2025 dari berbagai sumber ilmiah. Hasil menunjukkan bahwa bahan seperti paraben, triklosan, dan 1,4-dioksan menyebabkan pencemaran dan toksisitas lingkungan, sedangkan kemasan plastik menjadi sumber utama limbah mikroplastik. Alternatif berkelanjutan seperti penggunaan senyawa alam sebagai bahan baku seperti ekstrak tebu, minyak zaitun, isolat protein whey, atau pun bahan kemasan bersifat biodegradable seperti bahan kemasan berbasis PLA, selulosa, dan kitosan menunjukkan potensi tinggi untuk mengurangi dampak lingkungan. Di sisi lain, penggunaan energi terbarukan, sistem waterloop, dan teknologi daur ulang di pabrik meningkatkan efisiensi dan mengurangi emisi karbon. Perilaku konsumen, khususnya Generasi Z yang peduli terhadap keberlanjutan, turut mendorong produsen untuk lebih bertanggung jawab secara sosial dan ekologis. Penelitian ini menegaskan pentingnya penerapan praktik kosmetik berkelanjutan demi menjaga keseimbangan antara perkembangan industri dan kelestarian lingkungan.

Kata kunci: kosmetik, dampak lingkungan, mikroplastik, perilaku konsumen

ABSTRACT

The global cosmetic industry continues to grow rapidly, with revenues projected to exceed USD 800 billion by 2030. However, the use of synthetic ingredients, plastic packaging, and energy- and water-intensive production processes has led to environmental impacts. This study examines the environmental impacts of the cosmetic industry through four key aspects: cosmetic ingredients, packaging, manufacturing processes, and consumer behavior. A literature review of publications from 2000 to 2025 obtained from major scientific databases was used. The results show that ingredients such as parabens, triclosan, and 1,4-dioxane contribute to pollution and environmental toxicity, while plastic packaging remains the main source of MPF. Sustainable alternatives, such as sugarcane straw extract, olive oil, whey protein isolate, and PLA-, cellulose-, and chitosan-based packaging

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materials, show strong potential to reduce environmental impact. Meanwhile, the adoption of renewable energy, waterloo systems, and recycling technologies in factories improves efficiency and reduces carbon emissions. Changes in consumer behavior, particularly among Generation Z, who are highly concerned about sustainability, also encourage producers to act more socially and environmentally responsibly. This study emphasizes the importance of implementing sustainable cosmetic practices to maintain a balance between industrial growth and environmental preservation.

Keywords: cosmetics, environmental impact, microplastics, energy efficiency, consumer behavior

INTRODUCTION

The global cosmetic industry has shown a remarkable upward trajectory over the past decade, reflecting both evolving beauty ideals and changing consumer values. According to Statista Market Insights (February 2025), global cosmetics revenue is projected to double from around USD 400 billion in 2018 to over USD 800 billion by 2030, highlighting the sector's sustained expansion [1]. Face cosmetics dominate the market due to the integration of skincare functions and continuous product innovation, followed by eye cosmetics, while lip and nail segments show moderate growth. Natural cosmetics are the fastest-growing category, driven by consumer awareness of sustainability, transparency, and ethical sourcing practices that increasingly shape purchasing behaviors [2].

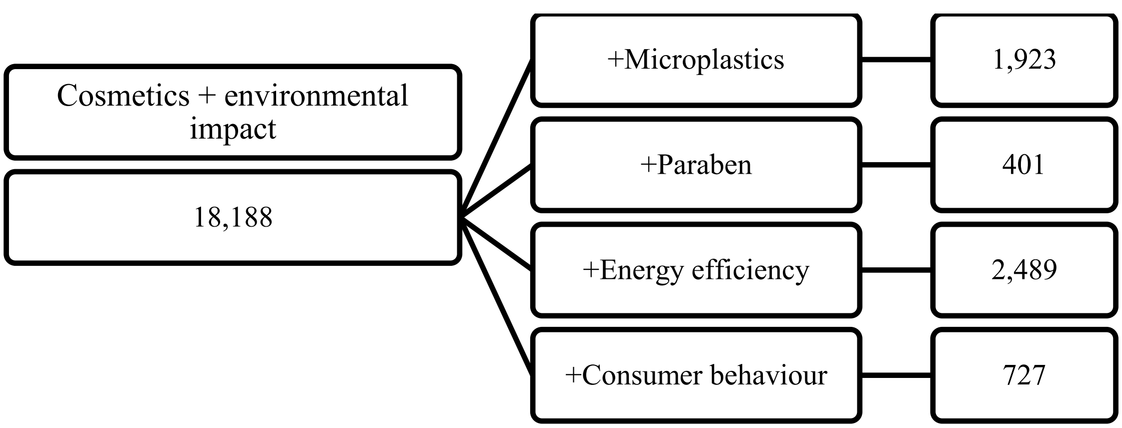
However, this massive growth has come at a significant environmental cost. The rising demand for cosmetics has led to the excessive use of petroleum derivatives in both product formulations and packaging, resulting in the widespread presence of plastics, parabens, microplastics, and synthetic polymers that persist in ecosystems [3]. In addition to visible packaging waste, harmful ingredients, such as UV filters, triclosan, and surfactants, have been identified as emerging environmental contaminants known to disrupt aquatic microorganisms and crustaceans [4]. In developing countries such as Malaysia, the circulation of counterfeit and chemical-based cosmetics containing toxic ingredients further intensifies environmental and public health risks [5]. Although regulatory bans on microbeads have begun, microplastics remain an unresolved global concern because of their pervasive accumulation in water systems. Meanwhile, the manufacturing phase of cosmetics production also contributes substantially to environmental degradation through high energy and water consumption, inefficient waste management, and carbon emissions, prompting industries to pursue cleaner production under IEE initiatives [6].

The social dimension compounded the problem: media-reinforced globalized beauty standards drive overconsumption of cosmetics as symbols of attractiveness and status rather than necessity. A study in Sri Lanka revealed that approximately 96.4% of individuals use one or more cosmetic products, demonstrating the extent to which beauty ideals have shaped daily habits across cultures [7]. Ultimately, the negative impact of synthetic cosmetics extends beyond human health, affecting air quality, marine life, and broader ecosystems, positioning the cosmetics industry as both a reflection of modern consumer culture and a pressing environmental challenge [8].

In light of these dynamics, the cosmetic industry stands at a critical crossroads—caught between its accelerating market growth and the mounting environmental. While innovation continues to reshape product offerings and consumer experiences, it also amplifies unsustainable practices that impact ecosystems and public health. Given this complex duality, it becomes essential to examine existing knowledge and research trends surrounding the environmental impacts of synthetic cosmetics. This literature review aims to critically synthesize current findings on the ecological and social consequences of cosmetic production and consumption, highlighting gaps in regulation, emerging contaminants, and the role of consumer awareness. By mapping the current academic discourse, this review seeks to provide a foundation for future research and policy directions that can support a more sustainable and accountable cosmetics industry.

METHODS

This study used a literature review approach to collect and analyze information about the cosmetics industry's environmental impacts. We retrieved articles and reports published between 2005 and 2025 from major databases, such as Scopus, Web of Science, PubMed, and Google Scholar. The search focused on four main aspects: cosmetic ingredients, packaging materials, manufacturing processes, and social consumption habits. Keywords included "cosmetics," "environmental impact," "microplastics," "parabens," "energy efficiency," and "consumer behavior." Studies were selected if they provided clear data or discussed pollution, waste management, resource use, or social factors influencing cosmetic consumption. Some research's were excluded because not meet cosmetics context (e.g household), conference abstract, patents, animal toxicology impact and duplication or similar results. Number of article that reviewed was listed below.



All selected articles were screened for relevance and reliability. The results were grouped into four thematic pillars: materials, packaging, manufacturing process and social habits. Because of the diversity of study designs, the data were analyzed descriptively rather than statistically. This review aims to present a clear overview of how cosmetic production and consumption contribute to environmental degradation while identifying possible directions for sustainability improvement.

RESULTS AND DISCUSSION

Beauty at a Cost: How Cosmetics Pollute Our Planet Everyday

1. Cosmetic materials

   The environmental footprint of the cosmetics industry is largely shaped by the chemical composition of its products. Many commonly used cosmetic materials are derived from non-renewable sources and persist in natural ecosystems long after use. These ingredients are often not fully biodegradable and can accumulate in soil, waterways, and marine environments, where they disrupt biological processes and pose risks to aquatic life. Hereby several materials which contribute significantly in the environmental sustainability.

   a. *Paraben*

      Parabens are commonly used as preservatives in various household, pharmaceutical, and cosmetic products. Because of their continuous discharge from manufacturing facilities and widespread use, high concentrations of parabens are frequently detected in urban and hospital wastewater effluents. Consequently, these compounds have been found in various environmental media, such as water, dust, and air. Raw wastewater samples have been reported to contain up to 20,000 ng/L of propylparaben and 30,000 ng/L of methylparaben, indicating significant environmental contamination [9]. Parabens, also known as p-hydroxybenzoates, are derivatives of p-hydroxybenzoic acid and are employed in the pharmaceutical, cosmetic, and food industries because of their desirable properties as preservatives and antimicrobials. Parabens work better against fungi than bacteria when it comes to preservatives. They also work better against gram-positive bacteria than against gram-negative bacteria. Combining them with other parabens may increase their effectiveness spectrum. Furthermore, they work well in alkaline, neutral, and acidic solutions up to pH = 8, after which their preservation properties begin to wane [10].

   b. *Triclosan*

      Triclosan (TCS), an antibacterial lipid-soluble substance, is a common preservative in many personal care products, including shampoos, toothpaste, detergents, hand soaps, deodorants, and sunscreens. Owing to its broad-spectrum antibacterial and antifungal properties, it is also widely used as an additive or stabilizer in fabrics, packaging, functional clothing, and as an antiseptic in many household products and medical devices [11].

c. *Dioxane*

Originally utilized as a fixative agent in a chlorinated solvent, 1,4-Dioxane ($C_4H_8O_2$, dioxane) is a synthetic chemical that is now found in many commercially accessible products, particularly food items. An organic solvent (ether), 1,4-dioxane is frequently used as a detergent and emulsifier. Therefore, it is frequently found in household and personal hygiene products such as shampoo, toothpaste, mouthwash, body lotion, shower gel, and baby lotion [12].

Table 1. Environmental Parameters Associated with Cosmetic Ingredients

Materials	Founding	Impact on the environment	Ref
Paraben	While DW sources usually have concentrations of parabens below 6 µg/L, wastewater treatment plants and surface waters have been observed to have values of over 100 µg/L. The existence of parabens in DW, even at low concentrations, presents a risk of human exposure and raises issues for the environment's microbiota and human health.	Interfere with hormonal synthesis and disrupt microbial communities, resulting in altered bacterial behavior and reduced biodiversity. Moreover, chlorinated parabens—formed during water disinfection—exhibit higher toxicity, posing greater risks to aquatic organisms and human health.	[13]
Triclosan (TCS)	The TCS concentrations in the US wastewater effluent varied from 200 to 2,700 ng/L, according to the research that tested them. Between 5,200 and 18,824 kg of TCS are thought to be loaded into US surface waters annually, with WWTP effluents accounting for almost half of this total.	TCS in the environment changes the bacterial population by biofilm development, impact respiration rates, denitrification and enriches for species capable of dehalogenation.	[14, 15, 16]12/11/2025 1:12:00 PM
Dioxane	Data on 1,4-dioxane emissions show that industrial discharges rose sharply from 645–1522	Kidney damage from long-term exposure to 1,4-dioxane through	[16, 17]

	tons in 2000 to 3868 tons in 2023. In the past, this chemical was directly released as a stabilizer for chlorinated solvents. Today, most emissions occur unintentionally from the production of poly(ethylene terephthalate) and ethoxylated surfactants, showing how the sources have changed over time. 1,4-Dioxane is ranked number 214 on the ATSDR Substance Priority List, highlighting its concern for health and the environment. Results from the U.S. EPA's UCMR-3 program also show that it was the second most common contaminant in U.S. public water systems, found at 21% of 4,864 tested sites.	drinking water consumption has also been reported, including glomerulonephritis, tubular necrosis, and degeneration of cortical tubule cells.	

The key environmental parameters and their respective impacts associated with cosmetic materials are summarized in Table 1. Parabens, triclosan (TCS), and 1,4-dioxane represent major chemical contaminants, each exhibiting significant persistence and ecological toxicity. Parabens, detected in both drinking and surface waters, disrupt hormonal balance and microbial biodiversity, with chlorinated derivatives posing higher toxicity risks. Triclosan contributes to antimicrobial resistance by exerting selective pressure on bacterial populations, while 1,4-dioxane emissions—largely from industrial sources—have risen markedly, with chronic exposure linked to kidney damage.

2. Packaging materials used in cosmetics

In addition to facilitating communication and the practical use of industrial cosmetic products, packaging plays an essential role in protecting and transporting goods [19]. It not only ensures product safety and quality during distribution but also acts as a powerful marketing tool. Effective packaging attracts consumers' attention, influences their purchasing decisions, and conveys brand identity and values [20]. The container type impacts both user convenience and consumer safety by affecting the delivered dose accuracy [20].

In the cosmetic industry, packaging is generally divided into three layers, each serving distinct yet complementary functions. The primary packaging layer directly encloses the product, protecting it from moisture, light, and air while maintaining its stability, safety, and quality throughout its shelf life. Secondary packaging surrounds the primary layer, offering extra protection during handling, transport, and storage, as well as supporting branding and consumer appeal through design and labeling. Tertiary packaging groups multiple units of primary or secondary packages for bulk distribution, ensuring efficient transport and protection from physical or environmental damage. Together, these three layers maintain product integrity, facilitate logistics, and enhance marketing effectiveness [21, 22]. However, achieving these functions requires the use of various materials each of which carries distinct environmental implications that merit closer examination.

a. Glass

   Glass provides a smooth, non-porous, and non-toxic surface with excellent impermeability, thus maintaining product purity and stability. Made from natural materials, it is chemically inert and resistant to most acids, except hydrofluoric acid, giving it both durability and a luxurious esthetic. The common types of glass used in cosmetic containers include soda, potassium or lead, and opaque glass. Soda glass, which is composed mainly of silicon oxide, calcium oxide, and sodium oxide, is widely used in transparent bottles, such as lotions. Potassium or lead glass contains silicon oxide, lead oxide, and potassium oxide, producing crystal glass with high clarity, which is often used in high-end perfume bottles. Opaque glass includes fine crystals that reflect light, giving a milky or jade-like appearance for decorative packaging. While glass is fully recyclable and can be reused indefinitely without losing quality, its fragility and weight make it less durable and more costly to transport compared to plastics or metals, contributing to a higher carbon footprint [23, 24].

b. Plastic

   Plastic dominates the cosmetic packaging industry because of its versatility, low cost, light weight, and ease of molding into various shapes and designs [25]. Plastic containers are resistant to breakage, making them safer for consumers and reducing product loss during handling and transport. Common plastics used in cosmetics include polypropylene (PP), polyethylene terephthalate (PET), polyethylene (HDPE and LDPE), polystyrene (PS), and acrylics such as acrylonitrile styrene (AS) and acrylonitrile butadiene styrene (ABS). Each type of plastic has distinct advantages. For example, HDPE and LDPE are flexible and durable for lotions and shampoos, PP offers excellent chemical resistance and is ideal for jars and flip-top caps, PET provides transparency and gloss similar to glass, and acrylics offer a clear, glass-like appearance with higher impact resistance [23]. Despite these benefits, the widespread use of plastic poses environmental challenges because most plastics are non-biodegradable, persisting for decades, and contributing to marine and land pollution. Plastic waste, especially polyolefins, is a major contributor to global pollution, with millions of tons of plastic waste entering the oceans each year and harming marine life [26]. While aluminum and other metals are gaining popularity due to their durability and recyclability, plastics remain dominant due to their cost efficiency and manufacturing convenience [28].

c. Metal

Beauty brands are increasingly adopting metal packaging as an alternative to plastic, offering a sense of luxury, durability, and brand distinction [29]. Tinplates made by coating mild steel sheets through dipping or electrolytic processes have been widely used for cosmetic packaging [30]. However, the trend has shifted toward lighter and more corrosion-resistant materials, such as aluminum. Aluminum is favored because it is lightweight, easy to mold, and suitable for use in aerosol cans, lipstick cases, compacts, mascaras, and pencils [30]. It also provides excellent protection against oxidation and microbial contamination. Aluminum surfaces are often treated or coated to enhance appearance and prevent corrosion. Brass, an alloy of copper and zinc, is used for decorative packaging items such as compacts or lipstick casings due to its gold-like appearance and high density. Steel and stainless steel are employed for products such as aerosol cans; while regular steel must be coated or plated to prevent rusting, stainless steel with added chromium and nickel offers high corrosion resistance [22]. Metal packaging also provides strength and recyclability advantages, making it more environmentally sustainable than plastic [32]. However, its limitations include higher production costs, susceptibility to dents or deformation (especially in collapsible tubes), and potential reactivity with certain cosmetic formulations, which restricts its use for all product types [33].

Table 2. Environmental Parameters Associated with Cosmetic Packaging

Materials	Founding	Impact on the environment	Ref
Glass	Glass manufacturing has a significant environmental impact due to its high energy consumption, mainly from melting raw materials like silica and soda ash at very high temperatures, which releases large	Increased CO_2 emissions significantly impact the environment through global warming, climate change, and ocean acidification.	[31, 32, 33]

	amounts of carbon dioxide. The process also generates other air pollutants, such as nitrogen oxides and sulfur dioxide, contributes to resource depletion through intensive raw material extraction, and produces solid and wastewater residues.		
Plastic	Microplastics are formed when larger plastic debris undergoes degradation processes such as photo-oxidation, thermal oxidation, hydrolysis, and fragmentation, breaking down into particles smaller than 5 mm. These tiny particles are highly persistent and spread through air, soil, and water due to their light weight and biodegradation resistance.	hey accumulate across ecosystems—from terrestrial to marine—causing ingestion and entanglement in wildlife, blocking digestive systems, reducing growth and reproduction rates, and leading to death in aquatic species. Chemically, microplastics release toxic additives such as bisphenol A (BPA) and phthalates, which bioaccumulate in the food chain, leading to hormonal disruption, oxidative stress, and biodiversity loss.	[37]
Metal	Steel production remains highly carbon-intensive, contributing ~7% of global GHG and 11% of CO_2 emissions	High levels of CO_2 and greenhouse gas emissions contribute significantly to global warming, climate change, and the disruption of ecosystems.	[38]

The key environmental parameters and their respective impacts associated with cosmetic packaging are summarized in Table 2. Among packaging materials, glass production emits large quantities of CO_2 and other pollutants due to high-temperature processes, whereas plastics degrade into microplastics that persist across ecosystems, leading to wildlife ingestion, bioaccumulation, and hormonal disruption. Metal, otherwise show relatively more environmental-friendly characteristic with 82.5% are being recycled. However, it still contributing to global GHG and CO_2 emission. Collectively, the data highlight how both chemical ingredients and packaging materials contribute to the cosmetics industry's environmental footprint through contamination, toxicity, and carbon emissions.

3. Manufacturing process
   The primary sustainability concerns during the cosmetics manufacturing process are waste management, water use, and energy consumption. As a result, industries are working harder to develop and implement cutting-edge solutions that reduce their carbon, water, and environmental footprints [39].

   a. Waste management
      Landfilling, incineration, improper dumping, and vermi-composting are the most prevalent waste processing and management practices in developing countries. The first three approaches have one or more disadvantages, such as contaminating groundwater and soil, polluting the environment through biomass burning, and affecting environmental hygiene and human health [40].

   b. Water use
      Water has long been a crucial component in the formulation and production of cosmetics. Water is necessary at every stage of the life cycle of a cosmetic product: it is one of the primary ingredients in a cosmetic formulation, and it is also needed for the production of packaging, equipment cleaning, heating and cooling processes, and raw material cultivation, all of which contribute to high consumption and major pollution impacts [41].

   c. Energy consumption
      Thermal energy predominates among the mechanical and thermal energy inputs used in the emulsion production [38]. The choice of raw materials and product manufacturing account for 22.7% and 19.6% of the total product sustainability score, respectively. Therefore, by lowering the energy required to produce raw cosmetic materials and finished goods, businesses can reduce their carbon impact. To further reduce carbon emissions, energy that cannot be reduced could be acquired from renewable energy sources [43].

4. Social habit
   Cosmetic consumption has evolved into a social habit that goes beyond basic needs and significantly contributes to environmental concerns in today's digital era. Constant exposure to beauty trends and influencer marketing on social media platforms has reshaped consumer behavior, creating a culture where image and appearance take precedence over necessity. Social media marketing tactics, which rely heavily on

personalized and engaging content, have made consumers—especially women—more susceptible to continuous persuasion, blending egoistic and altruistic motivations in purchasing decisions [44]. The widespread accessibility of online shopping further amplifies this behavior, allowing users to buy cosmetics with just a few clicks, encouraged by positive reviews and targeted advertisements [45]. Online shopping encourages the purchase of cosmetics due to easy access, a wide variety of product choices, and user reviews that influence consumer decisions [46]. As a result, cosmetics are no longer perceived merely as self-care products but have transformed into trendsetters and luxury symbols that reflect one's social status. This pursuit of beauty as a social statement drives overconsumption, leading to an increased environmental burden from packaging waste, excessive production, and the use of harmful chemicals. Thus, the intersection of social media influence, online shopping convenience, and the social prestige associated with cosmetics underscores a growing need to reconsider how beauty consumption habits affect both society and the environment [47].

Sustainable Beauty Choices: Redefining Cosmetic Consumption

1. Cosmetic materials

   As part of a larger push for circular production and green formulation, environmentally friendly components are becoming increasingly popular in the cosmetics sector. Eco-friendly cosmetic products prioritize biodegradability, renewability, and low environmental impact throughout their entire life cycle [48]. Upcycling, also referred to as creative reuse, reduces negative environmental effects and opens new market opportunities by turning waste materials into higher-value products. This framework manifests in various ways within the cosmetic industry, including sourcing sustainable materials, optimizing production processes, and reducing both energy and water consumption [49].

Table 3. Sustainable Cosmetic Ingredients

Function	Materials	Founding	Ref
Preservative	Sugarcane Straw Extract	Sugarcane straw extract contains flavones, hydroxybenzoic acids, and hydroxycinnamic acids. MIC of 3%–5% (w/v) against P. aeruginosa, E. coli, and S. aureus. Furthermore, the component in the W/O and O/W emulsions met the requirements of the USP 51 challenge test at 5% (w/v).	[50]
Emollients	Vegetable oils, such as olive oil	Olive oil derived from *Olea eur opaea* functions as an effective natural emollient due to its high oleic acid and	[51]

		linoleic acid content, which help soften and smoothen the skin by replenishing lipids in the stratum corneum. Emollient properties enhance skin hydration and suppleness	
Surfactant	WPI	This study demonstrated that WPI can produce nanoemulsions with the same droplet size and comparable physical stability as those stabilized by the synthetic surfactant Tween 20. Despite Tween 20 being more effective at lowering interfacial tension, WPI effectively prevented droplet coalescence during homogenization, resulting in stable emulsions. Moreover, WPI-based nanoemulsions exhibited higher apparent viscosity, providing a creamier texture while maintaining stability equivalent to that of Tween 20 formulations.	[51]

The results in Table 3 indicate that most sustainable alternatives used in cosmetic formulations are derived from natural ingredients. Sugarcane straw extract acts as a natural preservative with strong antimicrobial activity, olive oil functions as an effective emollient that enhances skin hydration and smoothness, and whey protein isolate (WPI) serves as a natural surfactant capable of forming stable emulsions comparable to those produced with synthetic surfactants such as Tween 20. Despite these promising results, the industrial use of natural ingredients still encounters several challenges, including inconsistency in raw material quality caused by agricultural variability, difficulties in large-scale production, higher processing costs, and potential stability issues during long-term storage. [49, 50] Addressing these limitations is crucial for achieving a complete transition toward sustainable, nature-based cosmetic formulations. In addition to substituting conventional materials with more sustainable options, regulatory policies and sustainability frameworks, as described in Table 4, play a vital role in encouraging industries to adopt environmentally responsible ingredients.

Table 4. Policy for a Sustainable Industry

Policy	Impact on the environment	Ref
Roundtable on RSPO certification	Produce sustainable palm oil and use the norm across the industry. Palm oil production has significant environmental and social impacts—such as	[54]

	deforestation, loss of biodiversity, and exploitation of workers or local communities. RSPO works to reduce these negative impacts by promoting best practices and ensuring accountability.	
Round Table on Responsible Soy	The certification guarantees that soy is sourced from a responsible production system that upholds environmental sustainability, social responsibility, and economic viability. In contrast, unsustainable soy cultivation can cause significant negative environmental impacts, similar to those associated with non-sustainable palm oil production.	[55]
Round Table on Sustainable Cocoa Production	Unsustainable cocoa cultivation contributes to deforestation, soil degradation, water pollution, biodiversity loss, and greenhouse gas emissions, particularly in tropical regions. The RTSC addresses these issues by promoting deforestation-free supply chains, agroforestry practices, and environmentally responsible cocoa production.	[56]

Palm oil is used in the industry as a source of biowax that functions as an emollient and emulsifier [53]. Biowaxes (BWs) obtained from palm oil exhibit physical and chemical characteristics similar to natural waxes such as beeswax and carnauba wax. They contain a high proportion of waxy esters (17%–36%) with long alkyl chains (C_{19}–C_{26} per carbonyl group), which contribute to their high melting points (ranging from <20 °C to 47.9 °C) and low penetration values (2.1–3.8 mm), ensuring mechanical stability and desirable texture in formulations. In addition, these palm-based biogases are sterile and biocompatible, showing no cytotoxic, phototoxic, antioxidant, or irritant effects, making them safe for topical applications. Owing to these favorable physicochemical and safety properties, palm-derived biowaxes serve as a sustainable and functional alternative to traditional animal or mineral waxes in human-use cosmetic and pharmaceutical products [58].

Soy and its derivatives, such as proteins and peptides, are commonly used in cosmetic formulations as conditioning agents for skin and hair, which improve softness, hydration, and elasticity [59]. These compounds are classified by the Food and Drug Administration as Generally Recognized As Safe (GRAS). Data from the US Food and Drug Administration's Voluntary Cosmetic Registration Program show that hydrolyzed soy protein is one of the most frequently used soy-based ingredients, mainly found in hair products. Glycine soja (soybean) protein is also widely used in skincare and hair coloring formulations. Safety studies have demonstrated that soy-derived ingredients are non-mutagenic, non-irritating, non-sensitizing, and non-phototoxic, even at concentrations up to 35%. Therefore, soy is a safe, multifunctional, and plant-based ingredient that is aligned with the growing demand for natural and sustainable materials in cosmetics [60].

Cocoa-derived phytochemicals have shown promising effects in both in vitro and in vivo skincare studies. For instance, catechins protect the skin from ultraviolet B (UVB)-induced damage by regulating antioxidant enzyme activity [61]. Additionally, cocoa pod extract demonstrated inhibitory effects on collagenase, elastase, and tyrosinase enzymes associated with skin aging—while clinical observations in human volunteers revealed reductions in wrinkles and improvements in skin hydration [58].

2. Packaging materials used in cosmetics
   Growing environmental concerns over packaging waste and resource depletion have prompted the cosmetics industry to seek more sustainable packaging solutions. Brands and manufacturers are increasingly adopting alternative materials that reduce ecological harm. These include biodegradable polymers, recycled materials, refillable systems, and bio-based plastics, which support the transition toward a circular economy. Oira et al. outlined several promising options for developing more sustainable packaging materials [63].
   a. *Wood plastic composites (WPCs)* are structurally versatile because they can be molded into diverse shapes and sizes, making them ideal for large-scale or irregular packaging designs [64].
   b. *Polylactic acid (PLA)*, a biodegradable polymer derived from renewable sources such as corn starch, sugarcane, and maize, is an eco-friendly alternative to petroleum-based plastics. The use of PLA in cosmetic packaging not only utilizes renewable feedstocks but also significantly reduces carbon emissions, energy consumption, and landfill waste compared to traditional plastics [65].
   c. *Cellulose-based materials*, obtained from plant cell walls, represent another sustainable option due to their biodegradability, renewability, and environmental compatibility, making them suitable for various packaging applications [66].
   d. Chitosan
      Chitosan, a natural biopolymer derived from chitin found in crustacean shells, consists of glucosamine and N-acetylglucosamine units that form a cationic linear structure. Its strong film-forming and barrier properties make it a viable candidate for sustainable packaging, particularly when blended with other biopolymers or plasticizers to enhance flexibility and mechanical strength [67].

Sustainable packaging innovations in the cosmetics industry are shifting toward environmentally responsible materials and design strategies that minimize waste and carbon emissions. Bio-based plastics, such as PLA and bio-PET, are derived from renewable resources and significantly reduce reliance on fossil fuels, although their effective recycling or composting still depends on proper waste management infrastructure [68]. The use of PCR further supports circularity by repurposing plastic waste and reducing the need for virgin polymers, although quality variation and sorting challenges persist. Refillable and reuse systems extend the lifespan of packaging, reducing single-use waste, but require consumer engagement and an efficient logistics system for return or refill. Minimalist and lightweight packaging approaches reduce the use of materials and transportation emissions while maintaining product protection and shelf stability. Compostable or biodegradable materials are also emerging as alternatives designed to decompose under specific environmental conditions, although their success depends heavily on proper end-of-life handling. Lastly, modular or multi-use packaging designs allow users to replace or reuse individual components, minimizing total waste generation. However, they require standardized materials and consumer awareness to ensure consistent use and disposal practices. Together, these innovations represent crucial steps toward sustainable packaging systems that align with circular economy principles in the cosmetics sector.

3. Manufacturing process

Effective sustainability in the cosmetic manufacturing process largely depends on three critical areas: waste management, water use, and energy consumption [39].

a. Waste Management

Modern cosmetic manufacturers are increasingly implementing the principles of circular economy to minimize waste generation and maximize resource recovery. Instead of disposing of industrial waste, companies now employ strategies such as reusing wastewater, recovering by-products, and adopting zero-waste production models. For instance, wastewater can be purified using phytoremediation systems—where plants act as natural filters—and later reused for non-industrial purposes, such as irrigation [69]. Brands such as L'Oréal have introduced such systems to reduce landfill dependency and promote closed-loop manufacturing. [70] Furthermore, solid waste from production is being repurposed into bioenergy or secondary raw materials, supporting the shift toward more sustainable and responsible production cycles [71].

b. Water Use

Water plays an essential role in cosmetic manufacturing, not only as an ingredient but also in the cleaning and cooling of equipment. Companies are moving toward water-efficient technologies and adopting “waterloop factory” systems, where water is continuously recycled and reused within the plant, to address sustainability challenges [72]. This approach drastically reduces freshwater consumption while maintaining high hygiene standards. Several manufacturers have also implemented rainwater harvesting systems that use collected water for sanitation and heating applications, thereby reducing the dependence on municipal supplies.

c. Energy Consumption
Reducing energy demand and greenhouse gas emissions has become a core objective in sustainable cosmetic production [66]. Many companies have transitioned to renewable energy sources, including solar, wind, and geothermal power, to run their facilities. The adoption of cold emulsification processes, where lower temperatures are used during formulation, also helps reduce both energy use and CO_2 emissions [74]. Moreover, smart energy management systems that monitor the performance of heating, ventilation, and air conditioning (HVAC) contribute to reducing unnecessary energy losses. Companies such as Shiseido and Aveda have made significant strides in these areas, operating with renewable power and innovating low-energy production methods [69, 70]. These combined strategies demonstrate how energy efficiency not only minimizes environmental impact but also enhances long-term operational sustainability in the cosmetic sector.

d. Sources of raw materials and ethical sourcing
Sustainability in cosmetic production is determined not only by what happens inside the manufacturing facility but also by the raw materials used in formulations. Ingredients sourced through unsustainable means, such as palm oil derived from deforested areas or minerals extracted under exploitative labor conditions, can severely damage a brand’s global reputation. As a response, many cosmetic producers are adopting ethical sourcing principles, which prioritize raw materials obtained through transparent, fair, and environmentally responsible supply chains. Certification schemes, such as Fair Trade, Roundtable on Sustainable Palm Oil (RSPO) , and EcoCert, are increasingly used to ensure that ingredients do not harm local communities or natural ecosystems. This approach aligns with environmental goals, enhances consumer trust, and reinforces a company’s image as a socially responsible enterprise [71, 72]

e. Process automation and digital efficiency
Digital transformation has become a crucial driver of modern cosmetic manufacturing efficiency and sustainability. Automated production lines reduce human error, shorten production time, and minimize material waste. Furthermore,

the integration of digital systems, such as the Internet of Things (IoT), artificial intelligence (AI), and real-time data analytics, enables manufacturers to monitor resource usage (energy, water, raw materials) with greater accuracy. These tools support continuous process optimization (CPO). For instance, AI can be used to fine-tune product formulations for maximum efficiency, whereas smart sensors can shut down idle equipment to avoid unnecessary energy consumption. Overall, digitalization not only enhances operational performance but also promotes adaptive, low-impact production systems that can respond flexibly to market and environmental demands [79].

f. Manufacturing transparency and reporting on environmental, social, and governance

Transparency in production practices has emerged as a strategic necessity in today's sustainability-focused business landscape. Global cosmetic companies are increasingly expected to publish sustainability or (Environmental, Social, and Governance) ESG reports that detail their carbon footprint, waste management efforts, labor practices, and overall sustainability policies. Such disclosures build consumer trust, meet international regulatory standards, and attract sustainability-driven investors. ESG reporting encourages companies to conduct ongoing evaluations of their environmental and social performance, identify operational risks, and set measurable long-term targets. As consumers become more conscious of business ethics and environmental impact, transparency in manufacturing has become a key differentiator and a critical component of corporate responsibility in the cosmetics sector [72, 73].

4. Social habit

a. Empties point

Several cosmetic brands have introduced take-back programs to encourage circularity and responsible consumption by encouraging customers to return their used packaging. The Body Shop's Love Your Body Club (LYBC) initiative rewards members with one stamp for every empty cosmetic container they return. After collecting five stamps, customers can redeem them for a trial-sized product or small items, such as the brand's popular hand creams [70]. Similarly, Kiehl's has maintained a long-standing recycling program that motivates consumers to recycle their empty bottles. Customers are required to wash, clean, and dry their containers before returning them to the store to ensure recyclability. Each returned bottle earns one stamp, and customers are also recognized for bringing their own reusable shopping bags. These programs not only reduce packaging waste but also foster consumer engagement in sustainability efforts within the beauty industry [81].

b. Refill packaging

Refillable packaging is a practical and eco-friendly approach to reducing waste within the cosmetic industry. In this system, a refillable parent container—such as a bottle, pouch, pod, tablet, or powder case—is designed for repeated use and can be easily replenished. The refill unit is typically made using less material than the original packaging, thereby lowering resource consumption and environmental impact. Refilling can be performed by pouring the product directly into the parent container, inserting a refill pod, or diluting a concentrated formula with water inside the same package. This method effectively reduces single-use plastic waste and carbon emissions resulting from new packaging production while promoting sustainable consumer habits through the continued use of durable containers [82]. Several cosmetic brands, such as Wardah, which offers refill options for its two-way cake and powder foundation products, have already adopted this model [73]. Similarly, The Body Shop provides refillable packaging for personal care items, including haircare products, shower gels, and hand washes [84].

c. Consumer behavior that favors eco-cosmetic companies

Consumers, particularly Generation Z, show a strong preference for cosmetic brands that prioritize sustainability and environmental responsibility. Their heightened awareness of environmental challenges and a personal sense of duty to protect the planet drive this behavior. They understand that the cosmetic industry contributes to pollution, waste, and resource depletion, motivating them to support brands that actively reduce their environmental impact. Transparency and authenticity are key values for this generation, as they seek companies that demonstrate real commitment through verifiable actions such as ethical sourcing, sustainability certifications, and eco-friendly formulations. Generation Z consumers often reject greenwashing and superficial marketing claims, instead favoring brands aligned with their social and environmental values. Social influence also plays a significant role; Gen Z relies on online communities, influencers, and peer reviews when choosing products, giving greater visibility to brands that genuinely uphold sustainable practices [85]. Research suggests that this consumer trend offers valuable insights for industry practitioners and policymakers, encouraging them to promote green product attributes by linking functional and emotional perceptions with ethical factors such as fair trade, cruelty-free testing, green formulation, eco-labeling, and sustainable packaging. These elements can strengthen the intention to purchase eco-friendly cosmetics and foster more sustainable production and consumption patterns [86]. However, other studies indicate that among various influencing factors, environmental awareness, affordability, and FOMO (fear of missing out) have a significant impact on the motivation to purchase eco-friendly products, highlighting the role of social trends in shaping sustainable behavior [87]. Despite these positive tendencies, challenges remain, particularly those related to product pricing [88]. Sustainable products often come with higher production costs, which can limit accessibility, especially among younger consumers who typically have more limited financial resources.

d. Influencer Marketing and Its Impact on Sustainable Consumption

Social media beauty campaigns involving influencers, particularly among Gen Z and millennials, play a significant role in shaping consumer behavior. When influencers consistently promote sustainable cosmetic brands, highlighting features such as clean beauty, eco-friendly packaging, and ethical sourcing, they can accelerate the adoption of green products in the market. However, if not accompanied by proper sustainability education, influencer-based marketing also carries the risk of reinforcing impulsive consumption trends. Therefore, both the industry and content creators must deliver messages that balance lifestyle aspirations with environmental responsibility. Sustainable influence should focus not only on esthetics but also on raising awareness of long-term environmental and ethical impacts [34, 83]

e. Consumer Education and Literacy in Sustainability

Consumers' lack of understanding of sustainability labels, certifications, and terms such as "organic" or "cruelty-free" often leads to confusion and contributes to greenwashing practices. Manufacturers, nongovernmental organizations (NGOs), and governments must implement educational initiatives to enhance consumer sustainability literacy. Public campaigns, informative QR codes on packaging, or collaborations with digital education platforms may be considered [90]. Well-informed consumers are more likely to make conscious and responsible choices, supporting sustainable product demand and influencing the shift toward ethical consumption patterns [91].

f. Community engagement and collaborative consumption

The emergence of online communities dedicated to sustainable cosmetics,such as product-sharing groups, recycling forums, or exchange platforms for unused cosmetic items, demonstrates that consumption does not have to be driven by individuals or be based on ownership. These collaborative consumption models support the principles of the circular economy and enhance social engagement with sustainability topics. Participation in such communities not only extends product life cycles and fosters a collective sense of environmental responsibility, encouraging consumers to rethink traditional consumption norms and embrace more resource-efficient behaviors [85, 86].

CONCLUSION

The global cosmetic industry continues to expand rapidly, but this growth has significant environmental and social consequences. Cosmetic ingredients, packaging materials, and manufacturing processes contribute to pollution, resource depletion, and carbon emissions. Chemicals such as parabens, triclosan, and dioxane persist in the environment, and plastic packaging generates large amounts of waste and microplastics. Although materials such as glass, metal, and biopolymers such as PLA and chitosan offer more sustainable alternatives, their production still requires high energy and cost. The industry is moving toward natural and biodegradable ingredients, eco-friendly packaging innovations, renewable energy use, and circular production systems, such as waterloop factories and zero-waste models, to address these challenges. Socially, consumer behavior has become a driving force for sustainability, with increasing demand for transparency, ethical sourcing, and environmentally responsible brands. Overall, achieving sustainability in cosmetics requires collaboration among manufacturers, policymakers, and consumers to balance economic growth with environmental stewardship, ensuring that the pursuit of beauty aligns with the preservation of the planet.

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CONFLICT OF INTEREST

The author declares no conflict of interest regarding the publication of this paper.

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