

Article

The Green Sciences Index: A Novel Approach for Assessing the Sustainability of Cosmetic Ingredients

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Abstract

The global necessity for sustainable development has prompted a significant re-evaluation of practices across diverse industries, notably influencing the cosmetic sector's approach to ingredient management. To address this imperative, the L'Oréal Group launched its "Green Sciences" initiative, aiming to support the transition toward more sustainable cosmetic ingredients. This article introduces the Green Sciences Index (GSI), an assessment tool designed for a structured and standardized evaluation of cosmetic ingredient sustainability to assist innovators in selecting ingredients during the early stages of development. Adopting a life-cycle perspective, the proposed framework assesses feedstock origin, ingredient manufacturing processes, and the environmental impact of an ingredient's end-of-life. The GSI was specifically designed with a focus on the global manufacturing pathway, from primary feedstocks to the final ingredients. It integrates an assessment framework inspired by the Principles of Green Chemistry for cosmetic ingredients, encouraging specific sustainable manufacturing practices, structured around "Biotechnology and Fermentation", "Eco-extraction and Physical Processes", and synthesis by "Green Chemistry". The practical application of the GSI is demonstrated through a series of concrete case studies featuring diverse ingredients. The GSI is an eco-design lever serving as a pre-screening orientation tool at the ingredient level, complementing comprehensive Life Cycle Assessments to guide development and innovation toward more sustainable cosmetic products.

Keywords: life cycle; green chemistry; ingredient manufacturing; biotechnology; eco-extraction; bio-based; recycling; mineral abundance; biodegradability



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1. Introduction

Growing awareness of the environmental impact of human activities has driven a global shift toward sustainable development, embraced by various industries. Following a new Special Issue published in 2023 in *Environmental Science & Technology* entitled "Accelerating Environmental Research to Achieve Sustainable Development Goals," [1] it is of significant value to illustrate substantial advances in research and methodology regarding sustainability in the well-being, beauty, and personal care sectors. The strong commitment of cosmetic companies [2,3] is key, and focus should be placed not only on their direct impacts but also on their indirect ones, related, for example, to supplier activity and the use of products by consumers. To reach these objectives and ensure activities are compatible

with a resource-constrained planet [4], the L'Oréal Group launched in 2020 a program ("L'Oréal For the Future" [5]) defining its sustainability commitments for 2030, using a continuous improvement approach aligned with the progress of scientific knowledge in the field. This program sets ambitious commitments, aligning with the Science-Based Targets initiative rationale [6] and addressing key areas such as climate, water, and biodiversity. Among the various stakes, natural resource preservation, sustainable sourcing, ingredient traceability, and product eco-design are particularly emphasized.

Recent initiatives, for instance the EcoBeautyScore [7], have addressed environmental impact at the product level, and existing tools like SPOT [8] focus on cosmetic product eco-design. These tools apply the Life Cycle Assessment (LCA) approach, based on the European Product Environmental Footprint framework [9], to evaluate and compare cosmetic products with one another. These tools provide insightful information at the product level and are efficient decision-support tools thanks to the processing of extensive data across the entire life cycle of products. In complement to LCA-based approaches, first-intention tools were developed to select ingredients with the best sustainability profile, especially regarding their manufacturing processes.

Indeed, cosmetic ingredients are a key lever to improve the sustainability of cosmetic products through the implementation of the Green Chemistry Principles defined by P. Anastas et al. [10,11]. The Sustainable Development Goals [12], defined by the United Nations Global Compact [13], strongly consider Green Chemistry a paramount approach to improve the management of man-made chemicals, leading toward sustainable chemistry [14,15]. Green Chemistry Principles can thus help in designing and developing sustainable cosmetic ingredients and products [16,17]. Hence, several evaluation tools focused on ingredients have been proposed by ingredient manufacturers or cosmetic companies.

For example, the Mane Group introduced the "Green Motion" tool [18] in 2015. Specifically designed for flavor and fragrance ingredients, it is particularly adapted for use by ingredient manufacturers. Green Motion aims to help process chemists and chemical engineers evaluate the "Green Chemistry" performance of chemical reactions in a rapid and simple way. The evaluation boundaries follow a gate-to-gate perspective, from the reception of raw materials in the factory to the exit of finished ingredients, and rely on seven fundamental concepts (raw materials, solvents, final products, wastes, reaction efficiency, process efficiency, and hazard/toxicity). The indicators used are mostly focused on process aspects (E-factor, yield. . .) and chemical hazard classification. While Green Motion is highly effective in analyzing specific manufacturing processes with an easy evaluation process and clear output, its scope regarding the upstream value chain and end-of-life is more limited. In terms of raw material origin, it distinguishes between renewable/petrochemical carbon and considers the type of transformation (physical/chemical or natural/non-natural). Regarding the end-of-life, the Green Motion tool focuses mainly on the aquatic toxicity of the final product. As it was primarily developed for organic, carbon-based compounds, this framework does not specifically address mineral compounds, which represent a significant category of essential cosmetic ingredients. Consequently, there was a need for complementary approaches to address the full diversity of cosmetic ingredients (e.g., polymers, natural extracts, bioactive molecules, and minerals).

More recently, in 2022, the Estée Lauder Companies introduced the "Green Score" tool [19]. This tool evaluates the "chemical components" of cosmetic ingredients with a primary focus on assessing intrinsic hazards to both human health and ecosystem health. A third pillar evaluates the impact on the environment, with considerations for the upstream value chain. First, the origin of raw materials is considered (petrochemical, biological, or mixed), as well as geographic traceability and potential certifications. Second, greenhouse gas emissions are evaluated for Scopes 1 and 2 at the ingredient supplier level. The Green

Score is thus an appropriate tool for comparing ingredients and accounting for nuances and trade-offs across the different aspects of sustainability considered in the tool. However, the parameters accounting for the sustainability of ingredient manufacturing are limited, as the focus is mainly on the chemical components of the ingredients themselves rather than the transformation processes. In addition, although the Green Score is able to address mineral components, the latter are not differentiated from raw materials of biological origin in the scoring system, underlining that the primary focus on the origin criterion is the phasing out of petrochemical raw materials.

Both the Green Motion and the Green Score are thus rooted in Green Chemistry Principles, each with different strategies and focus points. Those quantitative tools are also efficient Key Performance Indicators for piloting the continuous improvement of many aspects of ingredient sustainability. Finally, taken together, both tools highlight the existence of many indicators or parameters to account for the origin, the manufacturing, and the end-of-life of cosmetic ingredients.

In parallel, the L'Oréal Group has also significantly contributed to advancing the sustainability of cosmetics across several axes [20]: promoting the use of renewable raw materials [21], developing or promoting environmentally friendly manufacturing processes [16,21], and reducing the environmental impact of ingredients and formulae [22–24]. Indeed, evaluating sustainability parameters in isolation remains a major challenge, as a truly sustainable profile can only be captured when these different dimensions are considered collectively. Assessing one dimension while neglecting the others risks creating environmental trade-offs, where a renewably sourced feedstock might mask a highly hazardous process or a persistent end-of-life profile. Consequently, although past efforts led to valuable methodologies spanning specific challenges of sustainability and Green Chemistry, a single, global framework overarching these various axes was still missing for cosmetic ingredients.

Therefore, there remains a critical need for an integrated tool capable of bridging all these complementary approaches. Such a framework should, first and foremost, be simple and rapid enough to serve as an agile, first-intention orientation lever rather than a high-granularity performance measurement system. Furthermore, it must be applicable to any type of cosmetic ingredient and systematically cover the three key stages of its life cycle: origin, manufacturing, and end-of-life. To achieve this, the tool needs to trace the entire manufacturing pathway while embedding key concepts to lower the environmental impact of the cosmetics industry, namely the implementation of Green Chemistry and the preservation of all natural resources.

To address this challenge, the L'Oréal Group set up the “Green Sciences” initiative in 2022 [20], within the frame of the L'Oréal For the Future program. This initiative was developed to support the eco-design of cosmetic ingredients and to open new fields of innovation while offering consumers safe and effective products. As a core operational deliverable of this initiative, L'Oréal has developed the “Green Sciences Index” (GSI). Rooted in a life-cycle perspective—considering the origin of feedstocks, their transformation, and the ingredients' end-of-life—the GSI aims to serve as an agile, first-intention pre-screening tool. It is specifically designed to help researchers and formulators easily operationalize ingredient selection by identifying compliant candidates early in the development process. The GSI especially emphasizes the role of ingredient manufacturing, drawing inspiration from Green Chemistry Principles and aiming to prevent the depletion of the planet's natural resources. This article aims to detail the underlying evaluation process, and its role as an accessible, orientation tool. The application of the tool is then illustrated with concrete examples of cosmetic ingredients.

2. The Green Sciences Index: A Framework Built on an Ingredient Life Cycle Perspective

The global sustainability of cosmetic product manufacturers relies heavily on their value chains, especially concerning the ingredients used in their products. Consequently, the Green Sciences Index was developed to include a comprehensive ingredient-level life-cycle approach. It can assess the sustainability of any cosmetic ingredient using standardized methods and integrating existing indicators whenever possible. The GSI is structured into three building blocks representing the main steps across the ingredient's life cycle: origin, manufacturing process, and end-of-life. Each block is assessed through various qualitative or quantitative parameters, grouped into seven themes illustrated in Figure 1. The construction of the GSI and the selection of the parameters are detailed hereafter.

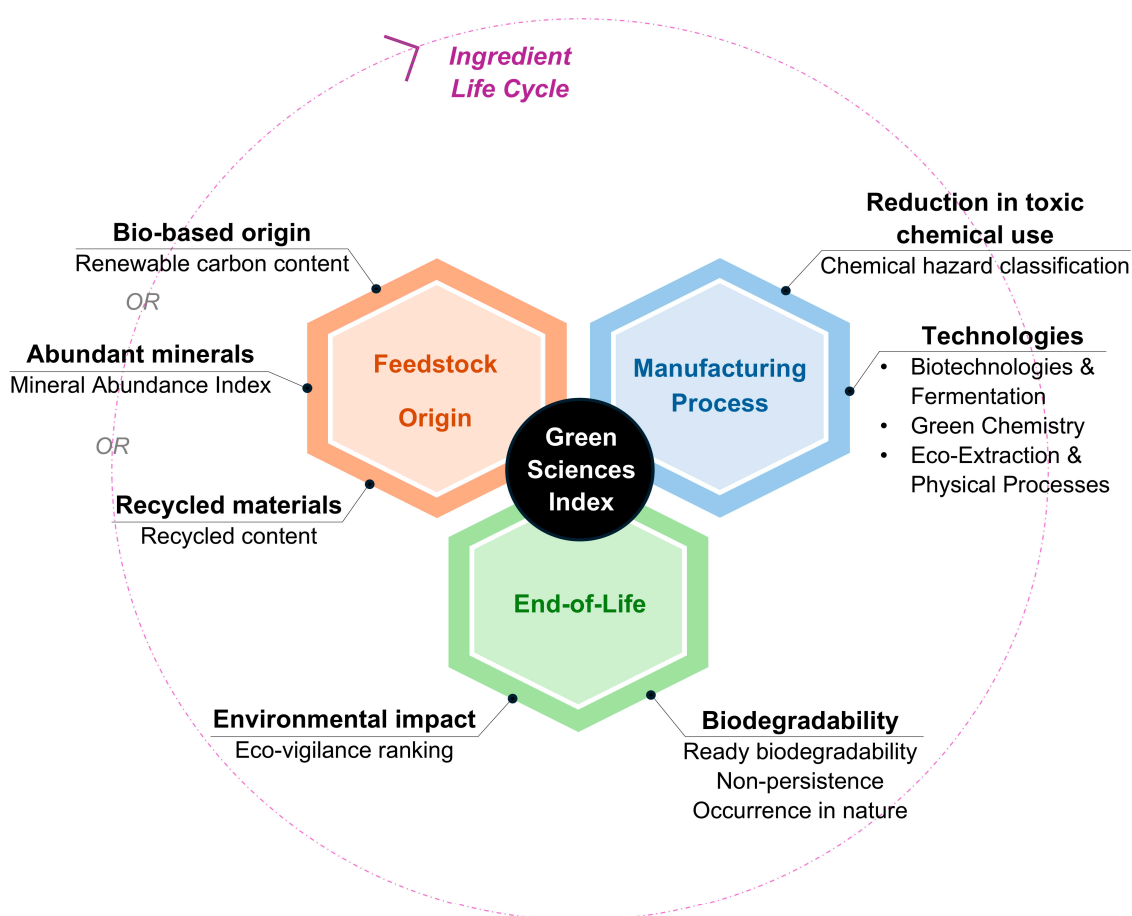


Figure 1. Global framework of the Green Sciences Index (GSI) from an ingredient life-cycle perspective. The diagram maps the GSI into three thematic blocks (Feedstock Origin, Manufacturing Process, and End-of-Life) across seven themes. These are evaluated using quantitative metrics (e.g., renewable carbon content, recycled content, and the Mineral Abundance Index), qualitative hazard and environmental criteria, and technological classifications, ensuring an assessment representative of the ingredient life cycle.

2.1. Origin of Ingredient Feedstocks

One key driver of the sustainability transition in the cosmetics industry is shifting the sourcing of ingredients toward more resilient and sustainable resources [25]. In the present framework, three possibilities are prioritized to fulfill the expectations on origin: an ingredient must either come from a bio-based source, an abundant mineral, or from recycled materials, as detailed in Table 1.

Table 1. Parameters and metrics used to assess the origin of cosmetic ingredients within the Green Sciences Index.

Conditions on Ingredient Origin		
Themes	Metrics/Criteria—Accepted If:	References
Bio-based origin <i>or</i>	>50% renewable carbon	ASTM D6866 [26]
Abundant minerals <i>or</i>	Abundant according to the Mineral Abundance Index	MAI [27]
Recycled materials	>50% carbon content from recycled sources <i>or</i> >50% by molecular weight or mass from recycled sources (for inorganics)	Internal definition based on [28]

2.1.1. Ingredients from Biomass

A significant challenge in the transition to sustainable cosmetic formulations is phasing out petrochemical ingredients and identifying plant-based sources as alternatives. To do so, robust metrics are required to steer and monitor this transition effectively. L'Oréal utilizes several methods to assess the renewability of ingredients, including ^{14}C analysis (ASTM D6866) [26], a method used in the USDA BioPreferred® Program [29]. This approach allows for accurate and reproducible assessment of the bio-based origin fraction in cosmetic ingredients. In addition, L'Oréal has defined an Origin Index to distinguish ingredients based on their origin [21]. In this framework, an ingredient is considered bio-based if its percentage of plant-origin carbon exceeds 50% of its total carbon content (Table 1). This is aligned with the standard ISO 16128 [30] defining a “derived natural ingredient” as being of greater than 50% natural origin; this includes biological and mineral origin as opposed to petrochemical, fossil origin. This threshold aims to select ingredients that are bio-based in the majority of their composition, for more sincerity toward formulators and consumers and to drive the shift from fossil to renewable ingredients.

The input data necessary to evaluate this criterion originates from ingredient manufacturers. The application of the above standards ensures a common framework reinforcing the reliability of data. Declarative %RC from suppliers can also be consolidated by cross-checking data on origin traceability or by analytical measurement as mentioned above. The wide adoption of this indicator across the cosmetic industry and its value chain also contributes to the large availability of data.

In addition, the shift toward bio-based ingredients generates a growing demand for biomass. This highlights the paramount importance of sustainable sourcing policies. It involves evaluating the holistic spectrum of environmental, social, and economic impacts of bio-based ingredients with a strong focus beyond tier-1 suppliers, extending to the farm or harvesting/collection area level. Therefore, sourcing ingredients responsibly is a must-have prerequisite to ensure that this shift is truly sustainable. Consequently, any ingredient that would not comply with L'Oréal's sustainable sourcing policy [31] does not qualify for the Green Sciences Index. Since sustainable sourcing is already assessed under a separate framework, it is not directly included in the GSI itself.

2.1.2. Ingredients from Mineral Feedstocks

The sustainable management of mineral ingredients, which cannot be considered renewable resources, presents another crucial challenge. To address this, a specific assessment methodology was developed in collaboration with the French Geological Survey (Bureau de Recherches Géologiques et Minières, BRGM). This first-of-its-kind methodology evaluates the abundance of non-energy mineral resources and defines a Mineral Abundance Index

(MAI) [27], which is a quantitative indicator from 0 (very scarce) to 100 (very abundant) aggregating 11 parameters. They not only account for the natural abundance of a mineral in the Earth's crust, but also its market availability and environmental impact, while integrating the influence of factors that could constrain (e.g., monopolies on resource exploitation or transformation) or promote future market changes (e.g., substitution of materials).

To facilitate the interpretation of the Mineral Abundance Index (MAI), the 0–100 scale is segmented into five qualitative classes: Very Scarce (0–20), Scarce (20–40), Moderate (40–60), Abundant (60–80), and Very Abundant (80–100) (Figure 2). While the MAI represents a continuous spectrum of geological and economic criteria without a single, static physical threshold, the 'Moderate' class (40–60) functions as a transitional evaluation zone. Within this intermediate range, variations in economic or geopolitical context can shift a mineral's overall availability. Consequently, instead of applying a rigid, universal cut-off score, the operational threshold is dynamically managed within this moderate zone to reflect these evolving economic and market realities. In practice, any mineral scoring within this intermediate corridor undergoes a more detailed risk analysis to validate its long-term supply security before being qualified through the GSI.

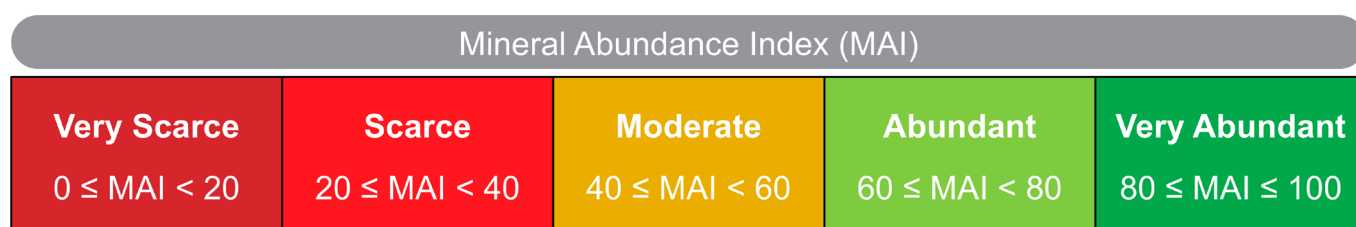


Figure 2. Qualitative segmentation of the Mineral Abundance Index (MAI) scale into progressive scarcity and abundance classes. This tiered classification provides an operational framework to evaluate ingredients of mineral origin without relying on a single, static physical threshold.

This metric is evaluated from a set of external data and methods published by independent institutions such as national geological surveys (BRGM, USGS. . .), academics (University of Yale), economic organizations (OECD, the World Bank. . .) (more details in [27]) or from open literature and market watch. The evaluation of the MAI is performed independently by the French Geological Survey (BRGM) and is made on a global market scale. In case data are insufficient or uncertain, the most stringent scoring is given in a worst-case approach, giving opportunities for improvements to the score in the future.

2.1.3. Ingredients from Recycled Materials

Relying solely on primary feedstocks can, however, bring economic, environmental, and technical limitations which can be overcome by using the principles of the circular economy. As highlighted by Loste et al. [32], the integration of such recycled feedstocks also directly supports the Principles of Green Chemistry—specifically Principle 1 (Waste Prevention) and Principle 7 (Use of Renewable Feedstocks)—by avoiding the extraction of virgin primary resources and minimizing waste generation throughout the value chain. The principles are recalled in Table S1 based on the work of Anastas et al. [10]. This synergistic relationship between Green Chemistry and circular economy principles represents a key driver for sustainable development.

Based on frameworks established by the Ellen MacArthur Foundation [28], L'Oréal has set up a framework and a definition for ingredients from recycled materials. Recycled materials are materials that have been processed and remanufactured from previously used products or waste. They originate from post-consumer waste (materials discarded by consumers after use, like used cooking oils or plastic bottles) or pre-consumer waste (materials generated during manufacturing processes, like scrap metal or CO₂).

Several key technical fields were specifically identified for sourcing recycled materials to produce cosmetic ingredients: waste from agriculture, food, and wood industries; plastic chemical recycling; Carbon Capture and Utilization (CCU); and industrial side-stream recycling.

For organic compounds, ingredients are considered recycled if over 50% of the ingredient's carbon content originates from recycled sources. For inorganic compounds, recycled ingredients are characterized by a recycled content over 50% by molecular weight or by mass. The 50% threshold serves as an incentive-based approach to foster progress across the supply chain. This choice aims to stimulate supplier innovation without imposing immediate technical barriers, while ensuring that the ingredient's composition remains meaningfully and predominantly recycled. In addition, for the sake of coherence and simplicity, this requirement is also aligned with the threshold set for the bio-based ingredients mentioned above.

The input data originates from the traceability of materials communicated by ingredient manufacturers, so the availability of data depends on the degree of transparency and supply chain complexity. However, circularity is by essence a collaborative work, necessitating that transparency between stakeholders be efficiently deployed, which is motivated by the benefits in procurement resilience and in innovation bringing competitive advantage.

2.2. Sustainable Ingredient Manufacturing

The manufacturing stage, which involves transforming raw materials into finished cosmetic ingredients, is another critical element in the life cycle of an ingredient.

2.2.1. Green Chemistry Principles Across the Whole Ingredient Manufacturing Pathway

The aim of the GSI is to promote transformation processes that are increasingly in line with the Green Chemistry Principles [10] (Table S1), minimizing or eliminating the use and generation of hazardous substances.

However, addressing all twelve Principles of Green Chemistry at once is a challenge, as it requires actions and data from actors upstream in the supply chain. Thus, the Green Sciences concept focuses at this stage on aspects directly related to manufacturing conditions, corresponding to Green Chemistry Principles 3, 4, 5 and 12 (Table S1). In the Green Sciences framework, this means tracing the manufacturing pathway starting from primary feedstocks and considering the toxicity of all materials used and generated along the whole value chain: reactants, isolated intermediates, solvents, catalysts, products and by-products. The retained criterion is to avoid substances presenting acute toxicity (category 1 and 2) or proven or suspected carcinogenicity, mutagenicity, or repro-toxicity. These hazards are defined by the Globally Harmonized System (GHS) [33] and included in the European Regulation on the Classification, Labelling and Packaging of chemical substances and mixtures (CLP) used as a referential [34] (Table 2). This involves ingredient manufacturer collaboration and transparency to declare their manufacturing pathways and the use of the European Chemicals Agency (ECHA) data as a reference for chemical hazards. In case no hazards are reported by ECHA, alternative sources may be used case by case (e.g., available safety data sheets). The reliability of declarative data is verified by confrontation with the existing literature in case of any doubt or missing information. A worst-case scenario is applied when the data quality or completeness is not ensured. In addition, and specifically for solvents, the work by Prat et al. [35] was used as a reference to evaluate the sustainability of solvents in the present Green Sciences Index. This approach on chemical toxicity encourages stakeholders to explore alternative manufacturing pathways and reaction conditions that avoid the use of hazardous substances.

Table 2. Parameters and metrics used to assess the manufacturing of cosmetic ingredients within the Green Sciences Index.

Conditions on Ingredient Manufacturing		
Themes	Metrics/Criteria—Accepted If:	References
Reduction in toxic chemical use	Neither acutely toxic nor CMR chemical inputs/outputs (reactants, isolated intermediates, solvents, processing aids, products, and by-products) based on the following classifications: H300-H310-H330; H340-H350(i)-H360(F, D, FD, Fd, Df); H341-H351-H361(f, d, fd).	CLP [34]

2.2.2. Fostering Cutting-Edge Technologies

In addition, the Green Sciences initiative identifies three key transformation pillars for ingredient manufacturing: “Biotechnology & Fermentation”, “Eco-extraction & Physical Processes” and “Green Chemistry” (meaning chemical synthesis designed according to Green Chemistry Principles) (Table 3).

Table 3. Manufacturing technologies categorized within the Green Sciences Index.

Provided That Criteria for Origin, Reduction in Toxic Chemical Use and End-of-Life Are Satisfied:	
Biotechnology and Fermentation	Biomanufacturing such as microbial fermentation, in vitro cell cultivation, etc.
Green Chemistry	For chemical synthesis processes
Eco-Extraction and Physical Processes	For physical processing only (without any (bio)chemical transformation of natural resources)

“Biotechnology” terminology is based on the OECD definition: “the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services” [36]. Biotechnologies include synthetic biology (the design and construction of novel biological entities) or biomanufacturing (the large-scale production of products using engineered biological systems). Biomanufacturing such as fermentation, cell culture, and cell-free processes (lysates, enzymes) with the help of strain, molecular, and metabolic engineering is of high interest to obtain sustainable and innovative ingredients.

“Eco-Extraction & Physical Processes” encompass a range of techniques that avoid any chemical transformation of natural resources. These include innovative methods like microwave-assisted and supercritical fluid extraction, or methods like solvent extraction or maceration using milder solvents. Beyond these, fundamental physical processes such as steam distillation, drying, crushing, grinding, and filtration are also explored and refined for their inherent advantages in isolating valuable components.

“Green Chemistry” syntheses encompass reactions involving the chemical conversion of natural resources, adhering to the manufacturing conditions mentioned above.

These three transformation pillars identified in the “technology” section of the GSI are not only constituents of this index, but also an output of the evaluation. Indeed, the GSI aims both to pre-screen ingredients and to shed light on specific manufacturing technologies valuable for the eco-design of cosmetic ingredients.

2.3. Assessing and Monitoring the End-of-Life of Ingredients

The final stage in the life cycle of a cosmetic ingredient is its end-of-life, corresponding to its fate after consumer use. The Green Sciences approach integrates two key indicators associated with the environmental fate or impact of ingredients at the end-of-life stage of cosmetic products (Table 4):

(i) Biodegradability

Table 4. Parameters and metrics used to assess the end-of-life of cosmetic ingredients within the Green Sciences Index.

Conditions on Ingredient End-of-Life		
Themes	Metrics/Criteria—Accepted If:	References
Biodegradability	Readily biodegradable <i>Otherwise</i> , non-persistent <i>Or</i> occurring in nature	OECD 301 and 310 [37,38] CLP [39] Naturalness guidelines [21,30]
and		
Environmental impact	Rated as Favorable or Reserved in Eco-vigilance ranking based on: Biodegradation, Persistence (P), Bioaccumulation potential (B), Ecotoxicity (T), Mobility (M), Endocrine Disruption for the Environment (ED Envnt), and GHS/CLP hazard classifications	CLP [39] GHS [33]

Three properties are accepted to demonstrate appropriate biodegradation capacity in the environment: Ready biodegradability, non-persistence, or occurrence in nature.

Ready biodegradability is assessed as a priority, according to OECD 301 and 310 test guidelines [37,38] or equivalent (e.g., ISO) test guidelines, as it indicates an ingredient's ability to rapidly and completely degrade in various environmental compartments. An ingredient is considered readily biodegradable if its biodegradation reaches a specified threshold (60% or 70%) within the 28-day period of the test.

Otherwise, non-persistence is evaluated according to the methodology for the regulatory classification, labeling and packaging (CLP) of substances and mixtures in the European Union [39]. Non-persistence is the capacity of organic ingredients to be degraded by biotic (biodegradation) and/or abiotic (physicochemical) degradation in the different environmental compartments in a short enough period, without generating persistent organic by-products, thus preventing potential long-term effects. This capacity for non-persistence in the environment is measured by ready biodegradation tests (a readily biodegradable ingredient is in fact non-persistent) or other screening tests (such as extended ready or inherent biodegradation tests), or simulation tests aiming to determine the half-life in different environmental compartments and quantify possible organic persistent by-products, following appropriate OECD or equivalent (e.g., ISO) guidelines, as detailed in the regulatory CLP methodology [39].

Ingredients occurring in nature are considered not to be of concern with regard to biodegradability or persistence in the environment. The natural occurrence property of ingredients is indirectly estimated by using the classification “natural” from the L'Oréal naturalness methodology [21], or “from natural origin” in specific cases (e.g., a plant cell extract not chemically transformed but cultivated from glucose; glucose itself is naturally occurring and obtained from chemical hydrolysis). This naturalness framework is based on the ISO 16128-1:2016 standard on technical definitions and criteria for natural and organic cosmetic ingredients [30].

(ii) Eco-vigilance ranking

Eco-vigilance ranking is an internal ranking system based on six key environmental parameters (biodegradation, Persistence (P), Bioaccumulation potential (B), ecoToxicity (T), Mobility (M) through soil and groundwater, and Endocrine Disruption for the Environment (ED Envnt)) and the chemical hazard classifications, assessed following the regulatory CLP methodology and the United Nations GHS hazard classifications [33,34]. It categorizes

ingredients into four levels: Favorable, Reserved, Unfavorable, and Blocking. The criteria associated with the four levels of eco-vigilance are described in Figure 3.

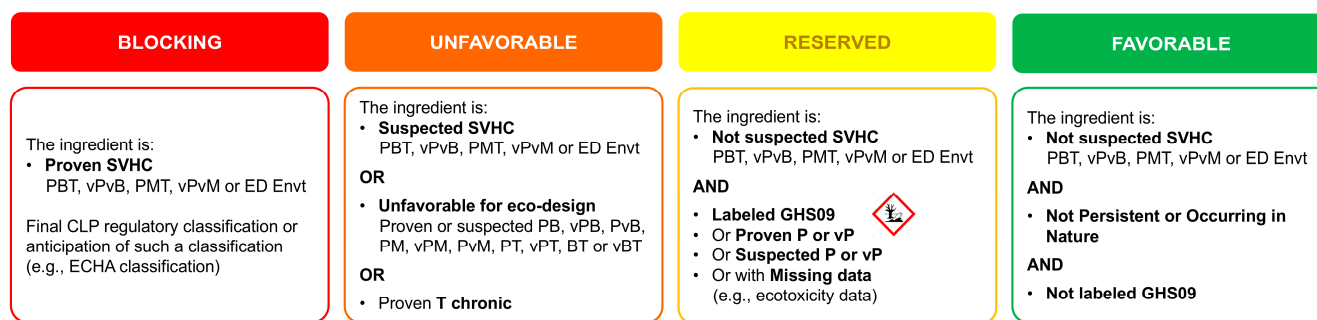


Figure 3. Details of the Eco-vigilance ranking of cosmetic ingredients used to assess the end-of-life impact within the Green Sciences Index. Note: All abbreviations are defined in the Abbreviations Section. Additional definitions are provided as follows: (i) SVHC: An ingredient considered a Substance of Very High Concern—i.e., PBT, vPvB, PMT, vPvM, or ED Envt—according to the CLP hazard classifications. (ii) Unfavorable for eco-design: An ingredient considered as PB, vPB, PvB, PM, vPM, PvM, PT, vPT, BT, or vBT—according to the CLP hazard classifications. (iii) T chronic: An ingredient proven to be classified as T according to a chronic ecotoxicity test. (iv) GHS09: Labeling (pictogram) for an ingredient classified under H400, H410, or H411—according to the GHS/CLP hazard classifications.

This ranking system is used to promote the use of readily biodegradable, or non-persistent, ingredients with a favorable (green) eco-vigilance profile or possibly ingredients with a reserved (yellow) eco-vigilance profile, while discouraging or eliminating those with an unfavorable (orange) or blocking (red) profile in line with the chemical CLP and GHS hazard classifications, mitigating potential environmental impacts associated with the disposal of cosmetic products.

External data sources (e.g., databases from the European Chemicals Agency, eChemPortal, or data shared by ingredient suppliers) are preferred to internally generated data (e.g., test data or data derived from modeling). The reliability of the data used to evaluate the environmental fate or impact of ingredients at the end-of-life stage of cosmetic products is systematically verified to ensure the robustness and reproducibility of the results.

2.4. Aggregation of Parameters and Green Sciences Index Output

Given the multitude of parameters and concepts embraced within L'Oréal's "Green Sciences" initiative, a holistic and simplified approach is essential for effective implementation. This is the driving force behind the development of the "Green Sciences Index", a binary assessment tool designed to aggregate these various parameters and provide a comprehensive, easily interpretable view of an ingredient's sustainability profile across its entire life cycle (Figure 1). According to this framework, a cosmetic ingredient has a positive "Green Sciences Index" if it meets all the included conditions:

- Sourced from nature, (considering bio-based feedstocks or abundant minerals) or from recycled materials.
- Manufactured with processes exempted from acutely toxic (category 1 and 2), carcinogenic, mutagenic, or reprotoxic chemicals.
- Biodegradable while also having a favorable or possibly reserved Eco-vigilance ranking.

If one or several of the above conditions are unmet, the "Green Sciences Index" is considered negative.

If the above criteria are met, the GSI is considered positive; depending on the manufacturing process used, the ingredient is then categorized as originating from "Biotechnology & Fermentation", "Eco-extraction & Physical Processes", or "Green Chemistry" syntheses.

As the GSI serves as a pre-screening tool to select ingredients, the focus is on the compliance to all selected criteria without hierarchizing. All the criteria thus have the same weight in the GSI.

3. The Green Sciences Index: A New Approach to Support Innovation in “Green-by-Design” Ingredients

The Green Sciences Index was widely deployed across L’Oréal’s cosmetic ingredients portfolio. Hereafter, it is illustrated by different use cases demonstrating the applicability of the tool (Table 5). Nevertheless, the GSI is applicable to any type of ingredient, regardless of its nature or its function in cosmetic formulations.

Table 5. Application of the Green Sciences Index to case studies, highlighting the pass/fail system on criteria and the dual conclusion: overall compliance to criteria (positive/negative) and manufacturing technology categorization.

	Peony Cell Extract	Lauryl Laurate	Rose Stem Extract	Glycine
Feedstock origin	Bio-based (plant) %RC = 100% <i>Pass</i>	Bio-based (plant) %RC = 100% <i>Pass</i>	- Bio-based (plant) %RC = 100% - From recycled materials (100%) <i>Pass</i>	Petrochemical <i>Fail</i>
Manufacturing conditions	Absence of chemicals with acute/CMR toxicity <i>Pass</i>	Absence of chemicals with acute/CMR toxicity <i>Pass</i>	Absence of chemicals with acute/CMR toxicity <i>Pass</i>	- Formaldehyde (H350, H330) - Hydrogen cyanide (H330) <i>Fail</i>
Ingredient end-of-life	Biodegradability: - Propanediol: Readily Biodegradable - Peony cells: Naturally occurring <i>Pass</i> Eco-vigilance: Favorable <i>Pass</i>	Biodegradability: Readily Biodegradable <i>Pass</i> Eco-vigilance: Favorable <i>Pass</i>	Biodegradability: Naturally occurring <i>Pass</i> Eco-vigilance: Favorable <i>Pass</i>	Biodegradability: Readily Biodegradable <i>Pass</i> Eco-vigilance: Favorable <i>Pass</i>
Conclusion	Positive Biotechnology and Fermentation	Positive Green Chemistry	Positive Eco-Extraction and Physical Processes	Negative N/A

3.1. Peony Cell Extract Suspended in Propanediol

Peony cell extract, rich in polyphenols, possesses antioxidant and anti-inflammatory properties and reinforces the barrier function [40]. This ingredient illustrates a positive

Green Sciences Index profile, aligning with comprehensive sustainability criteria across its life cycle. First, it is derived from 100% plant material, specifically dedifferentiated native cells of French Paeonia buds. Moreover, the source of glucose used for cultivation comes from French beetroots. The cells are suspended in propanediol, which is sourced from a bio-based feedstock. This cosmetic raw material (peony cell extract in propanediol) thus has a renewable carbon percentage of 100%. This validates the first aspect of the GSI regarding origin.

Second, the manufacturing process, illustrated in Figure 4, leverages advanced biotechnologies. This includes *in vitro* cell cultivation, shoot proliferation using coconut water, and thermal elicitation, followed by cell suspension in propanediol. Propanediol itself is obtained from bacterial fermentation of glycerin. The extract is then filtered, disrupted, and clarified. The manufacturing process does not use any acutely toxic (category 1 and 2) or CMR chemicals across the overall value chain from primary feedstocks to the final cosmetic extract. The second aspect of the GSI, on the manufacturing process, is thus validated as well, and this cosmetic raw material is then categorized as manufactured by “Biotechnology & Fermentation”.

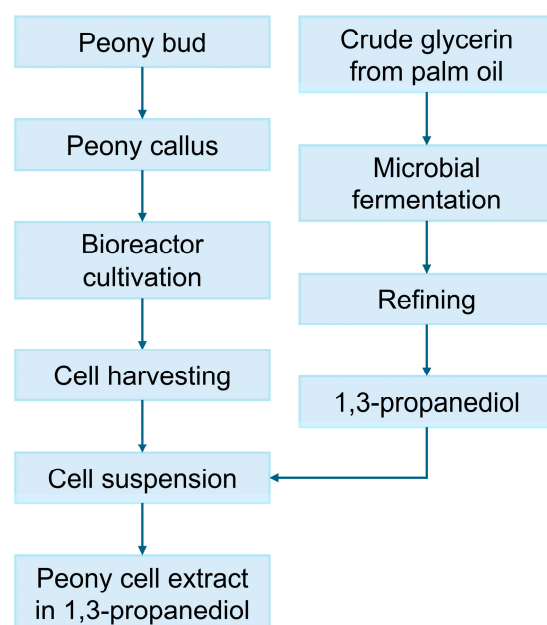


Figure 4. Schematic flowchart of the manufacturing process of peony cell extract suspended in 1,3-propanediol.

Third, regarding the end-of-life profile: the OECD 301 test confirmed the ready biodegradability of propanediol, and the peony cell extract is composed of naturally occurring substances as it is obtained from natural (non-genetically modified) cells and the extract was not chemically modified. Therefore, the extract is considered not to be of concern with regard to biodegradability or persistence in the environment. Furthermore, the extract is non-ecotoxic based on aquatic tests. As this ingredient mixture has no environmental hazard classification of concern (see Figure 3), it is thus qualified with a “Favorable” eco-vigilance ranking. The third aspect of the GSI is thus validated.

With all conditions met, the Green Sciences Index of this peony cell extract is consequently positive. Rich in valuable compounds, this extract not only offers beneficial properties but also fully embodies the principles of Green Sciences.

3.2. Lauryl Laurate

Lauryl laurate is another illustration of a positive Green Sciences profile. Used as a fatty ester to substitute silicones in formulas, lauryl laurate provides light and non-sticky

emollient properties. Its origin is entirely derived from a plant feedstock, with a %RC of 100%.

The manufacturing process of lauryl laurate is a prime example of “Green Chemistry” synthesis, illustrated in Figure 5. First, lauric acid and lauryl alcohol are obtained without the use of acutely toxic or CMR chemicals. The key synthesis step involves bio-catalyzed esterification utilizing lipase immobilized on resin, vacuum heating, and subsequent filtration. Notably, the process requires no purification step, and the enzyme used is reusable, significantly minimizing waste and energy consumption. The biocatalysis leads to a shorter reaction time, atom economy, and a better yield compared to classical esterification.

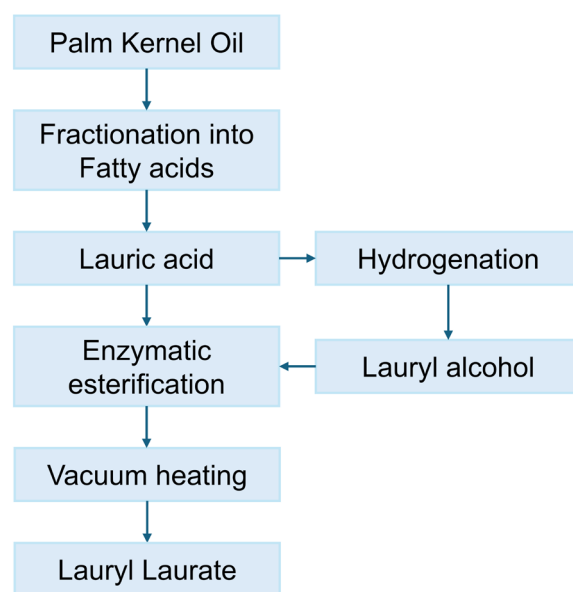


Figure 5. Schematic flowchart of the manufacturing process of lauryl laurate.

From an end-of-life perspective, lauryl laurate exhibits ready biodegradability in OECD 301 tests. Aquatic ecotoxicity tests performed on a structurally similar ingredient confirm its non-ecotoxicity and support its minimal environmental impact. Therefore, it conforms to the conditions necessary to achieve a “Favorable” eco-vigilance ranking.

These combined attributes underscore lauryl laurate’s alignment with Green Sciences principles, making it a sustainable choice for cosmetic formulations.

3.3. Rose Stem Extract

The rose stem extract represents another illustration of an ingredient with a positive Green Sciences Index profile. This rose stem extract is used as an active ingredient in formulas, conferring antioxidant properties mainly due to the high content of polyphenols. Its origin is 100% plant-based (%RC = 100%), derived from *Rosa centifolia* cultivated in France. Moreover, this extract is produced from rose bush stalks, leaves, and suckers—parts of the rose plant that were initially not exploited and were considered waste in agriculture. This ingredient is thus both bio-based and from recycled materials (100% of the composition).

The manufacturing process utilizes “Eco-Extraction and Physical Processes” (see Figure 6): a hydroalcoholic extraction conducted at temperatures below 100 °C for a short duration, followed by efficient separation of solid debris through centrifugation, filtration, and atomization [41]. These steps ensure that harsh chemicals are avoided. Furthermore, the extract demonstrates favorable end-of-life criteria as it is composed of naturally occurring substances, was not chemically modified non-persistence, and is non-ecotoxic in aquatic tests, ensuring a “Favorable” eco-vigilance ranking (cf. Figure 3).

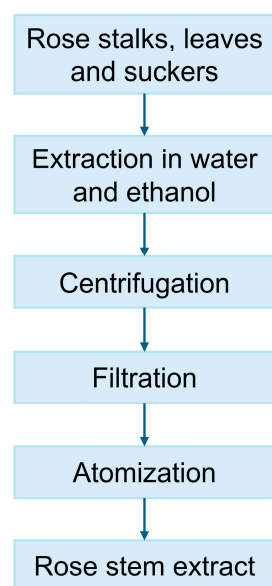


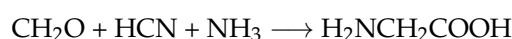
Figure 6. Schematic flowchart of the manufacturing process of a rose stem extract.

Rich in polyphenols, this rose stem extract not only delivers desired properties but also embodies the holistic sustainability approach advocated by the Green Sciences Index.

3.4. Glycine

Glycine is the simplest amino acid, naturally present in skin peptides. The glycine produced so far on an industrial scale and available on the market is of petrochemical origin [42]. Indeed, the production cost is low compared to alternative methods because of the simple, non-chiral structure of glycine. Some alternative solutions are being developed but have not yet reached a viable industrial scale. In consequence, the GSI criterion on the origin is not respected (%RC = 0%).

Glycine can be produced in the Strecker process [42,43] by reaction between formaldehyde, hydrogen cyanide and ammonia, as illustrated by the simplified scheme below:



This reaction involves chemicals with a problematic toxicity: formaldehyde is a carcinogenic 1B (H350) and acutely toxic (H330) substance, while hydrogen cyanide is also acutely toxic (H330). Therefore, the use of such chemicals is not aligned with the GSI criterion on the manufacturing process either.

Finally, glycine presents a favorable end-of-life profile; it is readily biodegradable in OECD 301 tests and not ecotoxic, leading to a “Favorable” eco-vigilance ranking.

The traditional sourcing and manufacturing of glycine are thus not compliant with the GSI criteria, rendering a negative conclusion, as traditional glycine is obviously not aligned with the Principles of Green Chemistry. In this case, no manufacturing technology is highlighted among the defined categories.

4. Discussion and Perspectives

4.1. The GSI as a Decision-Support Tool

The GSI aims to serve as an orientation tool for the rapid pre-screening of cosmetic ingredients, supporting researchers and formulators—regardless of their level of expertise—in quickly selecting the most sustainable options. It was designed specifically for ease of use and seamless operationalization. The resulting selection process identifies compliant ingredients based on a limited set of input data, making it a qualitative rather

than a quantitative analysis. After selecting appropriate ingredients, their environmental impacts can be further investigated and refined using LCA methods. This workflow optimizes analytical resources by prioritizing intensive LCAs on pre-selected ingredients. The GSI is thus intrinsically designed to be complementary to LCA. Moreover, the index delivers a dual-output conclusion: a binary assessment of criteria compliance and a prominent characterization of the green manufacturing technology employed.

Table 6 proposes a methodological comparison of several existing sustainability tools within the cosmetic industry with the Green Sciences Index. This highlights that each tool is designed for specific scopes, audiences, and objectives, making them highly complementary.

Table 6. Comparative methodological analysis of key sustainability tools within the cosmetics industry (Green Motion by Mane [18], Green Score by the Estée Lauder Companies [19], the proposed Green Sciences Index, and LCA-based tools).

	Green Motion	Green Score	Green Sciences Index	LCA-Based Tools (e.g., SPOT, EBS)
Primary objective	Sustainable process optimization	Ingredient hazard and sustainable footprint profiling	Agile eco-design orientation	Detailed environmental footprinting
Primary target users	Process chemists	Product developers and formulators	Product developers and formulators	LCA and sustainability experts
Applicability scope	Flavor and fragrance ingredients	Mainly organic chemical components	All types of cosmetic ingredients	Versatile: ingredients, formulas, products
Lifecycle boundaries	Gate-to-gate	Cradle-to-gate perspective	Cradle-to-grave perspective	Versatile (e.g., cradle-to-grave, cradle-to-gate)
Data input requirements	Moderate (principally quantitative)	Moderate (hybrid qualitative and quantitative)	Moderate (hybrid qualitative and quantitative)	Intensive (highly quantitative)
Resource preservation metrics	Renewable raw material origin and compliance to “natural”	Renewable raw material origin, sourcing traceability and certifications	Integrated (bio-based, recycling and Mineral Abundance Index)	Indirect (abiotic resource depletion impact categories)
Manufacturing process evaluation	Final reaction step (gate-to-gate parameters)	Indirectly (via cradle-to-gate GHG emissions)	Entire pathway (from feedstocks) + technology classification	Entire supply chain (modeled via physical flows)
Decision-making logic	Quantitative score (0–100)	Quantitative score (0–100)	Binary (Pass/Fail)	Quantitative score or rating

Green Motion and the Green Score are appropriate indicators of chemical hazard, either on the final ingredients or on their manufacturing processes. Green Motion is also particularly adapted for synthesis efficiency. However, they do not capture the type of manufacturing process involved. On the contrary, the GSI not only accounts for chemical hazards but also highlights the manufacturing technology, providing synthetic data on the manufacturing for product developers, who are more and more sensitive to this topic. In addition, the GSI integrates the upstream manufacturing pathway into its hazard analysis, which represents a novel approach in the cosmetics industry to our knowledge.

In addition, regarding feedstock-related aspects, existing tools are often limited to a distinction between renewable and petrochemical carbon, which is only adapted for organic ingredients. In a highly novel approach for the cosmetics industry, the GSI is the only

sustainability tool to systematically integrate mineral abundance for inorganic ingredients (e.g., pigments, fillers, and UV filters), thereby proposing a comprehensive approach to covering the full diversity of cosmetic ingredients. Furthermore, with the emergence of increasingly diverse solutions coming from the circular economy and recycling, the integration of a specific metric introduces an additional lever. These three criteria thus constitute a coherent approach aimed at preserving the planet's natural resources to prevent their depletion.

Ultimately, LCA-based tools (such as SPOT or EBS) have indisputable value for regulatory reporting and comprehensive footprinting, but their application remains highly challenging during the early stages of ingredient research. Quantitative LCAs are heavily data-intensive, require extensive inventory data that are often unavailable in early R&I phases, and demand substantial time and expertise. Furthermore, standard LCAs typically do not account for the toxicity of process-specific chemical inputs (such as solvents) or the geopolitical scarcity of mineral resources.

The GSI solves this fundamental limitation by acting as an agile, qualitative gatekeeper. Instead of calculating quantitative impacts, it verifies the compliance of ingredients against a strict baseline of environmental and safety criteria. The GSI thus works in synergy with—rather than substituting—highly granular quantitative tools. This complementary relationship operates across three main interfaces:

- **Feedstock Sourcing:** The GSI primarily addresses the qualitative preservation of natural resources to avoid their depletion, while LCAs subsequently quantify the detailed environmental impacts (such as land use change or water stress) of that sourcing.
- **Ingredient Manufacturing:** The GSI prioritizes the strict limitation of hazardous chemical use and generation, actively encouraging Biotechnologies, Green Chemistry, and Eco-extraction processes. LCAs then assess the broader, cumulative environmental footprints associated with these manufacturing processes.
- **End-of-Life:** Both tools address the environmental fate of ingredients, with the GSI focusing on ready biodegradability and eco-vigilance ranking, while LCAs model the ultimate physical emissions and long-term compartment impacts.

Ultimately, by filtering out non-compliant candidates early in the development cycle, the GSI avoids the waste of analytical resources and ensures that intensive, quantitative LCAs are prioritized on the most sustainable and promising ingredients.

4.2. Rationalizing the GSI Design Choices

The Green Sciences Index integrates criteria spanning different steps of the ingredient life cycle. The choice of these steps was motivated by their contribution to the overall environmental impact of cosmetic formulas. Indeed, the GSI covers three out of four stages of a formula's life cycle: the ingredient origin, manufacturing, and end-of-life, which all have indirect impacts from the point of view of a cosmetic product manufacturer such as L'Oréal. The fourth stage, focusing on the product use phase by consumers, can be addressed through the formulation of the product, rendering it directly actionable by a cosmetic product manufacturer. Consequently, the criteria and input data considered in the GSI represent strategic stakes for the L'Oréal Group to achieve its sustainability transformation. For this reason, many of the criteria are historical indicators, which used to be managed separately as they also serve regulatory or corporate reporting purposes. However, from the standpoint of steering the sustainability transformation, there was a need for an aggregated management of these indicators to account for these different aspects of ingredient sustainability simultaneously. For example, the GSI ensures that a bio-based ingredient is also biodegradable and manufactured in conditions limiting hazards for health.

Furthermore, the binary conclusion of the GSI provides the simplicity required for a pre-screening, orientation tool, and is adapted to the aim of verifying the alignment with a limited number of sustainability expectations. Admittedly, this approach smooths over the nuances of the environmental performance of ingredients across the various dimensions of sustainability, as the aim is not to compare quantified impacts but to pre-screen and identify the best candidates. The simplicity of the approach is thus adapted to a first intention orientation tool. In addition, the binarity introduces a non-compensation principle: criteria improving sustainability cannot compensate for unfavorable ones. This ensures that only ingredients respecting all the minimum conditions are categorized as “best in class” through the GSI.

Once the GSI confirms that these conditions are met through a “positive” conclusion, it delivers its second output: it sheds light on the typology of the sustainable manufacturing process, categorizing it into one of the three technology pillars: “Biotechnology & Fermentation”, “Eco-extraction and Physical Processes” or synthesis by “Green Chemistry”. The categorization rationale is twofold. This framing echoes the current main areas of innovation in the production of cosmetic ingredients. The typology also follows a simple logic: technologies are distinguished between physical processing (“Eco-extraction and Physical Processes”), chemical synthesis without using living organisms (“Green Chemistry”) and synthesis processes using living organisms (“Biotechnology and Fermentation”).

The concept of “Green Sciences” is strongly inspired by the 12 Principles of Green Chemistry elaborated by P. Anastas et al. [10,11] In particular, the approach of utilizing renewable feedstocks rather than fossil ones—a core aspect of Green Chemistry—was initiated decades ago [16] and is an essential element of the Green Sciences Index. Similarly, ensuring chemicals do not persist in the environment is addressed through the biodegradability of cosmetic ingredients, constituting another major element of the approach. The imperative to reduce cosmetic ingredient toxicity to health and the environment is also of utmost importance, a concern considered through the Eco-vigilance ranking. Furthermore, the promotion of circular sourcing serves as a foundational approach to minimize waste, residues, and by-products while optimizing material utilization.

On the other hand, integrating the stakes related to the manufacturing of cosmetic ingredients among the Principles of Green Chemistry is more complex. Indeed, their exhaustive implementation requires accessing and processing substantial amounts of data, which can be proprietary information regarding the know-how of ingredient manufacturers. Ingredient value chains can also be intricate and difficult to map. As a first step, therefore, the Green Sciences Index utilizes qualitative data from manufacturers. The present approach is a preliminary proposal addressing several manufacturing-related Principles of Green Chemistry, though not exhaustively. Primarily, the reduction in hazards and toxicity of chemical inputs and outputs is integrated, especially for solvents and auxiliaries. The use of catalytic reactions is also considered and inherently favored, through manufacturing conditions that employ (bio)catalysts in “Green Chemistry” and “Biotechnology & Fermentation” processes. As the GSI functions as a binary and qualitative tool to remain agile and easy to use, some Principles of Green Chemistry involving quantitative aspects are not covered so far (e.g., energy consumption). This reflects a progressive integration linked to the existing complexity rather than purposeful prioritization. Additional aspects not currently covered will be discussed further as perspectives.

4.3. Methodological Rigor and Integrity

The GSI extensively evaluates the manufacturing pathways from the primary resources to the final ingredients. A large portion of the input data is provided by ingredient manufacturers across the value chain. Ensuring the availability and reliability of these

declarative data is thus essential. In an industrial context, this may be challenging due to supply chain complexity or data confidentiality. To optimize the reliability of declarative data, different measures are applied. First, many criteria of the GSI are framed by external standards or reference frameworks (e.g., from the ISO, the OECD, and REACH) or evaluated using data from third-party institutions (e.g., ECHA, BRGM), ensuring a common framework and independent validation. Declarative data can also be cross-checked, either by verifying the coherence of all provided data, through analytical measurements or via available literature and scientific watch. If any issue regarding the reliability or availability of data remains, a worst-case approach is adopted by assigning a negative conclusion for uncertain or missing information. This ensures sincerity in the final output and promotes greater transparency across the supply chain.

In addition, the GSI can be applied to any type of cosmetic ingredient. First, it integrates criteria adapted to both organic (i.e., carbon-based) and inorganic ingredients, either by being independent from the nature of the ingredient (e.g., the toxicity criteria), or by being specific. This is particularly notable for the criteria on the origin, with the introduction of the MAI dedicated to mineral ingredients, a unique approach in cosmetics to our knowledge. As for other criteria, the cosmetic ingredient type does not restrict their use and application. As discussed above, the applicability is constrained by the availability of data, and is dependent on the supply chain rather than on the nature of the ingredient.

4.4. Navigating Boundaries: Challenges and Future Evolutionary Paths

In its current form, the GSI is primarily a qualitative indicator with a binary nature for the sake of clarity and simplicity, which are necessary for an ingredient pre-screening tool. However, it does not reflect the nuances of the environmental performance of cosmetic ingredients that would otherwise allow an efficient comparison between ingredients. Transitioning to other systems could introduce more gradations. For example, a semi-quantitative scoring system would make it possible to continue using both qualitative and quantitative criteria, assigning them numerical weights and scores, and aggregating them into a final continuous score. This would allow formulators to benchmark ingredients more finely. Alternatively, a tiered scoring system could introduce a multi-level classification, providing more nuance without increasing data entry complexity.

Such alternative systems could also be appropriate from the perspective of adding supplementary parameters in the GSI evaluation to account for Principles of Green Chemistry more comprehensively. Indeed, the current binary system is adapted to the limited number of criteria but would not be appropriate with increasing data entry.

In an ambition for continuous improvement, future developments of the Green Sciences Index could account for the evolution and maturity of the industry in deploying manufacturing practices increasingly aligned with Green Chemistry. Thus, as additional perspectives, several other aspects could potentially be integrated to cover the Principles of Green Chemistry more exhaustively (Table S1). Most of the gaps to be filled relate to quantitative aspects. For instance, the following stakes could be worth considering:

- (a) The optimization of material consumption and atom economy, together with the reduction in manufacturing steps and the number of derivatives;
- (b) The reduction in waste quantity, toxicity, and environmental impact;
- (c) The reduction in water consumption and its impact on water quality;
- (d) The reduction in energy consumption and promotion of renewable sources;
- (e) The promotion of milder manufacturing conditions (e.g., temperature, pressure, etc.) and the reduction in physical hazards (e.g., flammability, explosiveness, etc.).

Finally, the GSI was designed from the perspective of cosmetic product manufacturers, but it is not intended to remain a closed internal tool. On the contrary, we actively invite

other actors in the cosmetics and fine chemicals sectors to adopt, test, and challenge this approach. It is through such collective implementation, shared industrial feedback, and external peer validation that the framework will continuously gain robustness, scientific legitimacy, and ultimately contribute to the global transition toward sustainable eco-design.

5. Conclusions

In retrospect, L'Oréal's "Green Sciences" initiative, first conceptualized in 2022, faced the critical challenge of translating key sustainability parameters into a streamlined and accessible evaluation process for practical implementation. The "Green Sciences Index" (GSI) provides this solution. Rather than acting as a highly granular quantitative Key Performance Indicator (KPI) or substituting for detailed Life Cycle Assessments (LCAs), this agile, first-intention orientation tool consolidates pre-existing qualitative and semi-quantitative metrics into a binary, non-compensatory framework. This allows for a rapid screening of an ingredient's compliance against a strict baseline of environmental and safety criteria across three key stages of its life cycle: feedstock origin, manufacturing process, and end-of-life.

It especially emphasizes ingredient manufacturing by systematically tracing the upstream transformation pathways, an aspect that is often only partially or indirectly addressed in existing sustainability tools for the cosmetics industry. By serving as an early-stage gatekeeper, the GSI optimizes analytical resources, ensuring that highly demanding, quantitative LCAs are prioritized on the most promising and compliant candidates.

Concurrently, the GSI is a driver for innovation and progress. This approach guides eco-design choices by highlighting the specific green manufacturing technologies employed (such as Biotechnology, Green Chemistry, or Eco-extraction) while clearly identifying areas for improvement. This index also serves a dual purpose: encouraging actions to align with established sustainability targets and promoting innovative solutions to be deployed more widely. This makes it a valuable tool to guide research and development efforts and to facilitate decision-making, ultimately contributing to the development of more sustainable cosmetic products.

Looking forward, the GSI also has the potential to facilitate communication and collaboration among cosmetic stakeholders across the whole value chain. To this end, we actively invite other actors in the cosmetics and chemical sectors to adopt, test, and challenge this methodology; it is through such collective implementation, shared industrial feedback, and external validation that the framework will continuously gain robustness and scientific legitimacy, and drive the global transition toward sustainable beauty.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18136760/s1>: Table S1: The twelve Principles of Green Chemistry (based on this work: [10]).

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Abbreviations

%RC	Renewable Carbon percentage
ASTM	American Society for Testing and Materials
B	Bioaccumulation/Bioaccumulative
BRGM	Bureau de Recherches Géologiques et Minières (French Geological Survey)
BT	Bioaccumulative and Toxic
CCU	Carbon Capture and Utilization
CLP	Classification, Labeling and Packaging (EU Regulation EC No 1272/2008)
CMR	Carcinogenic, Mutagenic, or Reprotoxic
ECHA	European Chemicals Agency
ED Env	Endocrine Disruptor for the Environment
GSI	Green Sciences Index
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
M	Mobility/Mobile
MAI	Mineral Abundance Index
OECD	Organisation for Economic Co-operation and Development
P	Persistence/Persistent
PB	Persistent and Bioaccumulative
PBT	Persistent, Bioaccumulative, and Toxic
PM	Persistent and Mobile
PMT	Persistent, Mobile, and Toxic
PT	Persistent and Toxic
PvB	Persistent and very Bioaccumulative
PvM	Persistent and very Mobile
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SPOT	Sustainable Product Optimization Tool
SVHC	Substance of Very High Concern
T	Ecotoxicity/ecotoxic
T chronic	Chronic Toxicity/Chronically Toxic
USDA	United States Department of Agriculture
USGS	United States Geological Survey
vB	very Bioaccumulative
vBT	very Bioaccumulative and Toxic
vP	very Persistent
vPB	very Persistent and Bioaccumulative
vPM	very Persistent and Mobile

vPT	very Persistent and Toxic
vPvB	very Persistent and very Bioaccumulative
vPvM	very Persistent and very Mobile

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