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THE GREEN SCIENCES INDEX: A NOVEL METHOD FOR ASSESSING THE SUSTAINABILITY OF COSMETIC INGREDIENTS

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Introduction

Growing awareness of the environmental impact of human activities has driven a global shift towards sustainable development, embraced by various industries. Among them, the cosmetic industry is facing sustainability concerns notably regarding the choice of sustainable ingredients[1,2]. To step up a transformation process and ensure activities are compatible with a resource-constrained planet[3], specific targets must be set. Very early on, some companies realized the urgent need to act in favor of sustainability, targeting for instance the increase of biodegradability and the implementation of the Green Chemistry principles[4] (Table I).

1. *Prevention* - It is better to prevent waste than to treat or clean up waste after it has been created.
2. *Atom Economy* - Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. *Less Hazardous Chemical Syntheses* - Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. *Designing Safer Chemicals* - Chemical products should be designed to affect their desired function while minimizing their toxicity.
5. *Safer Solvents and Auxiliaries* - The use of auxiliary substances (e.g., solvents, separation agents) should be made unnecessary wherever possible and innocuous when used.
6. *Design for Energy Efficiency* - Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

7. Use of Renewable Feedstocks - A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. Reduce Derivatives - Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided, if possible, because such steps require additional reagents and can generate waste.
9. Catalysis - Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for Degradation - Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for Pollution Prevention - Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently Safer Chemistry for Accident Prevention - Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Table I : The Twelve Principles of Green Chemistry (based on the work of Anastas et al.[4])

To give an example of the advances of this transformation process, the L'Oréal group has launched in 2020 a program ("L'Oréal For the Future"[5]) defining its sustainability commitments for 2030, in a continuous improvement approach following the progress of scientific knowledge in the field. This program sets ambitious commitments, aligning with the Science-Based Targets Initiative[6] rationale and addressing key areas such as climate, water, biodiversity. Among the various stakes, natural resources preservation, sustainable sourcing, traceability of ingredients or products eco-design are particularly considered.

Concomitantly, the L'Oréal group set up the "Green Sciences" program in 2020. It is an internal initiative encompassing all the scientific disciplines and knowledge necessary to meet "L'Oréal For the Future" commitments. It was developed to support the way cosmetic ingredients are designed and formulated, and to open new fields of innovation, while offering the consumers safe and effective products. Especially, it is a key lever to contribute to the preservation of natural resources and contribute to the group's global eco-design approach on cosmetic products. Indeed, the "Green Sciences" initiative is based on an ingredient life-cycle approach, considering the origin and cultivation of feedstocks, their transformation to obtain cosmetic ingredients, as well as the ingredients end-of-life through products disposal. To support this initiative, a novel indicator entitled "Green Sciences Index" was developed (Figure *1*) and provides a holistic, rigorous, and comparable assessment of the sustainability of any cosmetic ingredients, using standardized methods and, whenever possible, existing indicators. This article focuses on the parameters selected to build this “Green Sciences Index”.

The Green Sciences Index: A method based on an ingredient life cycle approach

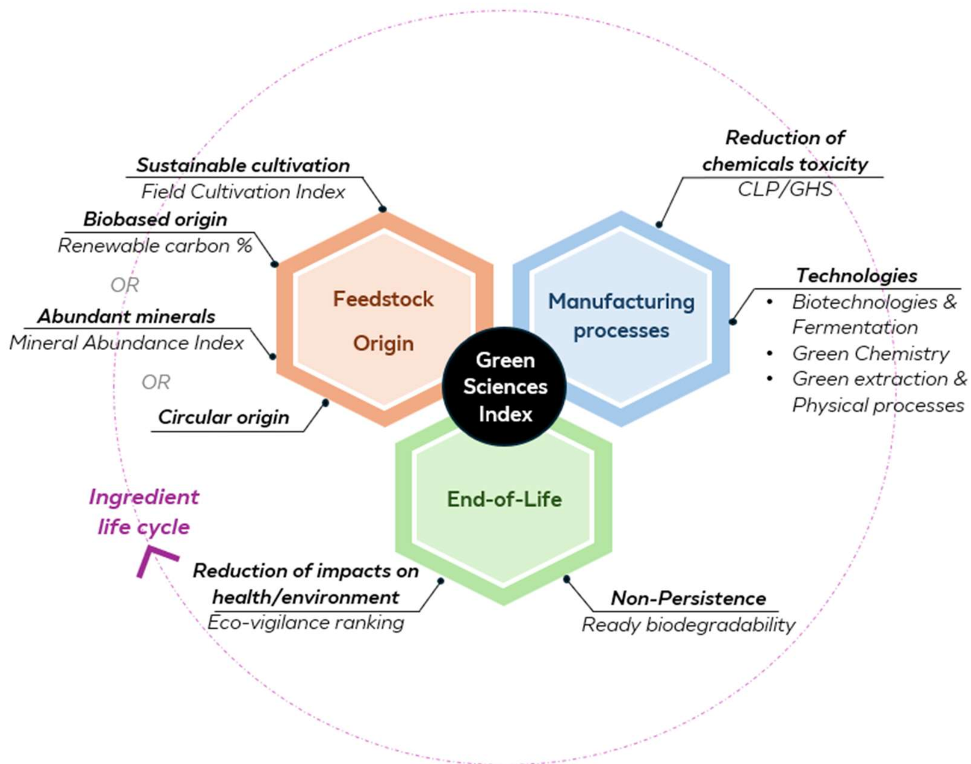

Figure 1 : Parameters of the “Green Sciences Index” through ingredient life cycle approach

Origin of ingredients feedstocks

One key driver of the sustainable transition in the cosmetics industry is shifting the sourcing of ingredients towards bio-based resources, abundant minerals, or circular economies.

A significant challenge in the transition to sustainable cosmetic formulations is phasing out petrochemical ingredients. This necessitates to identify and source bio-based alternatives. To do so, robust metrics are required to steer and monitor this transition effectively. L’Oréal utilizes several methodologies to assess the renewability of ingredients, including the ISO 16128[7,8] standards for determining natural and natural origin content, as well as an Origin Index[9] to distinguish between ingredients based on their origin. The biobased content of ingredients is evaluated through ^{14}C analysis (ASTM D6866)[10], a method used in the USDA BioPreferred® Program[11]. An ingredient is considered biobased if its percentage in Carbon of plant origin exceeds 50% of its total carbons. This approach allows for accurate and reproducible assessment of the biobased origin fraction in cosmetic ingredients.

As a key lever of a sustainable transition, the switch towards biobased ingredients induces a rising demand on biobased feedstocks. This necessitates an even stronger focus on the sustainable sourcing of biomass. It is worth noting that the proposed methodology does not address this stake directly, as the sustainable sourcing is managed through separate methodologies and initiatives, in line with the existing framework[12,13,14]. The sustainable sourcing of the biomass is then considered as a pre-requisite to the Green Sciences initiative.

Focusing on agricultural practices, L'Oréal has developed the Field Cultivation Index (FCI)[15], a multi-criteria assessment tool designed to evaluate the sustainability of agricultural practices. This tool analyzes 31 practices across five key environmental outcomes: soil health, water management, biodiversity preservation, pest management strategies, and carbon emissions. The FCI primarily focuses on regenerative agriculture, a set of practices aimed at restoring soil health, increasing biodiversity, and enhancing ecosystem services. However, the FCI also acknowledges other sustainable farming systems, including reasoned agriculture, extensive agriculture, precision agriculture, organic farming, and agroecology, reflecting a flexible and adaptable approach to sustainable agriculture.

The sustainable management of mineral ingredients, which cannot be considered as renewable resources, presents another crucial challenge. To address this, a new 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)[16], which considers not only the natural abundance of a mineral in the Earth crust, but also its availability on the market and integrates the influence of factors that could constraint or promote future market changes.

Relying solely on primary bio-based feedstocks can however bring economic, environmental, and technical limitations which can be counterbalanced by circular economy. Based on frameworks established by ADEME (the French Environment and energy management agency) and the Ellen MacArthur Foundation, L'Oréal has defined a "circular-based" ingredient as one derived from over 50% (by weight, excluding water) of either recycled feedstock or recently valorized co-products. On the one-hand, a recycled feedstock is a material derived from a recycling loop, having been transformed to re-enter economic circuits. A recently developed co-product, on the other hand, is a side-stream material that would have previously been considered as a waste but is now repurposed through specific investments in equipment or innovative processes. The company explores four key technical fields for bio-circular sourcing: wastes from the agriculture, food, and wood industries; plastic chemical recycling; Carbon Capture and Utilization (CCU); and industrial side streams recycling. These approaches align with the synergistic contribution of green chemistry principles to the circular economy and sustainable development.

Ingredients sustainable manufacturing

The manufacturing stage, which involves transforming raw materials into finished cosmetic ingredients, is another critical element in the life cycle assessment. The manufacturing processes need to be adapted to the complexity of biobased feedstocks compared to fossil ones. In addition, the traditional industrial processes need to be reinvented to be more and more in line with the Green Chemistry principles[4] (Table I) that aim to minimize or eliminate the use and generation of hazardous substances. However, addressing the twelve principles of Green Chemistry all at once is a real challenge as it requires actions and data from actors upstream the supply chain. So, the Green Sciences concept focuses in a first approach on aspects directly related the manufacturing conditions, corresponding to the green chemistry principles 3, 4, 5 and 12 (Table I). In the Green Sciences method, this means considering the toxicity of all materials used and produced, by avoiding substances presenting an acute toxicity or a proven or suspected carcinogenicity, mutagenicity or repro-toxicity. This involves getting a full traceability of manufacturing conditions, starting from primary feedstocks, and to assess the toxicity of reactants and isolated intermediates, solvents, catalysts, and by-products. It encourages the stakeholders to explore alternative manufacturing pathways and reaction conditions that avoid the use of hazardous substances.

In addition, the Green Sciences identifies three key transformation pillars for ingredient manufacturing: the “Biotechnologies”, the “Green extraction & Physical processes” and the chemical syntheses designed by “Green chemistry”.

Biotechnologies are further divided into synthetic biology (the design and construction of novel biological entities) and biomanufacturing, e.g. fermentation (the large-scale production of products using engineered biological systems). Green Extraction & Physical Processes encompass a range of techniques that avoids any (bio)chemical transformation of natural resources. It includes 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 and biochemical conversion of natural resources, adhering to the manufacturing conditions mentioned above.

<u>Assessing and monitoring the end-of-life of ingredients</u>

The final stage in the life cycle of a cosmetic ingredient is its end-of-life management, encompassing its fate after consumer use. The Green Sciences methodology integrates two key indicators associated to the environmental fate or impact of ingredients at the end-of-life stage of cosmetic products: (i) Ready biodegradability as a priority, otherwise degradability in line with REACh non-persistency criteria[17] or occurrence in nature based on the above-mentioned ISO 16128 standards on assessment of naturality[7,8]; (ii) Eco-vigilance ranking.

Ready biodegradability is determined according to OECD 301[18] & 310[19] test guidelines and 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. Eco-vigilance ranking, based on United Nations GHS hazard classifications[20] and five key environmental parameters (biodegradation, persistency (P), bioaccumulation potential (B), ecotoxicity (T), and mobility (M) through soil and groundwater, aligned with the 2023 Classification, Labelling and Packaging criteria)[21] categorizes ingredients into four levels: Favorable, Reserved, Unfavorable, and Blocking. This ranking system is used to promote the use of readily biodegradable ingredients with favorable eco-vigilance profiles and discourage or eliminate those with unfavorable or blocking profiles, mitigating potential environmental risks associated with the disposal of cosmetic products.

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*). Indeed, a cosmetic ingredient has a favorable "Green Sciences Index" if it meets all the included conditions:

- Sourced from biobased feedstocks, or from abundant minerals or from the circular economy. Additionally, for biobased ingredients, sustainable cultivation practices may be valorized to promote the ingredient as an innovation,
- And being manufactured with processes not involving acutel toxic, carcinogenic, mutagenic or reprotoxic chemicals. According to the manufacturing pathway used, the ingredient would then be considered as coming either from "Biotechnologies", "Green extraction & Physical processes" or syntheses designed by "Green chemistry",
- And being readily biodegradable as well as having a favorable Eco-vigilance ranking.

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

Discussion and perspectives

The concept of "Green Sciences" is strongly inspired by the 12 principles of Green Chemistry elaborated by P. Anastas et al.[4] (Table I), and is designed to embrace the whole life cycle of cosmetic ingredients, from their sourcing from the natural resources to their end-of-life in the environment.

In a continuous improvement ambition, several additional aspects could potentially be integrated to the “Green Sciences Index” to cover the Principles of Green Chemistry more exhaustively. Besides, the progressive implementation of manufacturing practices more and more aligned with green chemistry among the industry may favor this strategy. Most of the gap to be filled in is related to quantitative aspects. For example, the following stakes could be worth to consider: a) the optimization of materials consumption and atom economy, together with the reduction of manufacturing steps and numbers of derivatives (principles 2, 8); b) the reduction of wastes quantity, toxicity and impact on the environment (principle 1); c) the reduction of water consumption and of the impact on water quality; d) the reduction of energy consumption and promotion of renewable sources (principle 6); e) the promotion of milder manufacturing conditions (temperature, pressure…) and reduction of physical hazard (flammability, explosiveness…) (principle 12).

The “Green Sciences Index” effectively complements Life Cycle Analysis in support to sustainable innovation, sharing a life-cycle perspective integrated with a green chemistry approach. Furthermore, it fundamentally incorporates sustainable management of natural resource to ensure their preservation.

Conclusion

L’Oréal’s “Green Sciences” initiative, encompassing numerous complex parameters, requires a streamlined approach for practical implementation. The “Green Sciences Index” (GSI) provides this solution. This binary assessment tool consolidates these diverse parameters, generating a readily interpretable, comprehensive assessment of an ingredient's sustainability impact throughout its life cycle. The GSI is also a driver for innovation and progress. This approach facilitates ingredients comparison, guiding choices and highlighting specific sustainability features as well as 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 &

Development efforts and to facilitate decision-making, ultimately contributing to the development of more sustainable cosmetics products. Looking forward, the GSI has also the potential to facilitate communication and collaborations between the cosmetic stakeholders across the whole value chain.

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