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Editorial

Development and Application of Green or Sustainable Strategies in Analytical Chemistry

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Analytical chemistry is bound to face growing challenges in the near future, especially for the quantification of trace analytes in complex matrices. Although the development of increasingly sensitive and specific instrumental techniques has achieved remarkable results, sample preparation is still a fundamental step, often limiting the whole workflow.

In the context spawned by recent international environmental policies that are responsive to the rapport of human activities with the surrounding environment, chemistry cannot hesitate to give its contribution. Almost pioneeringly, in analytical chemistry, we have been talking for some time about "green analytical chemistry", its guiding principles, and the development of eco-friendly analytical approaches.

Since then, awareness of eco-sustainability in analytical chemistry has evolved significantly, also targeting the establishment of referable and comparable metric systems to assess the environmental cost of analysis and, more specifically, that of sample preparation [1,2]. The analytical benefits of effective sample-prep are well known, and among the approaches that provide the greatest environmental benefits is the wide portfolio of microextraction techniques, which include not only frontier solutions but also commercially available and affordable strategies [3–5]. However, the new and still-open challenge is to advance not only in eco-compatibility but mainly in eco-sustainability, thus rooting the future of analytical chemistry in new paradigms which are founded on the use of materials that are recycled, reusable, or from natural sources, therefore being sustainable [6].

It must be clear how the environmental footprint left behind must now be assessed comprehensively, with a broad look that encompass not only the laboratory practices but it is important to embrace the entire analytical process, from sampling to final determination. Hence, for example, it is vital to develop strategies that simplify sampling and counteract the need for costly and time-consuming transportation to analytical facilities [2,7]. While this urgency may sound somewhat unimportant to the most affectionate laboratory folks, it actually shows its weight in the context of international monitoring networks where sampling sites are multiple and often far from the few analytical centers [8–13].

Equally important is the oversight of energy demand to conduct the analysis. Using very sophisticated (and often energy-intensive) instruments is not always a real need, but rather an academic or research pursuit, which also requires high levels of skill training and operating costs. From gravimetric and volumetric techniques to sophisticated high-resolution mass spectrometry, a wide set of analytical instruments are encountered, and cost-effectiveness (including environmental) must be the guideline for a proper choice of strategy [14].

These evaluations are not unrelated to a proper knowledge of the analytical system under consideration and the potential of the used method, both aspects for which traditional optimization and evaluation approaches do not permit a full understanding. Although already used by some scholars and analysts [15–18], it is still desirable to increasingly involve chemometric and data analysis techniques in real case studies and method development. Only the release of optimization and response surfaces makes it possible to thoroughly get to know a method of analysis and its behavior, somewhat as one does with a person when

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Citation: Naccarato, A. Development and Application of Green or Sustainable Strategies in Analytical Chemistry. *Separations* **2023**, *10*, 32. https://doi.org/10.3390/separations10010032

Received: 2 December 2022
Accepted: 21 December 2022
Published: 5 January 2023

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one gets to know his or her personality and understands what are the most sensitive points that determine his or her emotional reaction.

Considering the above, this Special Issue aimed to collect studies that show the progress in analytical chemistry based on the arguments previously raised and discussed, with a particular reference to eco-compatibility and eco-sustainability. The collected articles range from studies aimed at the development of new materials to address the removal or extraction of target compounds from environmental and food matrices, to the use of less sophisticated techniques for analysis in the pharmaceutical industry.

The Special Issue includes a review by Chatzimitakos et al. [19], which provides a literature update on the current trends of magnetic ionic liquids (MILs) in different modes of sample preparation, along with the current limitations and the prospects of the field. MILs combine the advantageous properties of ionic liquids along with the magnetic properties, creating an unsurpassed combination, and their use in different extraction approaches including dispersive liquid–liquid microextraction, and matrix solid-phase dispersion were surveyed.

Pulsed electric field (PEF), as a sustainable innovative technology for the recovery of nutrients and bioactive compounds from *A. bisporus*, was explored in the contribution by Barba's group [20]. PEF facilitates the sustainable and economic isolation of compounds by using water as a solvent, thus reducing the use of organic solvents. In addition, it is a technology that reduces the temperature and time required for the extraction of the different compounds, thus preserving the thermolabile components. The application of PEF technology under optimal conditions to mushrooms increases the extraction of carbohydrates, proteins, antioxidant compounds, and minerals such as P, Mg, Fe, and Se compared to conventional methodology.

A low-volume fatty-acid mixture-based solvent was used by Francisco C. Franco and co-workers [21] for a simple and efficient microextraction method for the removal of dyes in aqueous solutions. The fatty-acid mixture presented a green and economic procedure for the extraction of toxic dyes in wastewater treatment. The experimental results reveal that even at a microvolume solvent availability, a fatty-acid mixture performs efficiently even towards hydrophobic contaminants 200 times its volume.

Ali et al. [22] reported the synthesis of a gum arabic–magnetite composite (GA/MNPs), which was characterized and assessed by several spectroscopic and analytical methods as an adsorbent for Pb(II) ions from synthetic wastewater. The GA/MNP composite is a partially bio-based material, and it demonstrated unique properties which permit a removal efficiency of 99.3% at the optimum conditions.

Additionally, an element known for its potentially toxic effects on humans and ecosystems is mercury, which was the target of the study carried out by Huang and co-workers [23]. Here, a manganese-doped manganese–cobalt–iron spinel adsorbent was prepared by the sol–gel self-combustion method and characterized by XRD, SEM, and VSM. Its use was explored providing theoretical guidance and a research basis for the development of efficient and recyclable spinel ferrite adsorbents for the trapping of gaseous elemental mercury (Hg^0).

The Special Issue included two contributions from Rainer's group reporting the studies on reusable materials to improve the extraction of target compounds. More precisely, in one study, they synthesized a novel [C_6-bis-VIM] [Br] crosslinked anion exchange polymer and subsequently develop an efficient extraction procedure for phenolic acids from aqueous samples [24]. The reusability of the sorbent used for dispersive- solid-phase extraction was investigated, and it resulted in being an efficient and sustainable anion exchange material with maximum recoveries ranging between 84.1 and 92.5%.

In the second study, the use of modified halloysite nanotubes was explored in the selective solid-phase extraction of toxic pyrrolizidine alkaloids as alternative candidates to polymeric resins [25]. Satisfactory results were obtained in an aqueous pyrrolizidine alkaloid mixture containing four of the six main structures of the pyrrolizidine alkaloid group as well as in spiked honey samples. Furthermore, halloysite nanotubes can once again be presented as an economical and environmentally friendly resource due to their massive natural occurrence and resulting low cost.

The use of less demanding and sophisticated instrumentation was addressed in the two contributions by Alam and co-workers, who employed the high-performance thin-layer chromatography for vitamin D3 estimation in commercial pharmaceutical products and the quantification of chlorzoxazone and paracetamol in commercial capsules and tablets [26,27]. The greenness of the proposed HPTLC-UV methods was assessed quantitatively by the "Analytical GREENness" (AGREE)metric.

I hope that you will enjoy reading the collection of papers included in this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

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