Showcasing research from Dr. Sylvain Antoniotti's laboratory, Chemical Institute of Nice, Université Côte d'Azur, CNRS, France.

A holistic vision for a sustainable fragrance industry

In this Perspective, the authors share their reflections and views on how the fragrance industry could globally embrace the United Nations Sustainable Development Goals (SDGs). Looking toward a future beyond green chemistry, after expanding considerations from mass and chemical yield to include safety, energy, and resources, it is now relevant to extend these technical aspects to encompass broader social and human dimensions. The key contribution of the SDGs is indeed a human-centred vision in a significantly broader approach.

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A holistic vision for a sustainable fragrance industry

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The fragrance industry embraced sustainability early on through natural sourcing and green chemistry approaches, even before these concepts were formalised. Today, competition, regulations, and consumer expectations call for a sincere and substantial implementation of sustainability across every dimension of the fragrance business. The United Nations Sustainable Development Goals provide a global framework of thinking. Aligning with these goals and recommendations can drive innovation, enhance social impact, and promote transparency, responding to environmental challenges and evolving consumer values.

Sustainability spotlight

The ever-growing demand and huge competition with thousands of launches of new perfumes each year combined with the desire of consumers for eco-conscious products have motivated key actors to adopt sustainability approaches. In this Perspective, we propose to systematically adopt UN SDGs grid to drive R&D, innovation and production in this industry. We browse activities and identify solutions connected with SDGs 1, 3, 9 and 12 and others that indirectly contribute to SDGs 6, 7, 8, 13, 14 and 15.

Introduction

The United Nations (UN) Sustainable Development Goals (SDGs) were adopted as part of the 2030 agenda for sustainable development, with the goal of guiding global efforts over a 15-year period toward ending poverty, protecting the planet, and support prosperity for all. For fragrance companies, aligning with these ongoing goals can profoundly influence their Research and Development (R&D), innovation and production agendas, especially as sustainability becomes a cornerstone of consumer and corporate priorities. Collaborators are also stakeholders in such significant shift meeting their own aspiration through fair Environmental Corporate Social Responsibility (CSR, or ECSR).

The global fragrance and flavour market heavily relies on chemicals, regardless of their biological or synthetic origin and was worth $34.86 billion in 2024. It is expected to be $36.55 billion in 2025 with a CAGR of 4.9%.[1] Other sources estimated the market size at $30.61 billion in 2023 with an anticipated CAGR of 5.4% from 2024 to 2030.[2] The fragrance and flavour market is indeed growing, with estimated 500 000 metric tons of material produced in 2015, and 800 000 in 2025 of which roughly 600 000 metric tons are for the fragrance market, with expectation to rise to *ca.* 850 000 metric tons by 2040 (Fig. 1).[3] This market growth is supported by the growing consumer interest in natural and sustainable ingredients. The global demand for sustainable perfume ingredients is thus expected to grow significantly between 2025 and 2032.[4] Market analysis shows a high willingness to pay by consumers for sustainable products.

Most ingredients are produced at the 1–100 metric ton scale, with 60% of the *ca.* 4000 ingredients used in modern perfumery being produced below 1 metric ton per year.[5]

Various scenarios can be elaborated to find resources to sustain this +40% increase, the most credible one being to increase the share of petrochemicals.[3] There is however room for improvement of the sustainability of this industry with more renewable, recycled, upcycled carbon-based materials.

The topic of sustainable fragrance chemistry has been partially reviewed in the scientific literature through various viewpoints by us[6–8] and by other groups,[9,10] but not though the lens of SDGs. General reviews on fragrance chemistry with historical perspectives[11–13] have been proposed and the general context also refers to green chemistry[14,15] and green engineering.[16] Reflections on fragrance and sustainability were also published in specialised press.[5]

While the UN SDGs are often stigmatized as constraints or cost centres, they present a wealth of profit-generating opportunities, especially for innovation-driven sectors like the fragrance industry. By aligning R&D agendas with SDG priorities, such as responsible consumption (SDG 12), climate action

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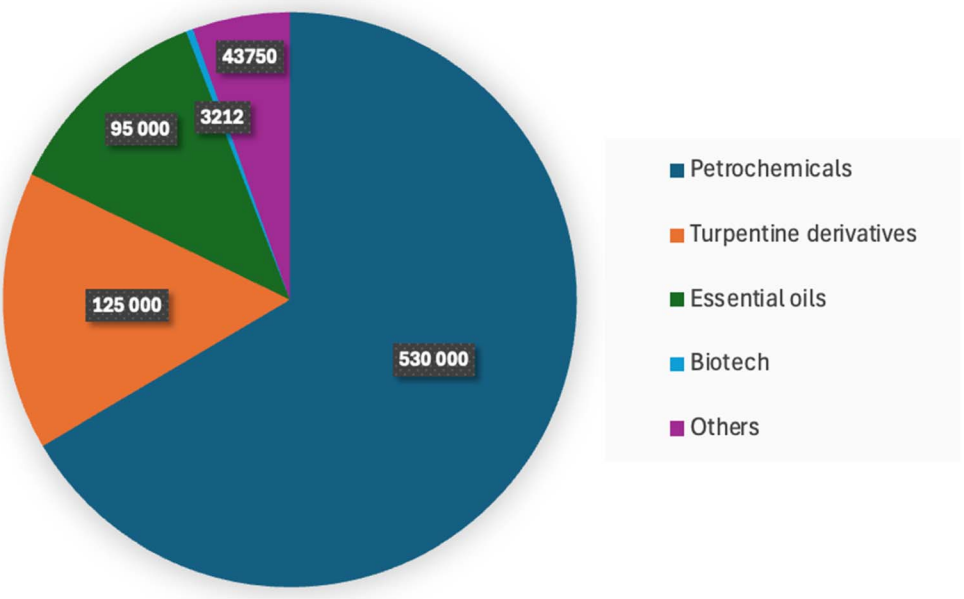

Fig. 1 Ingredients of the flavour and fragrance market by origin in 2025 (metric tons).

(SDG 13), or life on land (SDG 15), fragrance companies can modulate their technologies and unlock access to growing eco-conscious markets, reduce long-term operational risks, attract sustainability-focused investors, and foster consumer loyalty. For instance, improving biodegradability of ingredients or investing in more sustainable sourcing not only enhances brand image but can also lead to patentable innovations, cost efficiencies, and new premium product lines. Thus, the SDGs are not just moral or theoretical constraints; they are strategic levers for optimized and sustainable business models driving long-term profit, responding to an increased multifaceted demand from consumers.

In the present article, we attempted to predict how this global and planetary framework of the 17 UN SDGs is likely to influence the fragrance business all along its value chain.

Early efforts of the fragrance industry towards sustainability

The fragrance industry has experienced bioresource, atom-economy and up-cycling, decades before the terms were coined and the approach was valorised. This is because firstly, perfumery originally used natural ingredients obtained from odorous natural substances, mostly from plants diluted in vegetal oils;[17] secondly, among the first synthetic ingredients produced in early 1874, vanillin was made by oxidation of coniferin, obtained from the bark of conifers; finally, turpentine has been widely used as a source of α- and β-pinenes, used as is or converted into α-terpineol, camphor, linalool, geraniol, campholenic aldehyde and numerous fragrance materials.[18]

Early approaches for the implementation of green metrics have however been hampered by their lack of specificity or their narrow vision of the value chain together with the crucial question of adoption by diverse users with diverse expectations. Life cycle assessment metrics when they started to spread in the 90s were generally not relevant enough for the chemical industry and for industrial fragrance chemistry in particular.

However, in most instances, sustainability in chemical activities can be seen as relying on 4 pillars:

- Safety of chemicals and processes for operators, users and the environment

- Resources and their sober use, shifting away from petrochemicals towards biobased renewables, preferably from waste or non-food feedstocks

- Energy management and reduction of consumption, together with limiting carbon emission

- Waste prevention through the atom economy concept and the numerous derived approaches (step economy, one-pot reactions, domino/tandem reactions, multicatalysis, …).

Besides the 12 principles of green chemistry, the E-factor was introduced by Sheldon at the same time.[19] It specifically and solely considers the mass balance between waste and products. Other indexes based on mass calculations were developed, such as Effective Mass Yield (EMY), Mass Intensity (MI), Process Mass Intensity (PMI), or Reaction Mass Efficiency (RME). Although particularly relevant for industrial waste management and cost consideration (the primary purpose of the case study by Sheldon leading to the concept of E-factor), it completely ignores safety, availability of resources or energy consumption as the price to pay for high specificity. As concluded by Sheldon himself in the E-factor 15th anniversary paper, *we challenged the fine chemical and pharmaceutical industries to make the paradigm shift from a concept of process efficiency which was exclusively focused on chemical yield to one that is motivated by elimination of waste and maximization of raw materials utilization*, and that impact goes beyond arithmetic. The 12 principles of green engineering were presented by Anastas and coworkers as an

extension of the 12 principles of green chemistry, qualitative by nature in more practical directions.[16]

Building on this necessary paradigm shift, and the need to be able to communicate clearly to customers and to the public, GREEN MOTION™ was developed by French company Mane et fils. This tool enables the assessment of the health, safety and environmental impacts of manufactured ingredients for the flavour and fragrance industry, all criteria combined in a 0–100 scale.[20] This was probably the first time that a fragrance company went that far into developing metrics to evaluate the greenness of their products. Therefore, they had to adapt their processes to maximise the "*green score*" of final products. If the absolute value of a given ingredient can be hard to interpret, comparison of the scores of two different ingredients, two different formulas, or of two different chemical processes leading to the same ingredient make a lot of sense.

Most F&F companies have since adopted sustainability. IFRA and IOFI have partnered in 2016 to launch the Sustainability Charter explicitly mentioning UN SDGs as a reference.[21] Unfortunately, there is no standardized reporting framework that F&F companies can uniformly use to communicate their sustainability values, efforts and progress.

In 2018, Symrise has developed the product sustainability scorecard to evaluate the sustainability of their solutions[22] and IFF the "Toward a circular future" program.[23]

In 2019, Givaudan has launched the FiveCarbon Path™ as a part of the "A sense of tomorrow" program, aimed at increasing the use of renewable carbon, increasing carbon efficiency in synthesis (notably by including more biotechnology[24]), maximising biodegradable carbon, increasing the 'odour per carbon ratio' with high impact material, and using upcycled carbon from side streams.[25]

Following EcoScent Compass in 2018, Firmenich has announced the launch of the EcoIngredient Compass in June 2020, a new proprietary tool for the immediate assessment of fragrance molecules with respect to renewable carbon, biodegradability and green chemistry.[26,27] The evolution of the tool was released in 2023 with EcoScent Compass next generation.

In 2018, BASF also introduced the Biomass Balance Approach, which allows renewable resources to be used—either physically or *via* carbon credit mechanisms—as partial feedstocks as early as possible in the chemical value chain. This approach is certified by REDcert.[2]

The determination of the biobased content of chemicals is framed by norms EN 16785-1 and ISO 16128-2:2017 for cosmetics, while ISO 16620-1:2015 is dedicated to plastics. Many other initiatives towards sustainability have been launched in many industrial actors of the field worldwide, and the list above should not be considered exhaustive.

Strategic interests of shifting towards sustainability

Multinational leading companies have already included sustainability and the Environmental, Social, and Governance (ESG) principle in their agenda. The following examples are from the top 3 companies in sales, but most major companies have adopted ESG in their strategic plans.

Givaudan committed to contribute to the UN Sustainable Development Goals in 2017 and has now ESG at a high level of its governance and integrated in its strategy.[28] In the 2024 integrated report, key figures are the % of purchased renewable energy, the GHG emissions, the rating by the CDP for transparency and action on climate change and water security, and the rate of materials and services sourced responsibly, for example. As indicators of the non-financial performance, the scope of various GHG emissions is listed, together with water efficiency and water intensity measurements, energy consumption and waste management. Long term ambitions target to be a climate positive business and to reach 100% of materials and services sourced responsibly.

The dsm-firmenich 2024 integrated annual report tells us that sustainability has been implemented transversally in each division of the company.[29] Support to the UN SDGs is highlighted through business activities for SDGs 2, 3, 8, 12 and 13, and through people and operations for SDGs 4, 5, 7, 8 and 10. Their creation process encompasses economic, environmental, and social factors to attain sustainable and responsible business practices. Similar indicators on GHG emissions, water management, sustainable energy and land use have been adopted with a long-term ambition to be net-zero.

IFF in its 2025 sustainability report similarly highlights the implementation of ESG in the strategy with a large portfolio of actions and associated indicators.[30] R&D and innovation towards sustainable sourcing, processes and products are key drivers to achieve global goals such as becoming a net-zero company, together with GHG emissions, and energy and water management.

In general, aligning projects with the United Nations SDGs has enabled companies of various sizes to achieve economic benefit through enhanced brand reputation, access to new markets, and improved operational efficiencies:

- International Flavors & Fragrances (IFF) integrated sustainability into its operations by adopting the 12 principles of green chemistry and achieving certifications like LEED silver and Roundtable for Sustainable Palm Oil (RSPO). This enhanced IFF's reputation, leading to its inclusion in Newsweek's Green Rankings and Barron's 100 most sustainable companies list positively influenced consumer preference and financial performance.

- Sana Jardin, socially conscious fragrance brand initiated the Orange Blossom Project in 2015, supporting the indigenous Amazigh community in Morocco. By promoting sustainable practices and fair trade, Sana Jardin aims to preserve heritage knowledge while creating social change through commerce contributing to its market differentiation and customer loyalty.

- Luxury fashion brands (*e.g.* LVMH) invested in generative agriculture projects, such as agroforestry-grown cotton, to promote sustainability in their supply chains.

Broader studies indicate that sustainable initiatives can significantly enhance profitability: *e.g.* McKinsey research suggests that implementing sustainable practices can improve operating profits by up to 60%.[31]

Adapting processes and strategies towards increased sustainability has the merit to rethink the most adequate way to manufacture a product. Many processes were designed decades ago and are taken as immutable. Rethinking can lead to improved efficiencies especially as it can involve strategic raw materials common to various product lines.

The fragrance industry invests significantly in R&D – more than other sectors – and innovation is the driver for differentiation in a sector where more than 3000 new perfumes were launched in 2024. An average 8% of net sales is invested in R&D by F&F companies.[32]

The future growth will be supported by the ever-increasing influence of millennials and gen *Z* that value authenticity, ethics and cruelty-free products more than their elders. These consumers are placing growing importance on transparency and are quick to disengage from brands that lack clear information or rely on opacity and greenwashing tactics. They are thus more likely to accept innovation and new technologies provided they help addressing this quest for more sustainable products.[33] Social media rapidly amplifies consumer feedback and dissatisfaction, making it more difficult for companies to hide behind vague claims. In response, businesses are becoming more accountable and mindful, prioritizing clear communication to build trust and avoid the pitfalls of greenwashing.[34]

Designing R&D around circular principles like upcycling waste materials (*e.g.*, food or forestry by-products into fragrance ingredients) provides viable alternatives to fossil-based feedstocks and creates a distinctly different sustainability profile for the same end molecule. This expanded sustainability landscape can deliver added value, particularly by meeting the specific demands of niche market segments.

Looking at the future in a more global manner, after enlarging mass considerations to safety, energy and resources, it is now mandatory to enlarge these somehow technical aspects to global social and human aspects. The main addition of the UN SDGs is indeed a human-centred vision in a significantly broader approach that goes beyond fair trade.

Presentation of the UN SDGs

The 17 United Nations SDGs covering 169 targets were formalized in 2015 by the UN members and included in the 2030 Agenda for Sustainable Development (Fig. 2).

In contrast with the concepts discussed above, these SDGs are not specifically aimed at addressing the chemical sector and are significantly global.

Opportunities of R&D and innovation for the F&F industry

To project these goals into opportunities of innovation and evolution of the F&F industry, we may want to make a distinction between primary goals, where actions and improvements could have a direct-positive-effect and secondary goals, where the same would result in a more indirect contributing manner.

Primary goals could be for example SDG 1: No poverty, when thinking about the shared value generated along the product value chain from cradle to grave, or more poetically from field to skin for naturals. The UN Food and Agriculture Organization (FAO) often cites that over 80% of the world's extreme poor live in rural areas, emphasizing the link to agriculture and food security.[36] Agricultural and rural development interventions can reduce global poverty by providing growth-oriented tools,

Fig. 2 The 17 United Nations Sustainable Development Goals.[35] Reproduced from the United Nations Sustainable Development Goals web site (https://www.un.org/sustainabledevelopement).† † The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

including access to finance, training, and markets.[37] Therefore, a biomass-focused supply of F&F ingredients, aligned with CSR verification, supports this fundamental objective.

Another goal where direct impacts could be expected is SDG 3: Good health and well-being, where it is known that perfumes contribute to well-being of ourselves and people we are interacting with, and that well-being contributes to good health (and conversely).[38] Aromatherapy may have some positive effect on well-being, regardless of its actual biological mechanism, and the same goes for emotions provoked by different kinds of odors.[39] Studies are pointing out that specific essential oils have a positive effect on mental health, though neuroprotective properties.[40] Safety of ingredients, processes and infrastructure should obviously be guaranteed. Good health and well-being are also indirectly contributing to socio-economic benefit to rural communities for CSR compliant agricultural work.

With SDG 9: Industry, innovation and infrastructure, a wide range of improvements could be highly relevant: evolution towards sustainable extraction processes, reinventing enfleurage, implementing more biotechnology (either with isolated enzymes or microorganisms, including genetically modified organisms for optimized properties and efficiency), adopting innovative activation methods for synthesis, as well as advanced multicatalysis and hybrid continuous flow processes. This is an already active area, sometimes to comply also with consumer's needs, clients' requests, local regulations or collaborator interests (CSR). This could be envisaged through investing in green chemistry for safer, more sustainable ingredient production, and by collaborating with academia and startup companies to pioneer sustainable fragrance solutions through innovation.

For SDG 12: Responsible consumption and production, even if it could overlap the previous one, there are already examples with the boom of refills, new formats for fragrances, deodorants and cosmetics, and efforts on packaging (eco-design, recycling) or concentrated perfumes. For production, biobased chemicals such as biocyclamol, an identical chemical entity to dihydrofarnesol (although the impurities profile may vary) but with a significantly reduced carbon footprint and overall impacts typically coming along with petrochemicals. Reducing environmental impact requires more than just improving the biodegradability of ingredients; it also involves designing formulations that achieve the desired effect with fewer raw materials. Developing sustainable and biodegradable formulations can further minimize environmental footprint, contributing to a more responsible and efficient use of resources. Innovative ingredients have the potential to replace resource-intensive natural materials, particularly those that are rare or derived from endangered species (CITES) as well as to substitute large-volume petrochemical compounds with low-volume, advanced alternatives that deliver the same desired effect.[41] What have been done for animal-based ingredients is now being done for some plant-based ingredients as well, as it is being done with sandalwood.[42]

Another avenue is the generalization of circular economy models where the waste of a process is the feedstock of another one, ideally in a not-too-distant location to avoid transportation impacts. Similarly, sizable production units through innovative technology that could be located close to the consumption site for short circuits of distribution could be envisaged.

Secondary goals, with indirect impacts, could be for example in the case of SDG 6: Clean Water and Sanitation, which involves identifying innovation in process chemistry, engineering and agricultural practice to limit the use of water in cultivation and manufacturing. Water-less and water-free products are already on the market (*e.g.* solid cosmetics) but mostly displace the moment where water is used and do not reduce the use of water in the overall balance. SDG 7: Affordable and Clean Energy involves favouring transition to renewable energy in R&D and production facilities through energy-efficient methods for ingredient synthesis and extraction. SDG 8: Decent Work and Economic Growth involves engaging with communities to ensure fair trade and ethical sourcing in regions of the world where valuable natural raw materials are produced. The global need for change will be a driver of economic growth or to sustainable economy for those believing that growth on a finite planet with a finite capacity cannot last forever and must reach a steady state.

SGDG13: Climate action, occupies a particular position. Like all industries, the fragrance industry has a carbon footprint due to energy-intensive production and logistics. The footprint due to electrical consumption will be different depending on the regions of the world due to heterogeneous electric power production models from coal and natural to nuclear and to renewables. Relevant options could be to optimize energy efficiency in all manufacturing processes and distribution, towards carbon-neutral or carbon-negative products and invest in renewable energy for production facilities and transportation. For the F&F industry, the most effective way to reduce energy use is by designing more potent olfactory molecules that perform at lower concentrations, offering an alternative to bulkier molecules that require more energy to produce while achieving the same effect in the final consumer product.

For SDG 14: Life Below Water, it could be interesting to consider the entire life cycle of perfumes and cosmetics eventually ending up in water. The biodegradability and ecotoxicology of ingredients should be considered with the highest requirement, and ingredients should be designed with chemical features facilitating these goals. Here again, the development of highly impactful molecules can significantly reduce environmental impact at the end of the product's life cycle—particularly since, in many cases, they ultimately enter greywater systems. In the case of SDG 15: Life on land, progress could be attained by supporting sustainable farming practices for raw material production and promoting research on plant-based and lab-grown solutions to reduce pressure on endangered species.

Conclusion

By aligning their R&D agenda with the UN SDGs, fragrance companies can enhance brand value, as sustainability resonates with consumers. Today's investments will therefore translate into tomorrow's market shares. Addressing environmental and social challenges can also help reduce supply chain

vulnerabilities. The pursuit of sustainable solutions fosters technological advancement in a continuous innovation process. It prepares companies to adhere to increasing environmental and social regulations.

As observed or predicted across all sectors, artificial intelligence and the exploitation of large datasets are likely to play a role in improving the sustainability of the fragrance industry.[43] Specifically, the complex interplay of various impacts and the variability of formulas used in perfumery, from technical to fine fragrance, could benefit from *in silico* evaluation and deep learning approaches to help predict impacts when data are unavailable (*e.g.* for biodegradability, human, and environmental toxicity).[44,45]

Fragrance companies that integrate UN SDGs in their R&D strategies not only contribute to global sustainability efforts but also position themselves as leaders in a forward-thinking and responsible industry where sustainability tends to diffuse transversally to become an intrinsic feature of perfumery products.

The value of Nature as a common good is a concept that is not yet fully modelled and remains the subject of ongoing debate and research. Even after determining the value of a given element of Nature, it is not yet a price until someone is willing to pay for it? This complexity calls for the development of new knowledge in economics, and innovative business models.

Conflicts of interest

There are no conflicts of interest to declare.

Data availability

No primary research results, software or code have been included and no new data were generated or analysed as part of this review.

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