cosmetics

Review

Towards Sustainable Color Cosmetics Packaging

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Abstract: In spite of the significant progress towards sustainable cosmetics, mass-produced sustainable packaging has proven to be a challenge. The complexity of environmental, economic, social, technological, and policy considerations in conjunction with varying consumer behaviors and corporate goals can make it difficult to select an optimal strategy across heterogeneous supply chain components spread over the globe, and the cost and effort of developing, testing, and validating alternative strategies discourages empirical exploration of potential alternatives. This review discusses the challenges that can be expected in the context of broader sustainability efforts, as well as the experience gained in related fields, such as sustainable cosmetics and sustainable packaging, to identify potential pitfalls as well as promising trends towards the development of sustainable color cosmetics packaging. The findings suggest there may be little to be gained from attempting to induce customers to change their behavior, waiting for a significant increase in global recycling infrastructure, or expecting regulatory constraints to substitute for the lack of technological and business solutions. A research strategy is delineated towards the development of sustainable packaging that, with appropriate policy support, could minimize externalities and provide mass-produced packaging that is acceptable to both consumers and producers.

Keywords: sustainable cosmetics; sustainable packaging; sustainability strategies; consumer behavior; corporate social responsibility; technological developments

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1. Introduction

Personal care and beauty are important components of well-being. The development of chemicals to replace more expensive natural ingredients, as well as innovations in production techniques for improved quality and consistency in the 19th century, led to rapid growth in the cosmetics industry starting in the 20th century [1]. This growth was supported on the consumer side by increased prosperity, population growth and aging, and the presence of more women in the workplace [2]. The global beauty and personal care market was worth around USD 565 billion in 2022 and is projected to be worth USD 758 billion by 2025 [3]; and is estimated to be the third fastest market overall in terms of growth [4].

The cosmetics industry has faced concerns in terms of animal testing, health, and environmental impact, including for packaging, since the 1970s [1,2]. Animal testing is still permitted in 80% of the world [5]. Less than 20% of the 12,000 industrial and synthetic chemicals in cosmetics products are considered safe [6,7], and these often reach the aquatic environment directly or indirectly [8–10]. In addition to concerns regarding surfactants, chemicals such as UV filters, parabens, and triclosan are now considered emerging contaminants [11] as information accumulates regarding their ubiquity and their impact [12], including their toxicity to microorganisms and crustaceans [13]. Fake and chemical cosmetics containing toxic ingredients remain a concern in developing countries such as Malaysia [14]. Microplastics are a serious concern, and regulatory prohibitions on microbeads in cosmetics have only started to come into force, suggesting a long road ahead in reversing the damage they have caused [4,15].

Regulations on plastic waste are increasing in number, such as the EU Waste Framework Directive 2018/751 [16] and the French AGEC law [17]. Color cosmetics packaging is not the direct focus of such laws as it is not one of the largest polluters. Sustainability efforts in this area must then be consistent with regulatory needs and infrastructure availability, which have not always been designed for this type of packaging, and cosmetics packaging waste must not interfere with waste management practices in other areas.

There is also increasing consumer interest in sustainable packaging and plastic-free cosmetics [18–20]. Large cosmetics companies have set up impressive goals for packaging [21], and several cases are mentioned in the scientific [22–28] and trade [20,29–34] literature. Yet, popular brands typically do not offer sustainably packaged color cosmetics, leading to "*consumer helplessness in this regard, and a belief that changes should be led by cosmetics producers and government regulatory action*" [35].

The scientific literature specifically directed toward sustainable cosmetics packaging, especially for color cosmetics, is extremely sparse. A systematic review of sustainable circular packaging design for the cosmetics industry has noted that topics such as the circular economy, sustainable package design, and the cosmetics sector have not been considered in conjunction; similarly, consumer behavior has been studied on purchase intentions related to green products or packaging [36]. Reviews of the literature on sustainable cosmetics [28,37,38] have systematized the information into areas such as sourcing, manufacturing, packaging, distribution, and consumer and post-consumer issues to provide an overview of the situation following the structure outlined in [37], as well as typical corporate strategies. However, the available number of references directly related to cosmetics packaging sustainability are either in the low single digits or include case studies and gray literature. In terms of best practices with regard to design and life cycle thinking (LCT), most LCT in cosmetics is related to evaluating a specific product's environmental impact rather than developing new methodologies customized for cosmetics products [38]. A review of green purchase behavior with an aim of extending it to green cosmetics found a significant lack of consensus in the general literature, presumably due to a lack of separation of different product types, and suggested color cosmetics and personal health segments be treated differently [39]. For color cosmetics, where brand and quality are key, the focus could be on process improvements and appropriate policy support could be directed towards this end [39].

The environmental impacts of any particular packaging system depend on "*issues relating to its purpose, the length and nature of the supply chain, and recovery, re-use and disposal options*", and "*the interaction between environmental, commercial and social performance requirements also needs to be considered on a case-by-case basis*" [40]. For claims of recyclability, even the post-recycle market is now relevant [41,42], and scrap prices can be volatile [43]. The scant literature on color cosmetics packaging confirms that the relative environmental impact of products depends on specific details, such as which parts can be recycled [21] and the disposal techniques used [44], and that attempts to decrease certain environmental impacts can worsen others [45]. The empirical nature of technology makes it difficult to anticipate the entire range of possible effects due to synergistic effects, delayed effects, cause–effect chains, and even abuse [46,47]. The actual impact of a cosmetics package may only be discernible after its implementation. Implementations based on technological innovation and developments involve high fixed costs [26]. Any guidelines based on the prior literature that could help narrow down the myriad of potential pathways towards sustainability could be valuable.

This review considers the prior literature in relevant areas with the aim of delineating potential pathways for the development of sustainable color cosmetics packaging that could be mass-produced. Section 2 provides an overview of the industry and issues related to its sustainability. Section 3 analyzes the results from the literature in terms of the development of sustainable packaging. Considerations for sustainable color cosmetics packaging in the context of the reduce, reuse, and recycle framework are described in Section 4. Section 5 discusses a potential pathway for future research.

2. Background

Globalization helped create large cosmetics multinational corporations (MNCs) which often off-shored production and manufacturing facilities to developing economies [27]. Companies such as L'Oreal acquired Helena Rubenstein, while Unilever acquired Rimmel and Faberge, and Revlon bought Max Factor and Almay. By 2000, L'Oreal had 16.8% of the global market share, followed by Estee Lauder (10.9%), P&G (9.3%), Revlon (7.1%), and Avon (4.7%), with the top 10 accounting for 62.1% of the global market [1,2]. These cosmetics firms typically outsourced packaging [2]. Under deregulation, plastics production shifted to Asia, and post-consumption waste was also often sent to developing economies for disposal. Land-based plastics constitute almost 70–80% of ocean pollution via runoff from rivers and the coastline, which is overwhelmingly from Asian rivers [48]. Large cosmetics companies with sufficient clout to ensure adherence to terms by suppliers could outsource packaging to China, and at times, this had a substantial impact on the business models of cosmetics packaging producers in countries such as Turkey [49]. Nevertheless, products sold in specific markets required localization, and in many markets, western products have since been replaced by local, traditional ones [27]. Established companies may find it difficult to develop and implement new technological solutions and often use third-party collaboration with NGOs and other companies, followed by a scale-up [26].

Rising awareness of environmental and social issues led to an opportunity for smaller cosmetics companies in a market dominated by multinationals. Companies such as Burt's Bees, Tom's of Maine, and The Body Shop were all interested in the ethical dimension of consumer marketing and in creating an aesthetic that was biocentric and ethical, rather than anthropocentric, going beyond skin-deep beauty [50]. Cosmetic companies in the British Union for the Abolition of Vivisection (BUAV) were significantly smaller than those not in the association and were concentrated on a small segment of the industry, such as soaps and skin care products, implying a far greater impact in markets for the latter group [2]. BUAV member companies were more concerned about the environmentally acceptable attributes of their products with non-BUAV members satisfied with one or two attributes while continuing to develop products with animal testing for certain consumer segments, although there was internal disagreement within BUAV members as well regarding 'cruelty-free' products [2]. However, the survival rate of startups is typically low and even though the timing of several 'enviropreneurs' was in line with customer needs, they were often driven more by founder values rather than detailed customer needs analysis, and many boutique companies stalled. The Body Shop has since been bought by L'Oreal, and then sold to Natura [22,51], which is representative of many such startups, while large companies have often re-assimilated their divisions focused on sustainability into traditional ones [52].

There is a convergence in corporate social responsibility (CSR) and the circular economy (CE) amongst cosmetics MNCs, and CSR reports of eight cosmetics MNCs show a focus on CE that is is not observable in the CSR actions of SMEs [53]. MNCs fall under mandatory reporting requirements, and several of the statements are goals, such as objectives of zero waste in landfill and more than 90% recycling, or a recycling rate of 50%. Using the same sample, in terms of the adoption or pursuit of CE objectives, only four of the companies were clear about their CE objectives, and none of the firms used circularity ratios, although some used alternative sustainability ratios [54]. A sample of sustainable reports for the Italian cosmetics industry for the period 2014–2019 shows terms related to the environment to be somewhat more frequent but also shows CE to be under-reported for governance, strategy, management, and performance, indicating the need for greater institutional, regulatory, and stakeholder pressure on companies [55]. International cosmetics companies are increasingly creating lines using natural products, particularly for shampoos in conjunction with large chemical manufacturers who have set up lines for natural raw materials and who support fair trade and social programs in various countries [56]. A sample of eight small and large cosmetics companies in Brazil suggests the companies to be focused on environmental aspects in design and sourcing and that while CSR compliance is improving, compliance with design for sustainability (DfS) principles is still in its early stages [57]. Organizations with innovation power such as Natura, a Brazilian cosmetics multinational with 5000 organizations in its supply chain, can proactively introduce innovation to further green supply chain management, while companies that cannot innovate may simply be resigned to palliative social efforts and greenwashing [58]. Informal CSR may allow SMEs to benefit more from radical innovation rather than incremental gains in efficiency [59,60]. In plastics waste management, startups have attempted strong sustainability while optimizing for environmental impact, as opposed to weakly sustainable firms that were motivated by competition, competitive advantage, and financial motivations and optimized on economic factors while incorporating environmental variables [61]. Startups, though, occupied niche markets with limited scope for growth and were at a disadvantage in terms of access to technical expertise and financing [61].

The cosmetic industry has made significant attempts towards minimizing environmental and social impacts, including for packaging. Natura and its brands have been mentioned often in the literature with regard to environmental innovation, such as refillable packaging based on plastic film that reduces transportation impact and waste; products 100% free of animal ingredients; the use of plastic from sugercane; reductions in the products' water and carbon footprints; and annual sustainability reporting since 2001, with a focus on achieving the use of Brazil's biodiversity in a sustainable manner [22,23]. Case studies also include L'Oreal, which has set a goal to have 95% biobased materials, derived from abundant minerals or from circular processes [24], and has 10 rules for eco-design, including the use of safe packaging in terms of environment and health; reduction in material usage and unnecessary packaging; preference to large formats; the use of less impactful materials and those that come from sustainably managed sources; not shifting burdens to other parties; reusable packages; consumer guidance for appropriate disposal; and facilitating post-use management, which have been implemented in its sustainable product optimization tool [25]. The company also uses technological advancements and third-party collaborations for waste management, similar to L'Occitane [26]. DM Cosmetics has introduced greener packaging and inks; Frosch has introduced 100% high-density polyethylene from post-consumer recyclables; ZAO has developed bamboo packaging; and P&G is facilitating recycling through its PureCycle program, while Estee Lauder's MAC cosmetics has introduced Back-to-M.A.C. to return primary packaging for recycling [27]. Certain P&G brands also have resusable, recyclable, and refillable packages, while companies such as Lush (see also [22]) have, at times, removed all packaging, and several smaller companies have adopted similar approaches to reduce, reuse, and recycle [26].

2.1. Color Cosmetics

Cosmetics can be divided into skin care, hair care, color cosmetics, fragrances, and hygiene products. The color cosmetics segment relates to products that improve appearance, including foundation creams; lipsticks; and eye makeup, such as eye shadow, mascara and eyeliner. Effects such as the 'beauty premium' for natural phenotypes are known to have implications in real life, where decisions can be made instantaneously [62]. Makeup can also lead to a significant positive effect on judgments of attractiveness, competence, likability, and trustworthiness based on photographs on short inspection, and the same except for trustworthiness upon longer inspection times [62]. While primarily used for enhancing appearance, in the US, younger women may also wear makeup to boost their confidence, and more than a quarter of users report it as being beneficial to their mental health and well-being [63].

What is considered a desirable look may change over time [62]. Patent activity suggested the natural look or 'no-makeup makeup', iridescence, and transfer-resistance to be the focus around 2010 [64]. The industry literature suggests there is a rising trend for consumers looking for organic and natural products, including lipsticks [65], and the presence of harmful materials, such as lead and other heavy metals, may constrain the growth of the market [66]. Kyle Cosmetics, relaunched by Coty Inc., will feature clean and vegan formulas, as well as new packaging [67]. Nykaa has launched an organic lipstick that includes natural ingredients, such as shea butter, argan oil, and jojoba oil, as well as products with vitamin E and olive oil [66]. There was some pullback in color cosmetics such as lipsticks and eye shadows, even before the COVID-19 pandemic, as customers sought healthier products and thus a more natural look [68].

The industry was negatively affected by the pandemic although online sales increased, and activities such as in-store testing have been curbed even post-pandemic [69]. With the advent of mobile phones with cameras, applications have been under development for advising consumers on issues such as shade-matching [70]. AI techniques have been used to have consumers try on products virtually by Shisheido for the Europe, Middle East, and Africa region [71], by L'Oreal based on its Makeup Genius system, by Estee Lauder via its iMatch Virtual Shade Expert for foundation matching, and to create customized shades of lipsticks for customers, such as by Yves St. Laurent of L'Oreal [69]. Mass-market retailers such as department stores had been losing ground to specialty stores such as Ulta and Sephora, and young consumers trust influencers' opinions more than company advertising [68,69]. Online avenues such as websites, social media, and sites such as Amazon have permitted smaller startups to gain rapidly at the expense of incumbents in consumer products, and such companies can often hasten the product development cycle [69]. Given the rapid rise of global cosmetics use, such as in Asia, apart from organic and herbal ingredients companies have been focused on developing cosmetics specialized for different regions and ethnicities [69]. The Malaysian government even advised women to wear makeup at home during the COVID-19 pandemic to ensure domestic peace, among other suggestions that promoted gender stereotyping, and these were subsequently retracted due to the resulting backlash [72]. Post-COVID sales have rebounded in the US, especially amongst households with higher incomes, and trends include 'dopamine glam', metallic eye shadows, graphic lines, and blurring of the distinctions between color cosmetics and skin care [63]. Increased prices have often had to be matched with discounts and promotions, although the prestige beauty sector in the US has not been hurt by the less frequent use of such techniques [73].

In terms of packaging, the color cosmetics sector appears to have followed the example of the cosmetics industry in general, such as by the varied use of reduce–reuse–recycle–replace options along with attempts to introduce mono-material packaging to simplify recycling when the dismantling of packages is difficult. The Body Shop has extended its Refill Revolution program to makeup, including a 100% refillable aluminum case for Peptalk Lipstick, while Colorbar in India has introduced a 3-in-1 lipstick with a long-lasting and highly pigmented vegan formulation and 100% ultra-premium yet recyclable aluminum packaging [29]. HCP packaging has a 'Super Slim Refill Lipstick' that is aluminum-clad [30]. International Cosmetics Suppliers have launched 'versatile and sustainable' recyclable glass packaging options as demand for hybrid beauty continues to blur the line between makeup and skin care; Libo Cosmetics has introduced mono-material aluminum lipsticks that are durable and recyclable. Quadpack has introduced a line of Woodacity mono-material wooden compacts from European, sustainably managed forests as well as a versatile infinite polypropylene (PP) Panstick that is recyclable and has a refillable system, following the trend towards solidification where water is reduced or eliminated from formulas which makes it usable for a variety of solid formulations. HCP has launched PP/polyethylene (PE) mono-material family mascaras that also incorporate recycled materials and bio-based brushes. Mac has partnered with Knoll to introduce FSC paper and board for a keepsake advent calendar. Element Group has developed a mascara for CaliRay with 100% ocean-bound plastics as well as pencils in sugercane bio-based material and bottles in 75% post-consumer recycled materials, along with FSC-certified 100% PCR paper for paperboard boxes, and the CaliRay range is recyclable through the PACT collective initiative. Neen is a new brand with refillable compacts made in silicone with no metal hinges and has a partnership with a silicone recycler so that it can be recycled after multiple refills. MOB

Beauty uses 75% less material than traditional mascara and is made with PCR plastic, partially from ocean waste, and the package can also be used with lipgloss or a concealer. Cosmopak has a line of fully recyclable poyethelene terephthalate glycol (PETG) vials that can be used with various applicators, such as mascara wands, eyeliner brushes, and liquid blush, as well as glass vials that are usable and recyclable and biodegradable sponges made of plant and fruit-based ingredients. WWP packaging has a biopolymer collection created from sugercane for compacts and lip balms, as well as a jar with a satin finish that can replace ABS and polycarbonate components; these are 90% biodegradable under industrial composting, degrade ten times faster than PP, leaving behind no microplastics, and can incorporate up to 10% natural bamboo or coconut fibers, second or third generation biomasses of rice, wheat and coffee husk to create a natural look and feel, or include scented oils [31]. Baralan has added smaller glass bottles for liquid makeup to its line, while Knoll has developed a molded pulp advent calendar for Chanel, as well as an Ecoform plant-based pulp compact based on bamboo, wood, and sugarcane that is recyclable and has a clasp without a magnet and a detachable mirror [20]. A plant-based, recyclable, barrier protection coating has been developed by Melodea [32]. HCP also has a vintage-inspired Heirloom Collection in which "*PCR materials from trusted sources have been incorporated throughout for a reduced environmental impact*", while TaikiUSA uses makeup brush handles with FSC wood, upcycled and bio-based material, biodegradable PLA, and bamboo and uses vegan fibers and glue or mono-materials for easy recycling [33]. Cosmopack has developed a monomaterial tin compact as well as wooden compacts [34]. Additional examples are available as well [74].

2.2. Putting Packaging in Perspective

It is difficult to find peer-reviewed data on industry-specific figures. Online data from industry analyst reports can vary significantly. The figures presented can only provide a rough estimate.

The global makeup market was worth USD 39.58 billion in 2022 [71]. Using USD 565 billion for the total market size, the color cosmetics market would be less than 10% of the cosmetics market. Alternate figures for 2022 suggest skin care made up 41% of the market, followed by hair care at 22% and color cosmetics at 16% [75]. For 2022, the lipstick market size has been reported variously as USD 3.72 billion [76], USD 8.7 billion [77], USD 9.09 billion [29], and USD 16.6 billion [67], with an average of USD 9.5 billion, which can be taken as an order of magnitude indicator. The mascara market was worth USD 6.13 billion in 2022 [78].

The global cosmetics packaging market was valued at USD 51.6 billion in 2022 [79] and approximately USD 25 billion in 2017 when the cosmetic market was USD 532 billion [21]. The makeup packaging market was worth USD 7.62 billion in 2022 [80]. Plastic led with 52%, followed by metal at 23%, glass at 18%, and others at 7% [80]. The lipstick packaging sector in 2017 was worth approximately USD 2.8 billion [66]. In comparison, the global packaging industry was expected to grow to around USD 1.2 trillion between 2018 and 2028 at a rate of 3% [81], implying approximately USD 1 trillion for 2023. The plastic packaging market was estimated to be worth USD 230 billion [82]–USD 369.25 billion [83] in 2022. The makeup packaging sector is less than 1% of the global packaging market, and its plastic component could be 1–2% of the size of the global plastic packaging market.

Annual global plastic production in 2019 was 368 million metric tons and is predicted to double within 20 years [84]. Global plastic packaging demand has exceeded 147 million tonnes [85].

As per the Ellen Macarthur Foundation [86], for plastic packaging producers and users, L'Oreal used a total of 137,609 metric tonnes of plastic for first-use packaging in 2020, along with 1127 tonnes of reused plastic packaging, for a total of 138,766 metric tonnes. The percentage of reusable, recyclable, or compostable packaging was 30.3% in 2018, 32.7% in 2019, and 41.7% in 2020, with a target of 100% by 2025, where the target is aligned with the definition of recycling in the sense of 'in practice and at scale'. The percentage of reusable packaging increased by 1% over 2019. The post-consumer reuse (PCR) content of packaging was 4.7% in 2018, 7.1% in 2019, and 15.8% in 2020, with a target of 50% by 2025. There is some lack of clarity in the data because the revenue range is shown as USD 500 million to USD 1 billion, while L'Oreal is the largest cosmetics company in the world with sales of USD 37 billion [87]. This would be approximately 3750.44 metric tonnes per billion dollars in sales.

Unilever, the second largest cosmetics company, has several other divisions and uses 690,000 metric tons overall with no reused packaging, for total sales of USD 59 billion, out of which cosmetics sales are USD 25 billion [87,88]. The percentage of reusable, recyclable, or compostable packaging was 50.0% in 2018, 50.0% in 2019, and 52.0% in 2020, with a target of 100% by 2025; however, the target is not aligned with the definition of recycling in the sense of 'in practice and at scale'. PCR use was 1% in 2018, 5% in 2019, and 11% in 2020, with a target of 25% by 2025. The average usage would be 11,695 metric tonnes per billion dollars in sales.

Proctor & Gamble is also not a purely cosmetics company but ranks fourth in terms of cosmetics. Data on plastic waste are available for Proctor & Gamble on its website, and it uses 776,220 metric tons for total sales of USD 73 billion, out of which cosmetics is USD 14.4 billion [87,89]. On average, it would appear to use 10,663 metric tonnes per billion dollar in sales.

Data for Estee Lauder at number 3 with sales of USD 17.7 billion and Shesheido at number 5 with sales of USD 9 billion appear unavailable. Usage for L'Oreal could differ from that of Unilever and Proctor & Gamble because their revenues from other areas are greater than their revenue from cosmetics.

What follows is simply a hand-waving estimation to obtain a rough idea of the situation and must not be considered accurate to any degree. If it is assumed for safety's sake that the typical cosmetics company uses plastic at 3 times the rate of L'Oreal, it would be 11,251 metric tonnes per billion dollars in sales, which is also in the region of Unilever and Proctor & Gamble. For total sales of USD 600 billion, which is somewhat greater than the current estimated size of the cosmetics market, the usage would be around 6.75 million metric tonnes. This is less than the discrepancy in alternate estimates of the size of the plastic packaging market, such as 99.92 million tonnes [90] versus 147 million tonnes [85]. The color cosmetics segment would be even smaller.

Relevance of the Estimate

The above estimate is rough and is based on data with a significant range of possible values for any particular variable. In cases where the data are generated based on industry activities, scientific literature may have no option but to reference industry sources and use estimates based on anticipated growth rates (e.g., [21,27,45,81]). Scientific estimates in several areas are themselves subject to significant uncertainty. For instance, the absence of comprehensive field measurements for the flow of plastic debris to the environment requires the use of modeling and simplifying assumptions that ignore certain factors, implying that estimates that range from 4.8–12.7 million metric tonnes are only an indication of the scale of the issue [91]. Simplified models for estimating waste entering rivers and being transported to the oceans only have limited data and cannot account for complex processes in watersheds, and quantitative estimates "*remain crude*" [91]. Use of higher-resolution data along with the incorporation of effects such as wind direction and its impact on the transportation of plastics, precipitation, and terrain slope suggests the number of rivers that contribute significantly to ocean plastic pollution is higher than prior estimates by about 2 orders of magnitudes [48]. As compared to earlier models, recent research has suggested that fishing gear and plastic objects from shipping vessels may be a significant contributor to the North Pacific subtropical gyre, and the source may be five industrialized fishing nations, several of which are not usually associated with ocean pollution via rivers [92].

The order of magnitude of the plastic usage by the cosmetics industry is not small in absolute terms, and reducing it remains critical. It is similar to the rate at which plastic enters the oceans, which is currently considered to be 4.8–12.7 million metric tons per year [91], and the cumulative damage caused by marine plastics pollution is well-known. In terms of impact, the group Sea Shepherd [93] states "*[D]espite what most people think, common consumer plastics like cotton ear buds, throwaway cutlery, and shampoo bottles aren't actually the biggest culprits. The single biggest single source of plastic choking out the life in our oceans is made up of purposefully or accidentally lost, discarded, or abandoned fishing nets, ropes, FADs (fish aggregating devices), long lines, and plastic fishing crates and baskets.*" Such issues, for fishing gear, arise from a weight less than what either Unilever or Proctor & Gamble use, as GreenPeace [94] estimates annual pollution from such items to be 650,000 metric tonnes and estimates that on the whole they constitute 10% of the plastics in the ocean. Fishing gear is a significant source of large plastic pieces on the surface and could be the major contributor to pollution in certain areas, including the ocean floor [94].

Not much is known about any special impact of recycling color cosmetics packaging except the fact that their small sizes may cause rejection, in which case such items will either continue to pollute the environment or will be incinerated, or that trace contamination from contents could cause rejection of the entire batch and then the same procedures would apply to the batch itself. Thus, a key requirement would be that sustainability attempts for color cosmetics packaging should not interfere with appropriate waste handling procedures for other products.

2.3. The Problem for Public-Facing Sectors

Cosmetics, similar to single-use plastics, represent public-facing plastic. Such sectors often become the focal point of public attention regardless of their significance. For instance, the focus in many countries on single-use plastic is increasingly being replicated in the US, while it is industries where the use of plastics is not obvious, such as those related to clothing and fibers, that have the highest plastic intensity in terms of the value of plastics input per dollar of output on an aggregate level as well as for plastics most likely to cause pollution [95]. Similarly, a focus on microbeads in cosmetics may not necessarily be optimal as microplastics, which may also arise from degradation of larger plastic pieces, constitute a greater threat; and even with regard to cosmetics, glitter may have a greater contribution [96]. Yet policy has been aligned, albeit slowly, with avoiding microbeads due to campaigns against their use [96].

Attempts to satisfy customer perceptions, especially if they are misinformed, can lead to sub-optimal solutions. The EU and the US banned five parabens not commonly used in the cosmetics industry and the remainder were deemed safe, but due to consumer backlash the industry moved away from all of them, leading to the use of methylisothiazolinone which caused a significant increase in allergic responses and companies are slowly moving back to parabens [97]. The move towards 'clean' beauty, which has no definitions and conflicting lists of chemicals that should not be used, has led to the demonization of chemicals that are safe in the sense that the effect of a chemical depends on its dose. Given that cosmetics is a consumer-facing industry, manufacturers have had to comply with such demands [97]. Lush is acknowledged as a leader in efforts towards reducing packaging and is still accused of greenwashing as its products contain parabens and other harmful chemicals that are contrary to the image of naturalness projected by items sold without any packaging in its stores [98].

Consumers often overlook the production part of the impact and focus only on post-consumption utilization or the origin of the material, leading to widespread misconceptions, such as the relatively high ranking of paper-wrapped glass containers or bioplastic cups as being sustainable [99–101]. Paper, cardboard, and glass are considered indicators of sustainable packaging, while the use of plastic may be deleterious for sustainability communications [102]. Accordingly, it is not surprising that industry considers materials such as aluminum, glass, bamboo, wood, and paper to be sustainable materials [33]. Life cycle analysis (LCA) studies often do not cover all environmental aspects or pre- and post-purchase consumer behavior and may not provide the true environmental impact of the various materials that are often asserted as being the most sustainable by their respective industries [99]. Companies often create their own definitions of sustainability and sustainable packaging [99]. Only a few of the sustainable color cosmetics packaging methods mentioned in the industrial literature provide quantitative details in terms of cradle-to-cradle analyses and improvements in circularity ratios.

Such issues do not necessarily indicate consumer deficiencies. Only 5% of the marketing messages from green campaigns may be entirely true [103]. The literature suggests 67.75% of manufacturers provide incorrect recycling information, and 98% of the labels are false or are based on greenwashing to deceive customers [104]. It is not easy to inform consumers about the benefits of a recyclable product if experts disagree on its environmental impact [105]. Inconsistent findings in the literature regarding consumer environmental behavior and willingness to pay could be explained by the observation that consumers pay only for packaging they perceive as sustainable, and it is unclear how they can be expected to assess such issues if experts, companies, and governments disagree on the sustainability characteristics of different packaging [106].

Plastic from sugarcane, in the form of microplastics, can also have negative impacts on fish [107]. Paper and bamboo straws, intended as plant-based biodegradable replacements for plastic straws, from various regions of the world were found to have significant amounts of polyfluoroalkyl substances (PFAS), otherwise known as 'forever chemicals', which could be from a variety of possible sources, such as their deliberate addition for water repellency; the use of contaminated recycled fibers, raw materials, or processing water; or absorption in plants through contaminated soil [108]. Companies compliant with organic food certification by the EU, or certified based on protected designations of origin or geographical indications such as based on the EU Regulation 1151/2012 on quality schemes for agricultural products and foodstuffs [109] showed superior social performance, but their environmental performance was not better except for food-miles for locally-sourced produce [110]. The lower productivity of organic products negated any per-hectare gains in environmental impact, when considered in terms of per-ton impact [110]. Whether similar considerations could impact cosmetics packaging utilizing such plant-based materials may require further investigation.

The cosmetics industry is thought to create almost 120 billion pieces of packaging annually. When considered in conjunction with facts such as that packaging consumes almost 40% of all plastics manufactured and that most plastic cosmetic packaging is not actually recycled, the solutions suggested include avoiding packaging; asking companies to avoid plastics, and if this is unavoidable, using bigger containers and with resin codes 1 and 2, which are recyclable; and using glass or metal, which are infinitely recyclable, or cardboard and cork, which are biodegradable [111]. Elsewhere, when considered in the context of deforestation, such as in light of the fact that "*More than 120 billion units of packaging are produced globally every year by the cosmetics industry, contributing to loss of 18 million acres of forest annually*" [112], the deforestation is due to trees being cut to make throwaway cardboard boxes, paper wraps, and packing tissues, which consumes 18 million acres of forest every year, and clearing land for growing plant-based natural materials for cosmetics [113].

Some online sources suggest anything made of only glass, plastic, polystyrene, rubber, metal, paper, or cardboard, including empty beauty packaging and tubes along with their caps, glass bottles, metal tubes, and more, can be fully recycled and can be placed in recycle bins as long as they have been cleaned thoroughly [114]. Others suggest travel-size, sample-size, mini-size, or tester products may not be recyclable as they are too small to be handled by the sorting system in recycling facilities [115]. At best, they will be sorted out and landfilled or incinerated. Worse, they could contaminate an entire batch due to residues, an issue that also applies to glass or metal packages [115]. Yet others include under nonrecyclables, "*Lipstick cases, lip gloss tubes, mascara tubes, eye shadow cases, bronzer cases, foundation packaging, powder cases, eyeliner cases, eyeliner pencils, eyeshadow tubes, concealer tubes, concealer sticks, and lip liner pencils*" [116].

Issues with the recyclability of cosmetics has led to the advent of specialized services, such as TerraCycle. Simply using a plastic that is technically feasible to recycle and for which collection systems may exist, and marking it a resin code within chasing arrows, may no longer work towards a package being considered recyclable. The EPA has recommended abolishing the chasing arrow symbol and has suggested that there needs to be a demonstrated adequate market for the post-recycling material that should more than compensate the recycler for the cost of recycling, otherwise the tendency is to simply discard plastics other than codes 1 and 2 [41]. This implies that PP may not be considered recyclable. Similarly, PETG has been removed from recycling code 1 in California [117]. The Body Shop reports 68% of its current packaging as being technically recyclable, although it aims to make it 100% fully recyclable by 2025 [118]. Unilever does not define recyclability in the sense of 'in practice and at scale' [88]. Some of the recyclable color cosmetics packaging lines have been based on PP and PETG [31], and it is not clear which definition has been used.

2.4. Sustainable Packaging Defined?

For sustainability itself, there is reasonable agreement at the normative level, such as for the UN definition, "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [119]; the 17 Sustainable Development Goals (SDG) enumerating specific aims towards which sustainable development should progress [120]; and that for any approach to be sustainable, it must incorporate at least environmental, economic, and social considerations [121]. However, as research has progressed, there are now more than 300 definitions of sustainability [122,123].

The issue is that it is not easy to find an implementation path that can satisfy all criteria. For instance, the use of calcium carbonate to reduce the plastic content of a cosmetics tube, especially alongside post-consumer recycled plastic, was estimated to decrease the global warming potential by reducing CO_2 emissions as well as photochemical ozone formation related to human health; however, it did not change water depletion or total resource depletion including minerals, fossils, and renewables by a large extent, and it increased fresh water eutrophication [45]. The results would appear to pit SDG 3 (health and well being) and SDG 13 (climate action) against SDG 14 (life in water). A planetary boundaries-based procedure could help remove the subjectivity in prioritizing the indicators, although in the context of application to several L'Oreal products, it has been suggested that weighting factors for most indicators should be based on regional or local data rather than global values [124]. Analyses based on costing and social issues could also provide results different from environmental considerations [125].

EU objectives with respect to chemicals, such as zero pollution or a 'toxic free environment', may be unscientific, unrealistic, and ambiguous [126]. There are international disagreements on whether to prioritize indicators relevant to poverty reduction (SDG1) and inequality (SDG10) or SDG13 (e.g., [127–129]). Social support for climate action can disappear quickly if policy trade-offs in terms of the relative costs and benefits are not made explicit [130–133] and companies are leaving net-zero alliances [134,135]. This is not to imply that firms should not, or may not need to, implement carbon reduction or any other specific objective but rather that the significance of the various factors can change based on extraneous concerns.

The Sustainable Package Alliance (SPA) cautions that attempting to provide a definition for sustainable packaging assumes it is possible to provide one, and that simplistic definitions such as those provided by the SPA or the Sustainable Packaging Council (SPC) can obscure the complexities involved in minimizing the environmental impact of a product, such as when trade-offs might exist [40]. The aim for the SPA is to provide a set of principles that could guide decision-making [40]. A similar approach is observed in the definition provided by the SPC, which appears to now be available only through the Internet Archive [136], and in the Code for Responsible Packaging provided by the Industry Council for Packaging and the Environment [137]. Table 1 provides an outline of the factors considered. The definitions are not very different in terms of their normative aspects, such as the emphasis on functionality, cost, and environmental protection, as well as broad strategies in terms of reuse, recycling, or biodegradable materials [40]. The SPC definition is more specific with regard to renewable energy and materials and includes strategies such as the purchase of carbon credits [40]. The INCPEN code is more explicit about the properties important for functionality, compliance with legal requirements, labeling, and safety aspects such as for children and for occupational safety, and usability for individuals with varying abilities [137] with sustainability considerations relevant to packaging design being mentioned under Section 7.2 of the code, Other Environmental Considerations [137]. Beyond these broad principles, any specific strategies, such as the use of renewable energy or recycling versus reuse, result in disagreements [40]. National standards bodies could provide specific requirements as to what would constitute sustainable packaging within their jurisdiction (e.g., [138]).

Table 1. Sustainable Packaging Definitions.

INCPEN Responsible Packaging Code, 2002 [1]	
1. Functionality through the supply chain	1.1 Physical strength; 1.2 Barrier properties; 1.3 Contamination; 1.4 Closure and re-closure; 1.5 Communication; 1.6 Pack life
2. Honesty in presentation	2.1 Container size; 2.2 Double-skinned containers; 2.3 Headspace; 2.4 Environmental claims; 2.5 Gifts/ luxury items
3. Convenience to use	3.1 Ease of opening; 3.2 Removal of contents
4. Instructions, guidance and information	4.1 Clarity and legibility; 4.2 Helpfulness; 4.3 Environmentally responsible use of contents; 4.4 Environmentally responsible handling of used packaging
5. Legal requirements	Compliance with laws and standards governing the nature of packaging
6. Health safety and consumer protection	6.1 Tamper and pilfer resistance; 6.2 Appeal to children; 6.3 Child resistant packs; 6.4 Dispensing and closure devices; 6.5 Warnings; 6.6 Occupational health
7. Environmental aspects	7.1 Essential requirements; 7.2 Other environmental considerations
SPA Sustainable Packaging Definition, 2005 [2]	
1. Effective	1.1 Reduces product waste; 1.2 Improves functionality; 1.3 Prevents overpackaging; 1.4 Reduces business costs; 1.5 Achieves satisfactory ROI
2. Efficient	2.1 Improves product/ packaging ratio; 2.2 Improves efficiency of logistics; 2.3 Improves energy efficiency; 2.4 Improves material efficiency; 2.5 Improves water efficiency 2.6 Increases recycled content; 2.7 Reduces waste to landfill
3. Cyclic	3.1 Returnable; 3.2 Reusable; 3.3 Recyclable; 3.4 Biodegradable
4. Clean	4.1 Reduces airborne emissions; 4.2 Reduces water-borne emissions; 4.3 Reduces greenhouse gas emissions; 4.4 Reduces toxicity; 4.5 Reduces litter impact
SPA Sustainable Packaging Modified Definition, 2007[2]	
1. Effective: social and economic benefit	Functionality of each component of system; social and economic benefits of the packaging system as a whole; product-packaging ratio by weight; supply-chain costs; specific relevant, accurate and verifiable environmental claim consistent with ISO 14021; recycling logos and advice on recyclable packaging; plastics identification code correctly used on plastics packaging; instructions not to recycle on containers used for hazardous products
2. Efficient: doing more with less	Total weight of material used in the packaging system by sub-retail, retail, merchandising and traded unit; product-packaging ratio by weight; percentage of product that becomes waste before it reaches the consumer, e.g. is damaged in transit; percentage of product remaining in retail unit packaging once consumer has dispensed product; energy consumed over the packaging lifecycle; water consumed over the packaging lifecycle; pallet configuration and efficiency - cube utilization
3. Cyclic: optimising recovery	Collection and recovery systems for the packaging; national recovery rates for recyclability and compostability through relevant systems; percentage of the packaging by weight which can be recovered through available recycling systems; average percentage of recycled material, post consumer and total, and from a renewable source; percentage of stationary and of transport energy use which is from a renewable source
SPC Sustainable Packaging Definition, 2011 [3]	
A. Is beneficial, safe and healthy for individuals and communities throughout its lifecycle B. Meets market criteria for performance and cost C. Is source, manufactured, transported, and recycled using renewable energy D. Optimizes the use of renewable and recycled source materials E. Is manufactured using clean production technologies and best practices F. Is made from materials healthy throughout the life cycle G. Is physically designed to optimize materials and energy F. Is effectively recovered and utilized in biological or industrial closed loop cycles	

[1] Based on [137]. [2] Based on [40]. [3] Based on [136].

A lack of a common language can inhibit environmental progress as the same term meaning different things to different people limits its credibility, its applicability, and its usefulness in gauging improvements [122,139]. However, the underlying complexity of the situation implies that it may not be feasible to find a one-size-fits-all definition beyond normative guidance. The concepts of corporate social responsibility (CSR) [140] and the circular economy (CE) [139] face similar issues, as do terms such as innovation [141–143] and knowledge [144–147], which often appear in the context of sustainability. Further discussion is needed for achieving consensus across disciplines and sectors on terms such as 'bio-based plastics', 'bioplastics', 'biodegradable plastics', and 'plastic recycling', which pertain to complex properties and mechanisms [148]. Terms such as 'environmentally friendly' or 'green' are essentially meaningless and are often associated with greenwashing attempts [52]. The US Environmental Protection Agency (EPA) has recommended the following to the Federal Trade Commission [41]:

> *The term "sustainable" has become ubiquitous in the marketplace since 2012 and is used in many different contexts. Therefore, the marketplace would greatly benefit from specific guidance within the Green Guides. Companies should not be allowed to market their products as "sustainable" without completing full lifecycle assessments (LCAs) for each product and acquiring third party certification that the product meets each hotspot identified in the LCAs. Further, companies should not be allowed to market themselves as a "sustainable" company without fulfilling the above requirements for every product/service line offered and without performing an LCA on the company as a whole, including all suppliers and contractors.*

A cosmetics package that aims to improve upon current packaging must be evaluated from various perspectives, including its environmental, economic, and, potentially, social impacts over its entire life cycle on a case-by-case basis. It may need to be optimized subject to the constraints placed by current and anticipated regulations, both local and in customers' markets, as well as the specific constraints relevant to the supply chain all the way from raw material production down to the waste-handling practices at the final destination of the product. The optimization needs to be over the combined package–content system. Sustainability issues related to cosmetic formulations as well as the interactions between the package and the filler need to be considered.

Optimizing the entire filler–package system can lead to additional challenges. The greater susceptibility of natural ingredients to oxidation and the inability to use traditional antioxidants [149] implies that sustainable packaging holding natural cosmetics may need to provide superior barrier properties. It has been suggested that the waste in cosmetics comes not just from packaging but also products that are produced and returned unsold and those that are sitting in homes, unused [150]. Such waste could be reduced, and cosmetics could also become more affordable [151], if packaging size were to be reduced. Smaller packages, though, can create greater recycling issues, even for metal or glass packages [115]. While this may not be an issue for plastic cosmetics packages other than those with resin codes 1 and 2 as other resin codes are usually not recycled regardless of size and color cosmetics products often involve other codes, it has also been noted [115] that smaller packaging is inefficient as more containers are needed to pack the same volume of the filler and the total amount of plastic may actually increase.

The literature in fields such as single-use packaging and in cosmetics-related industries such as pharmaceuticals suggests sustainability attempts can require substantial investments and time, are often economically unfavorable in the absence of a business case, face poor coordination across the supply chain and issues with cross-team alignments, can run into technical difficulties, may suffer from a lack of expertise or training, may not have well-defined objectives, and may face issues related to regulations and their enforcement, as well as poor end-consumer awareness, all of which result in proposed solutions often not being scaled-up and commercialized [99,152]. While cosmetics products may not face the same level of regulations as pharmaceuticals, color cosmetics packages can be more complicated than single-use food packaging.

2.5. Supply Chain Actors for Sustainability

A simplified representation of the traditional cosmetics industry is shown in Figure 1. Solid arrows represent material flows, while dashed arrows are information flows. Packages are designed based on customer requirements in terms of shape, size, color, and finish. Packaging production is typically outsourced (e.g., [2]). Raw materials flow from suppliers to packaging producers. The product is then filled, distributed, and sold without any consideration of the post-use stage. Feedback at any stage is usually related to quality issues and delivery schedules. Each stage represents a complex set of activities and potentially global supply chains. Multiple companies may supply materials and parts to a packaging manufacturer, who may also outsource some of the production steps. Some cosmetics companies regularly add new products, while others may not, depending on their business models [1]. Even when the materials and processes are mostly well-understood, attempts to change packaging materials based on customer demand or cost considerations can be problematic [49].

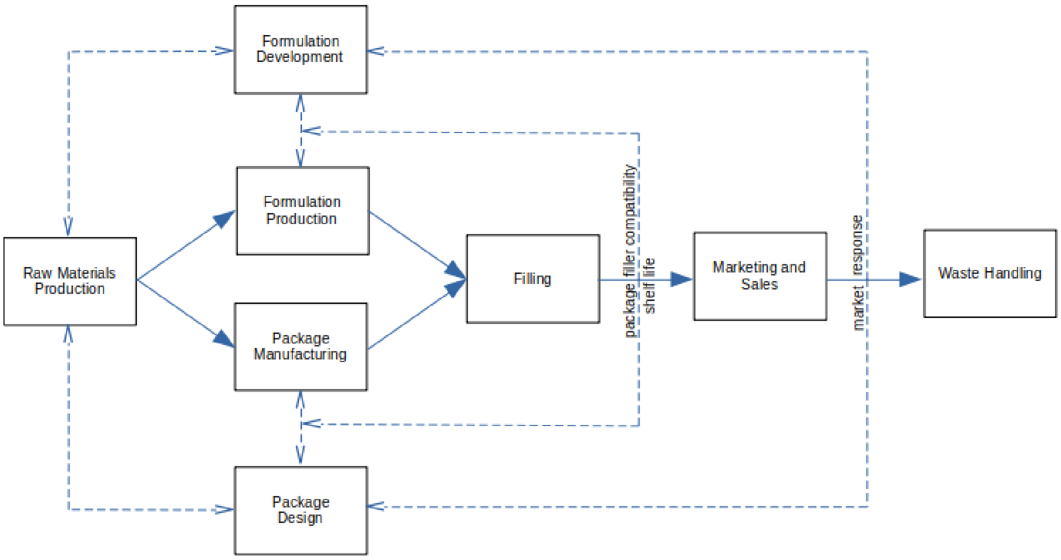

Figure 1. Schematic of traditional cosmetics industry.

Sustainability considerations add significant complexity, as shown in Figure 2. New, circular, business models must be developed [61,153,154]. Processes and products need to be redesigned and harmonized across the supply chain in view of new regulations and sustainability frameworks [155]. Novel packages, formulations, and additives must be validated for compatibility in terms of functional requirements such as shelf-life [156,157], as well as their health and environmental impact, keeping in mind the waste-handling infrastructure. The supply chain may need to be reformulated [155], and there remains a possibility of lock-in [158]. Even manufacturers of machines for processing the new materials may be relevant to the value chain [159]. Greater information sharing is needed across the supply chain [160], which may not always be welcome for competitive reasons [161,162]. Innovations such as smart circular supply chains need to be implemented across the chain, and varying levels of readiness and maturity levels across firms can influence further adoptions by their suppliers and customers [163]. New marketing approaches need to be employed to target different segments of consumers [164]. Based on the literature, external factors, including suppliers, distributors, customers, waste handlers, competitors, legislators, financial institutions, academia, media, and NGOs, may be relevant to green product development, in addition to internal factors including management, R&D, product development, and marketing, as well as purchasing, manufacturing, and sales [165]. The European Commission [166] notes that "*Rethinking and improving the functioning of such a complex value chain requires efforts and greater cooperation by all its key players, from plastics* *producers to recyclers, retailers and consumers. It also calls for innovation and a shared vision to drive investment in the right direction*". It is imperative to foster upstream and downstream collaboration, develop design capabilities for recyclable products, understand the effects of collaboration networks, and investigate supply chain power relationships [167].

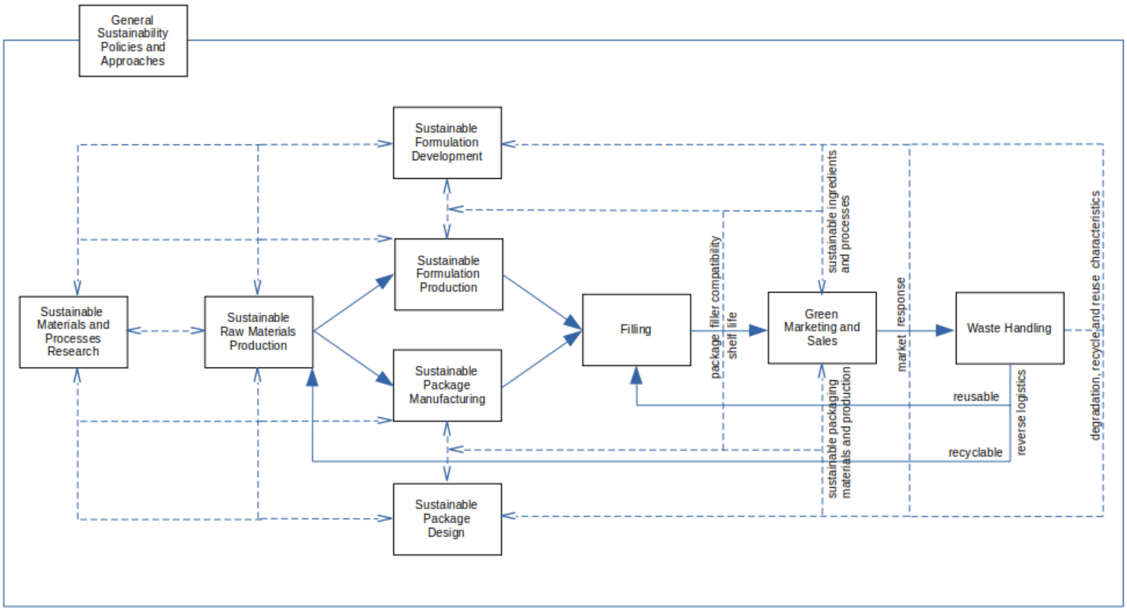

Figure 2. Impact of introducing sustainability considerations.

Environmental issues are inextricably intertwined with technological, social, and economic issues, as well as, especially for consumer industries, psychological factors with individual-to-individual variations. The inclusion of environmental considerations often requires engineers to interact with areas outside of their expertise [165]. Re-engineering the supply chain and internal processes could require input from several areas, as indicated in Figure 3.

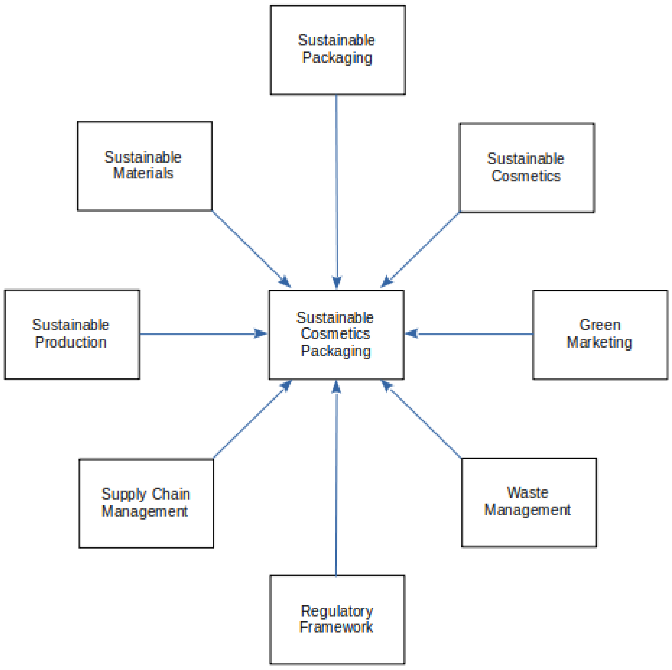

Figure 3. Areas related to sustainable cosmetics packaging.

3. Product Development Pitfalls

A brand represents the core characteristics of a company, and consumers on the whole form positive associations with brands they perceive to be credible and consistent over time [168]. Brand identity is a significant asset, and using a product while knowing it activates different areas in the brain compared to using it without being aware of the brand [169]. Positive brand associations override the basic pleasure response, and products should conform to the brand image [170]. Prior 'good' practices, developed over many years, may have helped establish brand characteristics that may be difficult to modify, and such attempts could even be counterproductive, such as with New Coke. Individuals expect the same brand experience across platforms, including apps [171]. While MNCs create separate divisions and brands for sustainable products, the same company selling environmentally friendly products in one division and those with a high environmental impact in others, or engaging in animal testing in markets that require them while selling 'cruelty-free' products elsewhere, could lead to perception problems. Empathy virtue is a significant factor in emotional attachments to brands, and multinational corporations buying sustainable startups can be problematic in this regard [172]. Green products are often more costly to produce and are subjected to greater uncertainty, and if successful, could also reduce sales of the existing traditional products of a company, implying little intrinsic motivation to introduce such products [173].

Packaging is often the first and only contact the customer has with a product before purchase, and the quality of the product and its ingredients must often be inferred from the packaging [174]. For beauty products, which have an implicit promise towards making the customer more beautiful, where beauty is itself an abstract concept, consumers may rely on visual cues for forming efficacy beliefs [175]. Proctor & Gamble suggests shoppers decide about a product in 3–7 s, just as they notice it, and brand awareness is key towards expectations of functionality in the absence of prior usage [176]. Even when product characteristics are known, given that most purchase decisions are made at the point of sales for such goods, a brand using a distinctive packaging can simplify the decision for the consumer [177], who may have to look through thousands of products within a few minutes during a typical shopping trip to a store. On the other hand, consumers may only use contextual cues primarily for unfamiliar brands, which implies sustainable packaging information will have a greater impact for unfamiliar brands [168].

Several factors such as shape, color, material, textual and artistic features [178], and convenience and functionality [177], are relevant to consumer purchase behavior. Visual elements, including color, shape, symbols, and text, remain critical towards developing emotional connections with consumers [179]. Package design remains important for impressions of quality as well, and in an eye tracking experiment with four lipsticks (Urban Decay, priced on average at GBP 16, Dior at GBP 25, L'Oreal at GBP 5, and Clinique at GBP 12), respondents, without knowing the lipsticks' prices, found the L'Oreal lipstick to be of the highest quality, while Urban Decay and Dior were ranked as low-quality, although the results could be subjected to the sample selection bias towards younger consumers [180]. Respondents listed material and color as the most attractive elements and stated that purchase intention was triggered by package attractiveness; plastic was the most preferred material in hairstyle, skin care, as well as makeup products, followed by glass, suggesting a preference for its user-friendliness and practicality [180]. Forty-six percent of US female cosmetics customers, with younger buyers being at 50%, suggested packaging to be influential or very influential to the purchase decision regardless of whether it was primary or secondary, sustainable, refillable, or made of plastic and glass [181].

Packaging can be extremely important for luxury price items [69], and with increased dependence on online delivery, especially for younger shoppers, the 'deboxing' experience has gained added emphasis on social media [181]. Companies are even developing packaging suitable for e-commerce [182]. However, sustainability characteristics are significantly behind attractiveness and functionality [181]. Similar results have been observed for perfumes, where verbal design was found to be more significant than visual due to the preference for the brand name, and several additional features were more important than environmental benefits [183].

3.1. Circular Strategies

The concept of the circular economy (CE) has arisen as a widely accepted approach towards implementing sustainable development as a closed-loop system that avoids new inputs as well as waste and emissions [123]. The CE strategy depends on the competitive strategy of the firm and, given the typically top-down nature of circular business models (CBM), it is essential to couple strategic planning to CBM [154]. There is little consensus on which method to use for selecting the most appropriate CE strategy, and so, no standard tools exist for identifying CE strategies [153].

Lack of consumer interest and a hesitant company culture, along with high up-front investment requirements and low prices for traditional materials, may act as barriers for CE, along with technical feasibility issues, such as those related to process design and optimization [184]. The European Commission acknowledges for plastics that "*(P)roducers currently have little to no incentive to take into account recycling or reuse of plastic articles or packaging when they design their products, and that the products are often highly customized and have specific additives to meet functional and aesthetic requirements which can complicate the recycling process*" [166].

Academic literature emphasizes biobased and biodegradable materials to replace plastics, while the media focuses on the recycling of traditional plastics [185]. Literature provides 44 business models related to plastic waste management strategies, although more probably exist, and tradeoffs exist between financial, environmental, and social issues, with less focus on social issues [61]. In the plastic waste management hierarchy, the prevention of waste generation is the most preferable and has the greatest financial opportunities, along with minimal environmental externalities; this is followed by reuse strategies, recycling, energy recovery, disposal, and finally, capture and removal, respectively [61]. There may be some overlap in terminology and, for instance, tertiary recycling or quaternary recycling may refer to the recovery of chemicals, including fuels and energy recovery by combustion [186].

3.2. Predicting Sustainability

Decision-making through mathematical methods reduces costs, time, and risk, such as for reverse logistics for packaging, and should be used to analyze the supply chain [187]. A model for shelf life estimation that can reduce the time and costs for empirical testing with new packaging materials has been developed [157]. Models are being developed for the skin-spreading behavior of sustainable alternatives to emollients [188]. Numerical approaches have been developed towards the formulation of shampoos and cleansing formulations for modeling the behavior of new ingredients [189]. An ability to predict the environmental, economic, and social sustainability of a package and the filled product could allow designers to consider several alternative strategies and product designs in a cost-effective and efficient manner. There is a need to integrate various areas, such as business considerations, engineering tools and models, as well as policy making, as part of the broader context of the green product design process [165], as well as for cosmetics products [190].

The integrated approach is not always feasible at present. In spite of the need and the research efforts and advances, the formulation of cosmetics such as emulsified products remains an art based on heuristic considerations rather than exact formulas or systematic procedures, and only a few products and processes are designed through model-based techniques due to the absence of adequate data and theories [190]. Modeling issues exist in individual areas ranging from material behavior to consumer behavior.

3.2.1. Consumer Behavior

There are more than twenty different models for green purchase behavior involving various values, attitudes, and beliefs, along with external and internal factors related to demographic, product, and social contexts [191]. None of the models that are typically used come even close to a complete explanation [192]. Commonly used models are difficult to validate, have low predictive power, and provide context-specific results, and there is only one report in literature of an intervention designed based on the dominant model [193]. The trend is towards models that integrate the concepts and factors of various models [194], which can increase their complexity, making validations difficult. Recent empirical research in consumer behavior theories in cosmetics across various countries, such as for Indonesia [195–197], Thailand [198], Malaysia [14], Romania [199], India [200–202], Hungary [203], Canada [18,204], and the UK [205], is based on a variety of models, such as the theory of planned behavior, perceived environmental reasoned action, and values–beliefs–norms, and uses a diverse range of factors. While the studies add to the empirical information and to the understanding of issues from various theoretical viewpoints, they remain difficult to unify and cross-compare [206]. Similar research into sustainable packaging [207–222] also considers a variety of countries using a variety of models and several factors. Even for green purchase behavior in general, there is still a need for continued research to investigate the applicability and usability of various marketing and management theories, and significantly more effort needs to be directed towards identifying green customer segments based on demographic, psychographic, and behavioral characteristics, especially using techniques such as data mining and artificial intelligence [223].Circular behaviors represent a range of activities, including recycling and reusing goods; acquiring certified green products or recycled, remanufactured, or reconditioned products; refilling products; product care and maintenance; waste separation; returning products at their end of life; sharing products and services; reducing consumption; and local and organic consumption, with political, economic, environmental, and demographic factors influencing such behaviors [224].

Enhancing the sustainability characteristics of products may be risky, as people could use more of a product when it is sustainable [225], especially if some consumers are compelled to buy the product for moral reasons even though they consider it ineffective relative to traditional products [226]. There has been some discussion as to whether individuals may adopt environmentally friendly behavior in areas where it costs them less to compensate for a lack of such behavior in other situations [227].

3.2.2. Material Behavior

A lack of sufficient and consistent information on the biodegradability of different plastics makes it difficult to discern the relationship between their properties and degradation, and while model-based analyses can help, issues remain for small molecules [228]. Case-based reasoning, a data-driven approach that requires less theoretical knowledge, has been used for biodegradation prediction to help reduce experimentation time for material selection [229]. The current industry view is that the cosmetics sector is one where bioplastics innovation is "*particularly poorly covered*" and that rectifying the situation would require significant upstream and downstream knowledge for implementation [230]. Lab testing as per standards may not provide appropriate data for real-life conditions as these can vary and be substantially different from the conditions specified by standards, often implying over-optimistic test results for biodegradability characteristics [91,228]. Materials that claimed to be 100% biodegradable were found to degrade approximately 8% in the digestive tracts of turtles, while in another case, only four of the six materials that were claimed to be biodegradable actually turned out to be so, suggesting the possibility of false claims [228].

3.2.3. Impact of Technology

Information technology tools, such as automation, the Internet of Things (IoT), big data, artificial intelligence (AI), and the blockchain, are increasingly being considered for applications under Industry 4.0 for sustainability and the circular economy [231–234] in areas such as green supply chain management [163,235,236], operations management [237], manufacturing [238], biowaste remediation and valorization [239]; in sectors such as pharmaceuticals [152]; and in applications such as green consumer research [223], computing environmental, social, and governance (ESG) ratings [240], climate science modeling [241], and even solar panel cleaning [242]. The use of techniques such as RFID tracking can help reduce waste in terms of on-the-shelf expiration [20]. At the same time, the concept of Packaging 4.0 can directly be tied into sustainability, all the way up to the post-consumer stage [243]. For instance, the use of embedded film transistors for near-field communications could provide consumers with up-to-date information about appropriate disposal technique, or, in combination with a phone app, the nearest appropriate disposal location for the product, as well as additional information, such as for new versions of the product and related products to develop brand loyalty, without compromising the aesthetics of the packaging. Embedded sensors could be used to detect product degradation, which is an important consideration for color cosmetics as such items are often retained for long periods of time without much use. Furthermore, the use of Industry 4.0 technologies in the context of packaging, denoted as Packaging 4.0, could also help improve the energy and resource efficiency of processes and, with vertical and horizontal integration, provide more effective production based on real-time data [243].

In packaging, such implementations have also implied that larger production companies increasingly sell not just a machine but the entire interconnected and networked line, which makes it difficult to insert new machines to deal with customer demands for sustainable packaging materials [159]. The SPC suggests for the use of PCR material that packaging producers in the supply chain may need to adjust their equipment or buy new equipment, and brands are urged to encourage them to do so or to consider finding new partners [244].

The introduction of automation in a packaging company could require significant upstream changes in the quality and consistency of product, which may be difficult to achieve under shop-floor conditions, and a cosmetics packaging company had to simply set aside such equipment [49]. The equipment can also be expensive, and labor cost savings of automation may prove illusory as it requires higher-paid technicians. Companies may not always be able to maintain their heavily used production molds in perfect, 'as-new', condition. While electric injection molding machines are more energy efficient, they may be less forgiving in terms of factors such as mold alignment. The same cosmetics packaging company, already facing cost competition from lower-cost Chinese manufacturers, was forced to buy a blow-injection machine for a lower cost material because its customers insisted on it and another competitor was providing such packages, even though the producer warned its customers the material was more permeable. In the end, all product was returned because the contents were drying out too soon, and the machine was left idle [49]. If color cosmetics brands wish to use such packages for their ability to market their products as recyclable, then changes in rules to account for the fact that codes other than 1 or 2 are often not recycled in practice could leave their packaging producers with unneeded equipment rather than 'investments'.

3.2.4. Social Sustainability

Social considerations have not been included to a significant extent in the CE literature, and research has focused on areas such as the necessity for creating new higher-skilled jobs via appropriate educational programs in areas related to CE implementation to balance the potential disappearance of lower-skilled jobs [245]. There is little consensus in the literature on the impact of technological development on issues such as employment [246]. AI is creating new concerns with regard to whether it will replace or augment human workers [247], especially as it can also replace mental labor, threatening middle-level jobs in the near future [248]. How CE improves equity remain vague [245].

3.2.5. Economic Sustainability

There is a lack of consensus in the literature as to whether the environmental attributes of packaging impact consumer purchase decisions [222]. While there may be both positive and negative attributes for sustainable packaging [102], consumers, when purchasing eco-design packages, may do so for personal benefit considerations rather than social factors, such as protecting the environment [249]. Frequent users of color cosmetics, which could represent more valuable customers, tend to care less about sustainable packaging [35].

Packaging can account for up to 40% of the retail price of cosmetics [175], and pricing has been a factor across various studies, but the effect of price on the purchase of cosmetics is complex. Consumers view sustainable cosmetics as a luxury item, may mistrust cheaper brands with green claims, and would be willing to pay a premium for it provided they could [205]. They may equate price with quality [250]. Consumer perception of luxury can be difficult to change. Glass packaging is considered an indicator of luxury that requires secondary packaging for protection, and secondary packaging is further associated with higher price [25]. Weight is also associated with luxury, which can be problematic for attempts to reduce packaging weight towards reducing environmental costs, while the use of large packaging formats can diminish the image of luxury and make products unsuitable for travel [25]. For green packaging in general, similar to the case for green cosmetics products [205], awareness of environmental issues may not suffice if there is a dearth of information regarding sustainably packaged products and low consumer budgets relative to the high price of such products [251].

Companies also seek to improve their ESG ratings as a means to attracting investment for economic sustainability. ESG investing has been assumed to be a significant driver of environmental protection on the premise that rewarding companies that perform well on the metric would motivate such behavior. There is little to suggest that the approach has been effective for improving financial performance [252–261]. The results may depend on the country [262,263], the sector [258,259,264], and the company's size [259,265]. ESG rating methodologies are themselves problematic [240,257,266–269], and results for financial performance and ESG ratings may depend on the rating methodology used [253]. Evidence now suggests that investing in firms with high ESG rankings, essentially directing funds to companies that are already green and may not be able to improve their environmental performance to a great extent while removing funds from firms with poor environmental performance that would need them to improve their performance, may actually end up worsening the overall impact [270].

3.3. Assessing Sustainability

Life cycle assessment (LCA) has gained prominence as a quantitative tool for the evaluation of products, services, and systems in the context of the CE [153,271]. Assessments based on the ISO-14040 [272] and ISO-14044 [273] standards; that provide the principles and framework, as well as the requirements and guidelines, respectively, for LCA; can be used to assess environmental effects associated with the product from raw material extraction all the way to disposal or recycling [274]. It is often used with subjective weights for different environmental impacts, and results are sensitive to assumptions. For instance, for cosmetics tubes, the allocation methodologies (see [43]) of 100:0 and 50:50 led to differences of 6–20% in the environmental impacts [45]. While the use of multiple datasets may increase its accuracy, LCA results studies have variously found the global warming potential of biodegradable mulch films to be 2–3 times lower than that for landfilling and incineration, and also, that composting and anaerobic biodegradation have a higher impact than incineration and energy recovery [228]. An airless pump that was found to have the lowest impact in all environmental categories relative to alternatives would have had the highest impact on ozone depletion if it were to be assumed that no lotion residue was left in the bottle [275].

Quantifying the impact based on LCA analyses remains challenging. For pineapple production, impacts due to the production of 1 kg of fresh pineapple were estimated in a study to range from 0.172 to 0.520 kg of CO_2 equivalent, with even wider variations in water requirements, and studies have variously found 32–60% of the carbon footprint to be during the agricultural stage, corresponding to 68–40% for the industrial stage [276].

LCAs are too technical and time-consuming [154]. Life cycle impact assessments (LCIA), which are based on LCAs, remain unpopular in manufacturing as the selection of appropriate datasets based on linked international databases is extremely challenging, and there is a need to connect raw data and eco-design via high-level conceptual models and decision support systems [277].

A five-step strategic planning decision framework for circular business models (SPDF-CBM) with recommended tools for each step has been presented and applied to a Brazilian cosmetics startup [154]. An excel-based sustainability tool based on life cycle thinking has been developed [278], and an LCA-based Ecolabel criteria has been developed for the personal care and cosmetic sector in Turkey [279].

Design for sustainable behavior is related to LCA, but rather than focusing on the consumption process of the product, it also incorporates the impact of consumer behaviors, which can indirectly affect the overall environmental impact [280]. Analyses such as LCC for life-cycle costing and variations such as sLCA for social consideration and eLCA for LCAs focused on environmental concerns, have appeared and often give different results due to their different aims as well as different data requirements, although frameworks have been considered to allow them to operate in parallel along with alternate schemes, such as cost-benefit analyses (CBA) [125]. Data availability remains problematic except for a few widely used materials [161]. LCA can also be applied at the organizational level (O-LCA), especially in conjunction with life-cycle costing (O-LCC), where the methodologies may recommended different courses of action [153].

The lack of ability to assess environmental and social impacts that turn out to be in line with subsequent real-life results is not a unique feature for sustainable packaging applications. The extensive use for over almost half a century of methods such as environmental impact analysis, which are often mandatory and are widely used across the world, show that the lack of accurate predictions leaving scope for disputes, along with varying stakeholder interests, have led to a shift in focus from mathematical modeling and computer codes for calculations to political considerations [281]. Efforts are still underway to study the efficacy of the various procedures related to EIA [282] and how sustainability assessments and the various measures and indicators can be placed in the context of local governance considerations [283]. The situation is similar for social impact analysis [284–286].

3.4. Regulatory Environment

The regulatory environment for cosmetics packaging is relatively benign, even in the EU. In the US, the FDA governs cosmetics, and their packaging must protect the product against mechanical, thermal, biological, chemical, radiation, electric, and compression damage, as well as tampering, while taking into account environmental conditions at each stage of the distribution process, such as transportation and storage, including potentially inadequate storage, to display [287]. Cosmetics packaging needs to comply with EU regulation EC1223/2009 on cosmetics products [288]; Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) [289]; the Packaging and Packaging Waste Directive 94/62/EC [290], as well as other relevant regulations, such as for packaging that may come in contact with food; prohibitions on the marketing of products such as cosmetics that could be mistaken for foodstuff due to their appearance, smell or packaging; and labeling that must not imply characteristics that are not present in products [291–293]. None of the regions of EU, US, Canada, Japan, China, or Brazil have the authority to approve cosmetics claims before a product is placed on the market, which often leads to non-compliance, and different claims can be allowed or prohibited in different countries [292].

The Fifth Environmental Action Programme of the EU encourages companies to produce green products by various measures [56]. The EU Emissions Trading System promotes the production of packaging in non-EU countries and will continue to do so until 2030, when such requirements are extended to external producers exporting to the EU [159]. Chinese SMEs in packaging, while under significant pressure from their external markets as well as governmental regulations, are on the whole unprepared for green supply chain management due to a lack of knowledge and management skills, appropriate organizational culture, financial strength, and recycling systems and typically value quality and price over environmental characteristics, with few proactively going beyond legal requirements [294].

Increasing use of nanomaterials, including smart nanomaterials, can be a challenge for regulations as not many data are available on their long-term risks [295]. For cosmetics, unlike for food packaging, where regulations are more stringent, information on the quantity of nanomaterials, size of particles, physical and chemical properties, intended function, toxicological profile, and exposure conditions needs to be submitted six months prior to the proposed introduction of a product in the market, and safety concerns can trigger a referral to the Scientific Committee on Consumer Safety for scientific opinion. The assessment needs to be for individual components as well as the entity as a whole. Differences in definitions implies REACH may not cover specific features of some nanomaterials, and it is possible that an ingredient considered a nanomaterial under cosmetics regulations is not considered one under REACH [295].

The implementation of EU policies into national law is heterogeneous, and the level of support can vary across member states [296]. Several member states have been cited for infringements, such as, for example, in June 2021, when 18 member states were cited for failure to implement one or more directives related to waste management in national legislation [297]. Such issues can make cross-border e-trade difficult [298]. The rules are also updated regularly (e.g., [299]) and can lead to significant push-back from impacted industries [300,301].

Regulations pertaining to ingredients are discussed in the literature [302,303], including the differential treatment of cosmetics [304] and the issues with unified 'one substance–one assessment' schemes [126], as well as the need for safety testing of natural products [203,303]. Cross-border issues apply here as well, [305], including the very definition of cosmetics [292], and regulations can also change [306]. Rules regarding animal testing are heterogeneous worldwide, with only China mandating such testing [198,307], which can lead to questions such as whether a product that was developed without animal testing elsewhere can still be classified as cruelty-free if it is also introduced in China.

4. Sustainable Packaging Strategies

Sustainable packaging can be based on plastics, paper (see, for e.g., [308,309]), glass, and metal [310–312] and can be minimalist, biodegradable, recyclable, refillable, or otherwise reusable. It is important to consider such post-use characteristics during the design phase itself [313]. For the packaging of organic cosmetics, the amount of packaging material should be reduced to the minimum necessary, and the amount of packaging material that can be reused or recycled should be increased, while the use of plastic materials (PVC, polystyrene, etc.), which are not biodegradable, is forbidden [314].

The literature provides some analyses for sustainable cosmetics packaging. The ecodesign of cosmetics tubes using LCA for varying quantities of mineral fillers, as well as post-consumer recycled material, has shown that lower-environmental-impact solutions were also lower in economic costs, and that the environmental impact of different stages varies by product; not all indicators may be better for sustainable solutions, including, for instance, freshwater eutrophication, and the allocation scheme used for the burden of recycling can also impact results [45]. In a direct comparison of powder cases, the design of durable packages was found to significantly outperform techniques such as dematerialization in terms of flimsier products, and it was noted that recycling could only help if packaging materials were fully recycled, which could depend on the user and the infrastructure [21]. In a comparison of a 120 mL glass bottle with an HDPE cap weighing 188.78 and 17.53 g, respectively, a 150 mL PET bottle with an HDPE cap weighing 25.59 and

7.55 g, respectively, and a 200 mL PET bottle with an HDPE cap weighing 77.1 and 21.65 g, respectively, for a total volume of 1800 mL, the 150 mL PET bottle was found to be the most environmentally friendly, and the glass bottle was found to be the least environmentally friendly. Additionally, the contributions of the various stages, such as manufacturing and post-disposal, were different across the products and varied with the disposal technique used [44]. While plastic production uses 40% less electricity than cardboard, the latter is overall more sustainable as it is produced from renewable sources and can be recycled easily, and if not recycled, it decomposes quickly in nature [315]. Processes such as 3-D printing can support sustainable manufacturing by reducing waste, energy use, and carbon emissions and have also found widespread environmental applications, such as for improving air quality monitors, filters, and membranes [316]. The EPA provides data on the proportion of materials being recycled, landfilled, or incinerated for commonly used materials, such as glass, aluminum, paper, and plastics [317].

Plastics comprise a significant proportion of packaging and packaging waste [318]. Several articles have reviewed the various types of plastics, the harm they cause, and waste management strategies [319–321]. Figure 4 suggests several approaches towards reducing plastic waste, including the remediation of waste already present [318,322], redesigning the package to reduce the quantity of packaging, creating reusable [323] or recyclable packages, or replacing plastic with other materials, especially biocomposites. Products using alternate materials could also be designed for reduction, reuse, or recycling or could be removed from the environment via biodegradation. The use of post-consumer recycled plastic is another option (e.g., [45]).

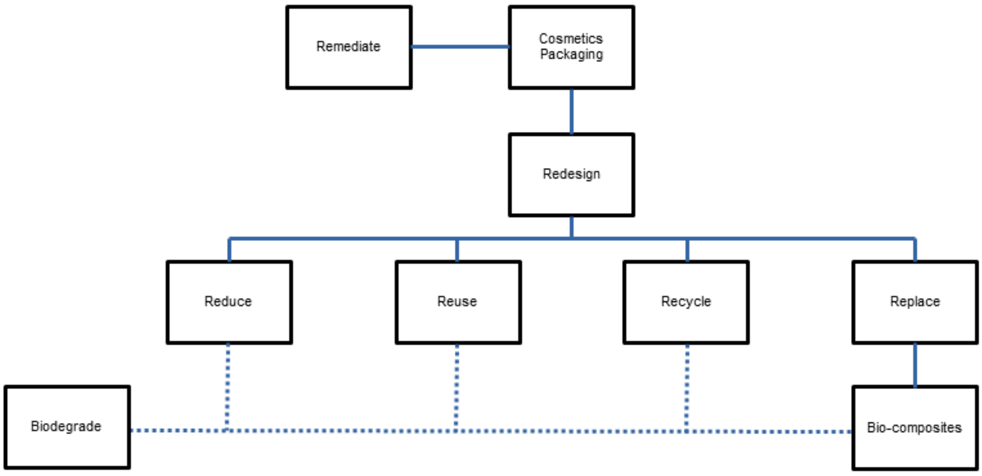

Figure 4. Options for plastic waste.

Techniques such as fungi-based bioremediation for plastic pollution are being researched, but there is a need to promote the biodegradability of petroleum-based polymers by eliminating biocides and antioxidant stabilizers while incorporating pro-oxidants [318,322]. Factors that can affect plastic degradation via pathways such as biodegradation, photodegradation, chemical degradation, and thermal degradation are complex and may interact and interfere with each other [324], and degradation can result in the release of atmospheric microplastics and nanoplastics, as well as harmful chemicals. Microplastics, once introduced, are difficult to remove in wastewater treatment plants; cannot be collected centrally; and with their large specific area and strong adsorption characteristics, can collect a large number of toxic and harmful substances, which make degradation more challenging. While degradation methods have been studied for specific cases, an environmentally friendly and efficient method that can be widely used in practice has not been identified as of yet [324]. Reducing microplastics may require a combination of strategies involving minimizing the loss of pre-production plastic pellets via initiatives such as Operation Clean Sweep®, extending producer responsibility, banning certain types of single-use plastics, supporting the recycling market via taxes on the use of unrecycled material or incentivizing the production of recycled plastics and initiating educational campaigns, developing bioplastics and biodegradable plastics, and improving wastewater treatment technology [325].

4.1. Reduce

Lush has reduced packaging to zero for certain items. Such approaches may not work in color cosmetics, where the contents may be sensitive to heat and light and may dry out without adequate barrier protection, and unlike soap bars, items such as lipstick, mascara, or compacts need to be carried around.

PCR material may require "*(B)rands with rigorous specifications for qualities like color, performance, and aesthetic qualities may need to make adjustments (to their specifications) in order to use higher levels of recycled content. This is especially true for paper and plastic packaging*" [244]. Packaging producers in the supply chain may need to adjust their equipment or buy new equipment. If recycled plastic is used to make cosmetics packaging instead of being used in other applications, and high-quality recycled plastic is in short supply and sells at a premium [244], then such material could be lost thereafter because of the difficulties in recycling color cosmetics packaging.

4.2. Reuse

Reusable packaging retains more value than recycled packaging [323]. The concept is not new and is still found in B2B for transport packaging in the form of crates and pallets and in B2C for primary packaging such as beer bottles, although bottles in general have been replaced by single-use packaging due to greater restaurant takeouts. Proposed EU mandatory guidelines of 10% for takeout and 20% for dine-in single-use plastics to be reusable by 2030 have received significant pushback from the industry, leading to concern from other stakeholders [301].

Reusable packages can be refillable, where the primary package is refilled at selected locations by bulk dispensers. A refillable parent package can be used in conjunction with refill packages that require significantly less packaging material; returnable packaging can require its return to the manufacturer. Similar strategies could include transit packaging that can be returned by door delivery, commercial crates and pallets for which industry-wide standardization can help, and wrappers that can be reused multiple times [323,326]. The economics of the approach is not clear. Bulk dispensers entail hygiene requirements and are at times outsourced to third parties; returnable packaging needs reverse logistics, and cost considerations include the distances involved, the rate of return, and turnaround time. Issues such as rejection rates due to improper use can also arise. Strict hygiene and the removal of all prior materials is required for food and cosmetics, and the packaging must also inhibit leaching [312]. If packages are to be returned to manufacturers for refilling, sorting procedures are needed to ensure manufacturers all obtain their own products for reuse. Many attempts are by small firms, although Loop is a circular shipping platform that works with major brands.

The strategies are varied and can also change. Experience with returnable packages has been mixed, such as for the Body Shop, which discontinued such packages made of plastic but is reintroducing them after 15 years in aluminum under its new owner, Natura [118,327,328]. Some companies use aluminum packages, such as Plaine Products [323] or We are Paradoxx [26]. On the other hand, Lush has announced it will move from reusable aluminum containers to sustainably harvested biodegradable cork containers [27]. In the absence of detailed information as to the basis for such decisions, it is not feasible to compare the approaches in a meaningful manner. Companies are reluctant to disclose the cost and revenue basis for their sustainability decisions for competitive reasons [161] or details regarding the economic aspect of sustainability [56]. This is reasonable, as the release of pricing information to a competitor had almost brought down one cosmetics packaging manufacturer [162]. Most such examples involve packages for products, such as shampoos, not color cosmetics. Kjaer Weiss has refillable makeup cases, such as a resuable compact that can be filled by the consumer, making them 30% cheaper than a new product, as well as refillable versions of mascara, lip gloss, and eyeliners [21]. Natura was the first company in Brazil to offer products for continuous use in a refill version, with 54% lower weight than regular packaging, and its Natural Sou brand is positioned as an intermediate price range based on savings generated from efficiency gains in production processes [23]. Its packaging is not ready-to-use but on a roll of plastic film, which results in lower transportation impact and the use of fewer vehicles. It occupies significantly less space and also generates much less waste at the time of disposal [23].

In the direct comparison of powder cases where durable and reusable packages were found optimal [21], the analysis estimated that the consumer would wish to apply the powder once a day and that a single case would last for 100 uses, and thus, the user would require approximately four compacts per year. Furthermore, it was assumed that the user would stop buying refills or would likely wish to change brands after a year.

It is not easy to extrapolate such results. Studies on exposure suggest data as to the quantity of application can often be difficult to determine [329]. The average woman may own about forty cosmetics items, of which only five are used regularly [330]. They typically own multiple products in the same category, although of different shapes and sizes, as well as different types, such as liquids, gels, and pencils. Furthermore, they may use only a few of them on a regular basis, and the quantities could vary by country [331,332]. A lipstick on average is estimated to provide 293 swipes [333]. Depending on how many times a day it is used, it could last 3–9 months for 1–3 uses provided it is the only one used. If three are used frequently, it could last for more than a year. If the shelf-life of lipsticks can be up to 2 years and infrequent users may use it for that long, even one refill would imply the consumer would need to retain the package for up to 4 years. There is also significant variability in usage in terms of the number of applications per day as well as the quantity of application depending on whether it is used for touch-up or for full application [334]. It is recommended that makeup be replaced every 6–12 months [335]. Expired cosmetics can give rise to bacterial growth and mold and may also become discolored [336].

If most color cosmetics are thrown without use or are used infrequently until they expire, creating more durable, refillable, packaging could be counterproductive as packages that are used only once or are discarded early for some reason would represent both an additional burden during production and could have a greater impact on the environment as waste. Fillers would need to be protected before they are placed in primary packaging by the consumer, such as during transportation and in retail shelves to maintain post-sales shelf-life upon sale. Primary packaging not meant to be returned to the manufacturer must be easy to clean out completely. Companies may use cheaper materials for hidden parts, such as the internal lipstick mechanism assembly [49]. If modifications to allow for complete removal of the previous product and aspects such as maintaining any tactile or audible responses of packaging during use for a prolonged period add to the cost of the package, the company could charge for the package upfront or could distribute its cost over refills. It is not clear whether competitors could introduce their own refills. While the cost of a coffee machine relative to coffee pods is different by orders of magnitude compared to cosmetics packaging versus their contents, the durability of a coffee machine is significantly higher as well, and the legal considerations may also be different. The experience of Nespresso [337–340] may be of interest as potentially many small companies can now join a growing market of producing coffee pods that fit its coffee machines [341].

Reusable packaging would be most useful in the context of frequent users who use up the formulation multiple times within the time they may wish to change the brand or at least the container. These are also the consumers who may care less about sustainable packaging [35]. It has been observed in general that only financially constrained consumers or those in developing countries practice end-use consumption that avoids the infrastructure costs and emissions associated with recycling [342]. As an example, for 1996, it was argued that insofar as 25 percent of the world's population consumes 85% of its wealth and produces 90% of the waste, even if the poorest 75% ceased all economic activity, the reduction in pollution would only be 10% [127]. The small size of color cosmetics packaging would limit its subsequent use for alternate purposes.

Overall, the efficacy of reusable color cosmetics packaging would depend jointly on consumer behavior, the environmental impact of the refillable primary packaging and the interim packaging used for fillers based on production and eventual post-use disposal, the waste-handling infrastructure available, as well as the possible behavior of competitors. Technological developments under the control of the packaging producer can only primarily impact how the required packaging features are implemented, not consumer behavior or that of competitors. Such developments are also constrained by the waste-handling infrastructure when the packaging is finally discarded.

4.3. Recycle

Plastic recycling can be primary, or closed-loop, which is often pre- or post-consumer mono-stream recycling involving the use of waste during manufacturing or from products returned to the manufacturer to produce the same products [343]. Open-loop recycling is the largest part of post-consumer plastic recycling. It involves the sorting of the waste, reduction of waste size, and extrusion and is usually associated with downcycling for lower-quality products [343], which after one or more recycles could end up in a landfill [319]. Traditional recycling plants can only handle a limited category of plastics and can be sensitive to even trace amounts of additives and may also not be able to handle multilayer packaging, mixed plastics, or fiber-reinforced composites [343]. Only 9% of the plastics produced have been recycled, and of this, only 10% has been recycled multiple times [343]. Recycling can also cause the release of harmful chemicals, especially during the heating phase, and can contribute to acid rain and greenhouse gases [319]. For instance, the recycling of plastics in developing countries is often associated with significant health hazards and environmental damage [344,345].

Several separation techniques, including optical, density, flotation, and electrostatic separation [293,320] and magnetic levitation [346] have been considered for separating recyclable items from nonrecyclable materials.

New techniques under active development for recycling challenging plastic wastes, such as various forms of chemical recycling, physical methods such as dissolution and precipitation, and energy recovery via combustion or thermochemical routes have been compared in terms of their environmental impacts and their technological readiness levels (TRL) [319,343] but may require high fixed costs. Not all recycling processes are beneficial for all materials. Chemical recycling may not be useful for PET, HDPE, LDPE, PP, and PS as the processes themselves have large environmental impacts [347]. There have been several technological innovations in this regard [186,343]. PVC is normally considered harmful to the environment; however, with only 43% of its mass being from petrochemical raw materials, PVC could be useful in the circular economy with the development of appropriate recycling technologies [348]. 3-D printing is another potential means for the reuse of plastic waste for certain plastics, although price reduction is required as the cost of commercial filaments is up to 200 times higher than raw plastic, and properties start to degrade after a few cycles [349]. An intelligent recycling system taking into consideration the various contradictory needs of cosmetics has been outlined [350].

In spite of technological improvements, plastic waste is often not managed properly in several regions, such as Africa, the Middle East, Asia, including India and China, and Latin America [351]. Littering and landfilling constitute the destination for the majority of the waste, with only 9% being recycled globally [351]. Waste management issues have become especially acute in the developed world after China, in 2017, banned the import of most plastics waste under its National Sword Policy [41,352]. Turkey, a major waste export destination for Europe, also cut back on plastic waste imports based on a Greenpeace investigation that found most of the waste was not being recycled as required but rather was being landfilled or incinerated, mostly near low-income neighborhoods, but subsequently reversed the ban except for HDPE and LDPE [353]. The tendency is to simply discard plastics other than codes 1 and 2 [41].

The quantity of new, petrochemical-based, single-use plastics has continued to increase faster than it has been possible to scale-up recycling, which remains a marginal activity depending on economic conditions [354]. In spite of regulatory targets, the plastics sector is behind in its attempts to transition to a circular economy [167]. Color cosmetics packaging often involves codes higher than 2. They are multi-material, multi-layered packages that are difficult to separate. Their small size has been considered a reason to not mix them with regular recycling but rather only recycle them via specialized services such as TerraCycle, especially as small amounts of residue can led to a whole recycling batch being sent for incineration. Size and contamination issues may apply to glass and aluminum as well.

Such issues are known in the literature; for instance, the aluminum pan of a reusable powder case was assumed to not be recyclable due to the possibility of powder residue [21]. Similarly, the presence or absence of residual lotion was shown to be significant for the determination of the relative environmental impacts of various potential products related to a bottle [275]. The issue is more whether consumers are aware of, or care for, such matters. 'Wish-cycling' causes a significant number of false-positive errors where items that should not be recycled are nevertheless placed in bins, hoping that they might get recycled [355]. Such errors are much more costly as they can result in entire truckloads getting rejected and being landfilled or incinerated instead, and the less-prevalent error of not recycling a recyclable item is relatively not that impactful. Nonuniform procedures across jurisdictions promote false-positive errors [355].

If plastics are entering the recycle stream faster than can be handled by existing systems, which also may typically only handle codes 1 and 2 [356], adding recyclable color cosmetics packaging to the mix does not really help the environment. It can only hurt by contaminating entire batches. Putting in new systems to handle small items whose total quantity is not very significant and which could also contaminate larger batches should not be the priority when the need is to increase the recycling of the much larger quantities of material that could be recycled in current systems but still are not. This applies to glass and aluminum as well, as such materials are currently not fully recycled either [317].

4.4. Replace

The packaging industry is already familiar with glass and aluminum, and their environmental characteristics with regard to production and recycling are available in the literature. Given the size of color cosmetics and the potential for contamination, recycling may still be infeasible. Except for cardboard and paper, none of these materials are degradable. We only consider bioplastics under replacement.

4.4.1. Biopolymers

One solution is to use bio-based polymers that do not require fossil fuels for their production [357]. This would include drop-in polymers similar to traditional ones [228], as well as synthetic polymers that are based on renewable biomass but require chemical processing. The organic carbon in biobased plastics, including synthetic polymers, originates in whole or in part from renewable biomass, and the ratio can be assessed by radiocarbon analysis based on ASTM D6866 [358] or ISO 16620 [359–363], where ISO16620-2 is equivalent to D6866 [358], for determination of the biobased content of plastics, [91,364,365].

Another possibility is to develop biodegradable polymers, whether from natural or fossil sources, that can degrade relatively quickly in the environment. Degradation should result in lower-weight molecules that are amenable to metabolization by microorganisms, leading to complete mineralization, with the final result being CO_2 or CH_4. Biodegradation may require specific conditions, such as industrial composting, anaerobic digestion, or agricultural soil and wastewater degradation. The rate of biodegradation of a polymer under various conditions is a critical characteristic in terms of its usefulness. PLA requires industrial composting for biodegratation, and there has been research into blending it with other polymers to increase its biodegradability. Additions to PLA for this include biobased polymers such as starch or chitosan, fossil-based polymers such as PCL, as well as pro-oxidants [366,367], although this could also lead to the issue of micropastics. Research into various aspects of biodegradibility has covered mechanisms; rates under various environments; factors that impact the rate of biodegradation; and standards, certifications, and evaluations (e.g., [91,228,366,368,369]).

Bio-based, biodegradable, and compostable plastics constitute a relatively small but fast-growing proportion of plastics that are desirable from sustainability considerations and for design for life, although the challenges of higher costs by a factor of two, and lower durability, remain [101,370]. Their use could be critical towards the long-term resolution of the environmental issues in conjunction with reuse and recycling, which requires products with easily separable and reusable materials and appropriate waste handling procedures [91]. Not all bioplastics are biodegradable. Some bioplastics can be recyclable and can be designed to improve their recyclability, such as PLA blends with chain extension [371]. The degradation of a particular product is a strong function of environmental factors such as temperature, humidity, and the type of microorganisms present; biopolymers can have widely varying rates of degradation, and it is not feasible at this time to create a biocomposite that is degradable under all possible conditions.

Household waste has been explored as a cheap source for bioplastics [372]. Seaweed polysaccharides have also been considered as a healthy and environmentally friendly source for biodegradable packaging, including for food and pharmaceuticals [373]. Comparisons of the mechanical, water permeability, and degradation properties of PLA, PGA, PC, and PHA are available in the literature (e.g., [374]). The literature has also discussed processing techniques for biopolymers [375] and for food packaging, production techniques, and parameters [376].

Several natural polymers from animal and vegetal sources have been considered as bio-based and biodegradable replacements [364]. These include proteins such as collagen, wheat gluten, or soy protein; polysaccharides, such as chitin from the shells of crabs, shrimp, and crawfish, as well from insects and from fungi; chitosan from chitin and their derivatives, as well as starch from potatoes, corn, wheat, and rice; bacterial polymers including semi-synthetic polymers such as PLA from the fermentation of sugars and fermentation to produce the natural polyesters PHA, PHB, and PHBV; and carbohydrate polymers such as xanthan, curdlan, pullulan, and hyaluronic acids [364]. The overall mechanical and degradation properties of such polymers depend significantly on their processing and blending, as well as the environmental conditions in the end-of-life disposal system [91]. There has been significant research into specific polymers, including their sourcing, processing, characterization, and applications, such as for biobased pullulan for body and skin contact applications [377] and lignin sourced from sugarcane byproducts [378]. Chitosan and its nanoparticles, which can act as an emulsion stabilizer, rheology modifier, thickener, and antimicrobial preservative, have significant potential cosmetic applications [379,380]. Terpene-derived copolymers can be synthesized in supercritical CO_2 and can be used to replace petroleum-based polymers that are also synthesized in petroleum-based organic solvents [24]. Waste feather keratin has been mentioned as a source of ecofriendly bioplastic films [381]. Due to the issue of investment requirements and land requirements for plant-based polymers, marine-sourced natural ingredients could be useful [382]. The design of polymers needs to be aimed at managing end-of-life characteristics [91].

Biodegradable polymers from fossil fuels include those with additives, such as oxo-degradable polymers with antioxidants that can react under UV light, inducing photodegradation, although there is a lack of consensus as to their biodegradability and with pro-oxidant additives such as Mn^{2+}/Mn^{3+}, which form hyroperoxides and can then be thermolysed or pyrolised to provide hydrophilic products with lower molecular mass that could be biodegradable [364]. Others include those with hydrolysable backbones, including aliphatic polyesters such as PGA, PLA, and their copolymer PLGA; polycaprolactone (PCL), polybutylene succinate (PBS), and its copolyeseters such as PBSA, poly p-dioxanone

(PPDO), and poly trimethylene carbonate (PTMC); aromatic copolyesters; polyamides and poly ester-amides; polyurethanes and polyanydrides; and those with carbon backbones, such as vinyl polymers [364,370]. Each category has several commercial products available and a range of application areas from medical applications, packaging, and agriculture to automotives, electronics, and construction. Various biodegradable polymers can also be blended and their properties can be modified via techniques such as grafting [364,370].

Biobased, non-biodegradable polymers had a production capacity of 884.5 Ktons in 2020, which was expected to increase to 1070.9 Ktons by 2025, with polyamide (PA), polyethylene (PE), polytrimethylene terephthalate (PTT), and polyethylene terephthalate (PET) being the dominant polymers [311]. Poly-lactic acid (PLA), starch blends, and polybutylene adipate terephthalate (PBAT) dominated the capacity for biodegradable polymers, which had a total capacity of 1226.5 Ktons in 2020 and is expected to increase to 1800.1 Ktons by 2025 [311].

4.4.2. Biocomposites

In applications involving the replacement of traditional plastics, natural or synthetic fibers are typically added to the matrix for reinforcement, load-bearing, and improving rheological and thermomechanical properties [370]. Natural fibers are preferable from an environmental viewpoint, such as the use of renewable sources and biodegradability, along with their high strength, low density, and low cost [370]. Natural fibers can be plant-based, including bast fibers extracted from the outer bark of plant stems, such as flax, jute, kenaf, and hemp, consisting mainly of cellulose or hemicellulose; leaf fibers from leaf tissues, such as sisal and pineapple; seed and fruit fibers, such as cotton, loofah, kapok, coir, and oil palm and coconut; or those extracted from wood, stalks, and grasses [370,374,383]. A comparison of the properties of fibers, of certain biocomposites based on these, their areas of applications, and case studies featuring these fibers are available [370,374,384]. Comparisons of this sort are also available for individual fibers, such as sweet palm [383] or banana fiber [385]. Recycled fibers may also be used for molded fiber products [386]. Animal-origin fibers such as wool are also being researched [387]. Cork–polymer composites with chitosan and PE-graft–maleic anhydride has been studied for its improved mechanical and thermal characteristics, as well as its antibacterial and antifouling properties [388]. Biomasses such as coffee grounds, nanocellulose, and date stones can be used to develop smart reinforcing agents in biopolymers, and research is underway towards the production of high-performance lignocellulosic reinforced materials that can overcome the issues of high humidity absorption, poor wettability, and incompatibility associated with these agents [389]. Organoclay could also be used for compatibilizing and reinforcing different, incompatible biopolymers, such as chitosan, carboxy methyl cellulose, and PLA [389]. Rice and wheat bran platelets, treated with beeswax, along with talc and calcium carbonate, have been considered for a PLA/PBSA matrix [390]. Metals and metal oxide-based nanofillers are also used [391].

Production processes for green composites [392], parameters for sustainability assessments of biocomposite-based rigid packaging [177], and considerations for multilayer packaging, which are traditionally particularly difficult to recycle; the use of biodegradable coatings and biobased adhesives based on PLA, PHA, bioPE and bioPET; upcycling involving controlled degradation along with a modification step to create a second-generation material that can provide new performance aimed at higher-value applications [293]; and LCA for bioplastic production, as well as life-cycle cost (LCC) and social life cycle assessments (S-LCA) [161,393] have been covered in the literature. Biodegradable plastics from fossil fuels as well as biobased non-biodegradable plastics can be processed similar to conventional plastics, while caution is warranted for biobased, biodegradable material that is susceptible to hygroscopic characteristics that can induce a loss of viscosity, foaming, thermal degradation, or hydrolysis which requires pre-drying to optimal levels while also avoiding overdrying; flow anomalies and wall slipping, especially for biocomposites based on natural fibers which may exhibit heterogeneity; degradation at higher temperatures;

and the need for modifications to avoid high shear rates as well as potential for flow hesitancy [394]. Biocomposites are also being considered for use in marine environments [395].

PLA has been investigated as a potential biodegradable replacement for traditional plastics for more than two decades [396,397] and has been studied extensively for extrusion, injection, and blow molding, among other processes, given its unique properties [398]. Various fibers have been incorporated as microfibers or nanofibers over the past decade to improve its properties, especially agricultural fibers such as jute, hemp, flax, lyocell, sisal, oil-palm and wood flour, as well as microcellulose nanochitin and nanolignin, to provide fully biobased and biodegradable materials (e.g., [399–404]). Research has been directed towards the composition, additives, and production conditions necessary to attain appropriate product characteristics, shelf life, and degradation, as well as special requirements such as UV absorption, flame retardancy, and antibacterial protection (e.g., [405–409]). Research has also been directed towards the optimization of injection processes and surface finish [410–413] and more recently towards additive manufacturing techniques and comparative analyses vis-a-vis injection molding [414,415]. Finally, studies have focused on degradation [416,417], product life [418], as well the potential for reusability via re-extrusion [419–421]. Reusability is important not just for environmental benefits but also due to the cost of the materials. PLA recycling is feasible, but the decrease in molecular weight suggests a limit to the number of cycles of reuse [293].

Research shows the promise of such materials for a wide range of applications, from biomaterial to automotive applications, based on composition in terms of fiber type and content, as well as any additives, material-production process conditions, and manufacturing conditions. Suitable materials have not been available for the cosmetics packaging industry up to this point. However, the cosmetics industry has gained significant experience in nanomaterials [422]. Recently developed novel PLA-based nanofiber composites hold significant potential for cosmetics applications based on bio-inspired processes and products from renewable feedstocks, by which technological innovations have been fostered to produce innovative non-woven tissues based on the use of chitin nanofibers and nanolignin complexes [423]. Efforts towards modulating the viscosity of PBDA and PBAT melts have been reported to facilitate the industrial extrusion of biobased beauty masks have been reported in the literature, and the properties of PLA-based bionanocompsoites incorporating chitin nanofibers using polyethyline glocol as a biobased plasticizer have been investigated to remediate their mechanical characteristics related to ductility and stiffness [424,425]. Efforts towards the development of flexible films and active molecular compounds in biomedical, cosmetics, and sanitary industries, as well as in related areas such as food packaging, have also been reported (e.g., [156,426,427]. Active food packaging, such as those based on biopolymeric nanocarriers containing essential oils (e.g., [392]), is a significant development as packaging must be able to protect food, and reducing its effectiveness in an effort to reduce its environmental impact could lead to wastage of the contents, which could have a greater negative impact on the environment. Multilayer antibacterial food packaging based on PLA, chitosan, and cellulose nanocrystals has been investigated [428]. Intelligent food packaging based on green materials can provide information about the history of the package as well as the quality of the contents, such as via time–temperature history monitoring to indicate unsafe food [389].

There is a lack of sufficient knowledge as to the impact of biodegradable polymers. PLA does not degrade significantly for 6 months in seawater, although the use of natural fibers could help speed up the degradation process. It is also potentially ecotoxic in marine environments [429] and with potentially problematic nanoparticles in freshwater [107].

Bioplastics also act as contaminants in traditional plastic recycling schemes requiring adequate separability [91]. It may not be possible to prevent consumers from mixing inappropriate waste streams [430]. Techniques such as near-infrared spectroscopy and hyperspectral imaging in the near-infrared region can be used to separate PLA [293]. Differential calorimetry and isotope ratio mass spectrometry can analyze various biodegradable and non-degradable plastics and can achieve high PLA discriminant accuracy, which can help with identification for bioplastics to detect counterfeited and mislabeled products and avoid sustainability fraud. This can also help improve plastic waste recycling [431].

The diversion of agricultural land and crops from food towards alternate uses can be problematic [432,433]. The need for fertilizers, deforestation, and grassland conversion along with loss of biodiversity are potential problems as well [394]. Nevertheless, the land requirement for biopolymers would be significantly less than land take for other purposes [228]. Additional potential problems include nanoparticles from biopolymer degradation (e.g., [107]) and degradation potentially promoting bacterial and spore infestations that could be inhaled [394]. Bioplastics may also involve the use of potentially harmful chemicals during manufacturing [351];

Insufficient industry experience relative to traditional plastics for various applications, especially in cosmetics packaging [230,434], as well as for the design of biocomposites incorporating the various sustainability considerations, and higher cost are also potential barriers.

In spite of the disadvantages, biodegradable plastics may provide a partial offset for littering and waste mismanagement and have fewer negative effects on the environment than traditional plastics even in cases of partial bioderadation, especially when created from waste biomass [228].

5. Discussion and Conclusions

The aim of the review is to consider whether a pathway can be found towards implementing sustainability in color cosmetics packaging based on current information, even though the issue has not been considered directly to a significant extent in the literature, and results for related areas only suggest that each situation may need to be examined on a case-by-case basis. The aim, specifically, is towards mass-produced packaging that can create a measurable impact and not niche applications.

5.1. Existence of Need

The British Beauty Council [19] suggests the risk of not changing is beginning to outweigh the risk of changing. While consumer behavior such as the gap between self-reported green purchase intention and actual green purchase behavior is well-known [435], color cosmetics packaging involves public-facing plastics, and not acceding to consumer demands can be costly for the brand image. Such areas are eventually likely to be targeted in terms of policies and regulations. Implementing changes for environmental protection and social welfare is costly, which is why regulations to enforce such changes are almost always opposed by industry [266], expect perhaps when larger companies, whose productivity drops significantly with efforts at environmental protection as against smaller ones [436], promote these to gain an advantage over financially weaker rivals [437,438]. Voluntary corporate action can decrease the need for regulatory and legal interventions [439,440]. Even as the EU moved to restrict cosmetics with microbeads starting in 2014, there was no Europe-wide ban until 2022, and only a few European and other countries as well as individual US states have taken legislative action because of the belief that cosmetics industries had responded significantly [96]. Furthermore, sources such as glitter have been ignored even though they are more widely used, and the industry is still discussing the time frame for leave-on products to allow for sufficient time for reformulation [96].

Given the technical challenges involved, starting now on a mass-produced color cosmetic package may provide a commercially viable sustainable solution in a few years, and companies starting early would be better prepared. There is little scope anymore for the "sustainability as a journey" [441] feint accompanied by ambitious goals towards reduction in environmental impact over appropriately long time frames, which admittedly was perhaps necessitated by a surfeit of normative demands from those supporting CSR and sustainability but no real pathway [2,140,165]. Measures and requirements for demonstrating sustainability, including mandatory reporting, are becoming increasingly stringent [442], and most companies are unprepared for it and may be overstating their sustainability [443]. Pledging support for SDG involves measurable objectives [440], and claims of sustainability may now require documented verification of product sustainability such as via LCAs covering the entire life cycle and the company based on similar analyses for the organization and its suppliers [41].

Most importantly, it could also be helpful from an environmental point of view to have time to develop a more appropriate solution rather than hurried measures that later turn out to be ineffective. Such a solution would be of value even if regulations requiring such packaging to be sustainable are never imposed.

5.2. Desirable Characteristics

The aim is to determine potential pathways towards enhancing the sustainability-related characteristics of cosmetics packaging in spite of the lack of consensus in the literature with respect to almost every aspect of the numerous issues involved with sustainable products. In this sense, the uncertainties inherent in the various aspects of environmental protection efforts help delineate the constraints within which the effort towards sustainable cosmetics packaging must operate.

Consumer uptake is indispensable for a product to succeed. Given the myriad of individual, social, and product factors that can impact consumer reaction to green products, the safest a priori assumption would be that ceteris paribus consumers would choose a product with less environmental impact. The literature has often emphasized the need for maintaining performance and price for green products. We already know what people consume [444], and perhaps it is not that important to learn about why or how. Companies have significant knowledge with regard to the characteristics and functionality that consumers desire for their traditional products, and adding the constraint of sustainability will not improve upon an optimum design sans the constraint. This is especially important for mass-manufactured products, which must satisfy the needs of a range of consumers. For such products, instead of experimenting with novel designs that may or may not appeal to particular segments of the customer base, it may be easier to simply adopt the constraint that *sustainable packaging must provide the same product characteristics and functionality as the corresponding traditional products and at the same price*.

This transforms consumer-related issues into a technical problem with regard to product characteristics, as well as a financial problem related to pricing. Adopting such a constraint does not mean the problem has been solved. Rather, it provides a specific goal for technical development and, subsequently, for cost analysis and policy support.

The removal of packaging altogether may not be feasible for color cosmetics, and the use of PCR would require the diversion of high-quality recycled plastics to a product stream, which may proscribe subsequent recycling while potentially detracting from aesthetics and perhaps the impression of quality. The applicability of reuse depends on individual preferences and behaviors, including usage characteristics which neither the packaging producer nor the cosmetics companies control, and even if they did, it would probably go against their economic interests.

Under current conditions, attempting to introduce recyclable color cosmetics packaging may violate the SPA's definition of sustainable packaging [40]. Under 'Cyclic', there is a suggestion that a product designed for one system, such as composting, should not contaminate another system, such as recycling. Color cosmetic packaging, because of its small size, codes higher than 2, and the potential for residues often essentially acts as a contaminant in the recycling of other waste. 'Clean' in the original definition as well as 'Safe' in the revised one seek to ensure a lack of harm to humans or ecosystems from all packaging components and suggests the precautionary principle be applied in case of doubt [40]. While it may not be harmful directly, most locations cannot recycle cosmetics packaging, and converting a few for this purpose can lead to an increase in errors of the type where nonrecyclable items are sent for recycling [355]. Such errors are more costly and more harmful to the environment compared to the loss of material caused by not recycling a recyclable item [355]. Marketing certain colored cosmetics as recyclable in some areas could be indirectly harmful to the environment as it could increase consumer confusion and lead to greater contamination of recycling batches.

New fossil-based plastic materials are entering the waste stream faster than they can be recycled, and the amount of plastic waste is growing [354]. Regions with relatively developed infrastructure and greater recycling capacity continue to export waste to countries where dumping, landfilling, and incineration constitute the most popular disposal techniques by far [228,351]. Plastic waste will not be decreased by the addition of more recyclable material to the waste stream if there is no capacity to recycle it. Globally, only 9% of the plastics produced are recycled [354]. Other than two outliers, a total of eight plastics manufacturers have targets of 20% of their plastics production to be based on recycled material by 2030, and this could potentially turn into greenwashing if it is not implemented [354]. Diverting resources towards enhancing the ability of existing recycling facilities to handle the relatively small quantity of color cosmetics that are problematic would waste resources that could be applied towards enhancing the recycling capacity for the significantly larger quantity of plastic waste that is instead headed for landfilling or incineration.

Recycling of all bioplastics, including biodegradable ones, has been recommended for the recovery of materials [445]. Any benefits of recycling for bioplastics, such as retaining some of the energy and resources used towards the creation of the material while reducing the impact of the production processes, are only obtained if the material is actually recycled [21]. Bioplastics designed primarily to be recyclable would again be subjected to capacity constraints as well as the availability of infrastructure. Consumers will also continue to mix these recyclable bioplastic color cosmetics packaging items with regular plastics for recycling. This could cause a rebound effect [430].

A fully soil- and water-biodegradable packaging would entail one, simple, universal directive to not recycle color cosmetics packaging but to put them in the trash. This could apply to glass and aluminum packaging as well, at least when they are being discarded. If some bioplastic biodegradable packages are still attempted to be recycled, with increasing use of bioplastics separation schemes already under development, the separation of color cosmetics products would be possible both based on size as well on material, and the subsequent landfilling of such rejected items would not be an issue. In regions where landfilling is the preferred means of disposal for the bulk of plastic waste, it would be disposed of appropriately anyway. Even partial biodegradability in soil and water would directly help reduce plastic waste and ameliorate the burden on landfills [228]. The downside is the lack of appropriate materials, especially for color cosmetics. While this may take time and effort, the development of such a material and its implementation will not interfere with recycling of other materials. Thus, for color cosmetics, another constraint would be that *the proposed sustainable material must be designed to maximize biodegradability under specified environmental conditions and minimize the production of microplastics*.

The true impact of a new material may only become apparent after it is incorporated into full-fledged production. Significant up-front investment requirements for material-specific production machines can impede attempts to explore and employ new, sustainable materials all the way to commercialization. To reduce the upfront investment-related risk associated with initiating the mass production of a particular product, the next constraint would be that *the new materials must be processable on existing machines, with modifications in tooling and process parameters if needed*.

The four constraints listed above would need significant technical development given the lack of experience in the cosmetics industry vis-a-vis biodegradable materials. The design of materials that provide biodegradable products with similar characteristics as traditional ones is not a novel aim, but it requires emphasis at the outset so as to narrow down design choices and avoid a plethora of potential sustainability strategies and corresponding designs, each with its own acceptability issues and post-use infrastructure requirements. The focus can then be on the development of the product and validating its feasibility from various relevant perspectives, starting from raw material sourcing and ending at the post-disposal characteristics of filled products under field conditions. The lack of such a material at present is the prime reason such research should be initiated at the earliest opportunity so that companies are ready to implement such packaging in the future.

Lab testing and shop-floor production can be quite different, and results from the former cannot be the basis for final validation towards implementation in the latter. In the absence of models that could provide reasonable predictions, such validations need to be empirical. This makes implementation attempts expensive, time-consuming, and risky. It also necessitates participation from across the supply chain, which adds to the complexity and difficulty of coordinating such attempts, although it could also be beneficial as the greatest level of environmental, social, and governance performance is achieved via collaborative projects, followed by in-house efforts, and finally via outsourced projects [446].

Given the risky nature of such efforts along with the potential benefits for the population at large, *such efforts could be funded by governmental agencies to the extent that participants do not make a profit out of the funding*.

5.3. Proposed Research Program

Figure 5 shows the possible constituents of a group to help implement sustainable packaging. Unlike horizontal alliances that are needed for cooperation on tasks such as standardization, the validation of a particular sustainable packaging for cosmetics will involve vertical alliances extending beyond the traditional supply chain.

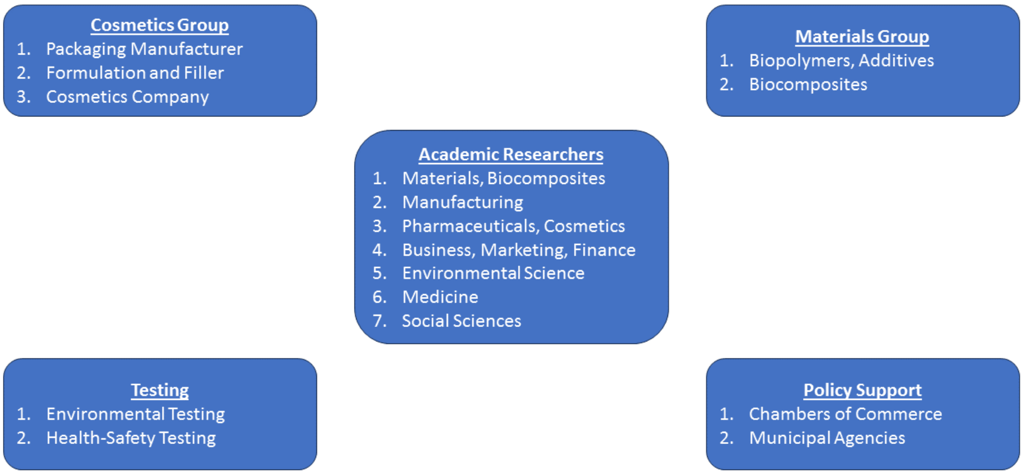

Figure 5. Participants required for the development of commercially applicable sustainable packaging.

The cosmetics component would include a packaging manufacturer interested in implementing sustainable packaging, along with a company that produces formulations and fills the packages and a company that sells cosmetics under its brands. Given the necessity of experience in production processes to be able to implement change, these companies need to be highly experienced and proficient. Information-sharing concerns could be exacerbated with new and unknown partners, while long-standing business relationships may already have generated trust and familiarity with each others' pricing structures and business practices. Additionally, large companies typically do not experiment with new technology but rather prefer to partner with third parties for development and scale up successful ones. This suggests that experienced and proficient SMEs who have built long-term business relationships with each other could be considered for the cosmetics group.

The materials group would consist of companies, potentially startups, that produce biopolymers and additives, as well as novel biocomposites. Testing would be comprised of companies or research facilities that can carry out environmental testing, health-safety testing, as well as market testing, but the latter can probably be the cosmetics company itself. The policy support group would be comprised of chambers of commerce and municipal agencies involved in waste handling or environmental protection. Material development is still often in the research phase, and academic researchers would have a significant role from multiple perspectives. The supply chain components could be spread over different countries, with cosmetics companies in a region with relatively lower costs. Research-oriented SMEs related to materials could be in countries with a greater emphasis on research. Universities in proximity to such groups can also act as key facilitators in the process while helping guide development and testing based on the scientific literature, along with broader research into social considerations.

The overall steps of the procedure are in Figure 6.

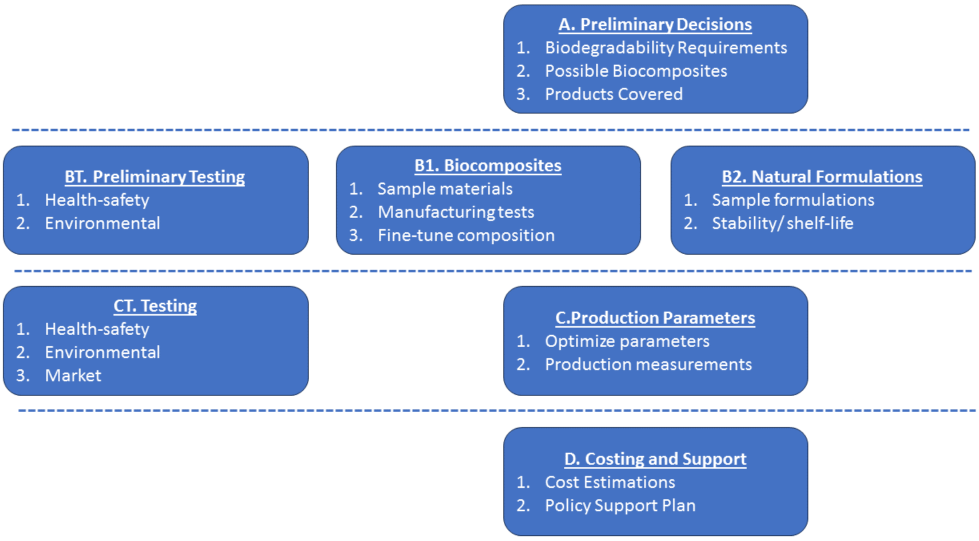

Figure 6. Steps towards the development of commercially applicable sustainable packaging.

With the focus on achieving the greatest possible biodegradability and the same functionality as the traditional product, the preliminary decisions would relate to potential blends that could be employed for each of the different types of products sought to be replaced, including considerations such as the potential for scale-up and the environmental conditions expected under post-use disposal.

The second phase would include samples of proposed packaging materials and formulation ingredients being produced and being sent for environmental and health safety testing, as well as for production tests and for formulation and filling. Production tests would evaluate the usability of the materials on existing equipment, as well as their compatibility with different finishing processes. The package producer and the filling company would provide feedback to the materials companies for fine-tuning the composition of the materials based on preliminary testing, and materials not meeting health safety requirements or those potentially toxic to the environment would need to be removed from consideration. This could be an iterative process.

The third phase would be the optimization of process parameters for the fine-tuned materials and determining their production-related measures, such as their cycle times, defect rates, and power consumption. Filled samples would also undergo stability and shelf life evaluations, and optimal production parameters would be determined for filling as well. Material resources, energy, water usage, and similar comparisons can be conducted for the new product at each stage of production using the actual production data and the corresponding values for the prior product. Finally, samples could be sent for overall product health safety and environmental testing and could also be provided to other downstream companies and consumers for their evaluation, both with and without knowledge of their sustainability characteristics.

The successful completion of the technical phase of testing would be followed by costing and attempting to determine the required costs of the parts at various stages, which would allow the final price of the product to remain the same. For this, policy support could initially be sought in the form of tax subsidies or other financial incentives. Once scale-up has been achieved for the group and it has been determined that additional raw material capacity can be brought online, other companies can be incentivized to shift to the new materials by removing any subsidies on traditional fossil-based raw materials for this purpose. Finally, once companies in the market gain experience with such materials, the policy can be changed to one mandating the new materials.

As such materials become established and are adopted for widespread use, equipment manufacturers would be able to produce machines that may be better suited to such materials, and companies could replace existing equipment with such machines, potentially to improve production efficiency and quality, if it made business sense to do so.

Any interpretation of the literature can always be somewhat subjective. The lack of consensus in the literature is often so great that different reviews of the same literature may come to different conclusions. The approach presented here is not exclusive, and it is always possible that other researchers may come to alternate conclusions based on considerations such as the potential problems with biodegradable plastics, their high costs, the loss of all inputs through the supply chain, and the aspirational nature of the goal of developing biodegradable materials that can provide similar aesthetic and performance characteristics for color cosmetics packaging. Making comparisons across such approaches is outside the scope of the current work. There is a conspicuous lack of literature directly related to the development of sustainable packaging for color cosmetics. In this regard, motivating, in some measure, the development of alternative pathways could perhaps be one of the main aims of this work.

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