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TRANSFORMING ANALYTICAL SCIENCE: A COMPREHENSIVE REVIEW OF GREEN ANALYTICAL CHEMISTRY

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ABSTRACT

GAC is a modern discipline that aims to redesign analytical chemistry with an environmentally friendly approach. A new area of analytical science called "green analytical chemistry" (GAC) uses the twelve green chemistry principles in chemical measurement to lessen the effects on the environment and human health. GAC offers a framework for environmentally friendly analytical techniques that preserve high accuracy and precision while reducing the use of hazardous reagents, conserving energy, and avoiding the production of hazardous waste. The use of green solvents like water, supercritical carbon dioxide, ionic liquids, and other bio-based substitutes in conjunction with energy-efficient techniques like microwave and ultrasound assisted methods that speed up reaction kinetics and reduce power requirements is emphasized by recent developments. Progress in green instrumentation, including miniaturized and portable devices, microfluidic lab-on-a-chip systems, and automated platforms, has likewise decreased sample and energy consumption. To assess and guide these efforts, standardized tools such as NEMI, AES, GAPI, AGREE and AMGS have been developed to evaluate the "greenness" of analytical methods and promote global comparability. GAC was born out of the need for a more mindful approach. One of the most

dynamic fields within Green Chemistry is the development of analytical methodologies, leading to the emergence of GAC. Every decision and action in analytical work affects both the final product and its broader surroundings. The future of green chemistry, along with the future of our environment and society, is also explored in this article.

KEYWORDS: Green Analytical Chemistry, Eco-friendly, NEMI, Greenness.

1. INTRODUCTION

The goal of Green Analytical Chemistry is to reduce or eliminate the use of toxic substances and waste generation, to use screening methods for simple qualitative measurement designed to avoid processing large numbers of samples required for full quantitative analysis in large labs, and to replace them with ion-site and in-vivo technologies. A transparent evaluation of the method's greenness will take into account important factors such reagent toxicity, waste creation, energy usage, and user safety. Additionally, a thorough evaluation of the approach that incorporates analytical and practical criteria and strikes a balance between usefulness and greenness.

Green Analytical Chemistry (GAC) is an evolving field that aims to reduce the environmental and health impacts associated with chemical analysis. Traditional analytical methods often rely on toxic reagents, generate large volumes of hazardous waste, and require significant energy consumption. In contrast, GAC focuses on designing analytical procedures that are safer, more efficient, and environmentally sustainable without compromising analytical performance.

The concept of Green Analytical Chemistry is derived from the broader framework of green chemistry and emphasizes minimizing the ecological footprint of analytical processes. It promotes the use of safer chemicals, reduction in sample and reagent quantities, and the development of energy-efficient techniques. Advances such as micro-scale analysis, automation, and solvent-free methods have significantly contributed to the growth of sustainable analytical practices.

A central aspect of GAC is its guiding principles, which provide a framework for developing environmentally friendly analytical methods.

These principles include

- Direct analytical techniques – Avoiding sample preparation when possible to reduce waste and chemical use.
- Minimal sample size and number of samples – Reducing the quantity of materials required for analysis.
- In situ measurements – Performing analysis at the source to eliminate transportation and storage impacts.
- Integration of analytical processes – Combining steps to minimize resource use and waste generation.
- Automation and miniaturization – Using smaller-scale instruments to reduce reagent and energy consumption.
- Avoidance of derivatization – Eliminating unnecessary chemical modifications that produce extra waste.
- Use of safer solvents and reagents – Preferring non-toxic, biodegradable, or renewable substances.
- Energy efficiency – Conducting analyses at ambient temperature and pressure whenever possible.
- Generation of minimal waste – Designing methods that produce little or no hazardous by-products.
- Multi-analyte or multi-parameter methods – Obtaining more information from a single analysis.
- Use of renewable materials – Favoring sustainable resources over non-renewable ones.
- Real-time analysis for pollution prevention – Monitoring processes continuously to avoid environmental contamination.

By implementing these principles, Green Analytical Chemistry not only reduces environmental damage but also improves laboratory safety, lowers operational costs, and enhances overall efficiency. As sustainability becomes a global priority, GAC is increasingly recognized as an essential approach in research, industry, and environmental monitoring.

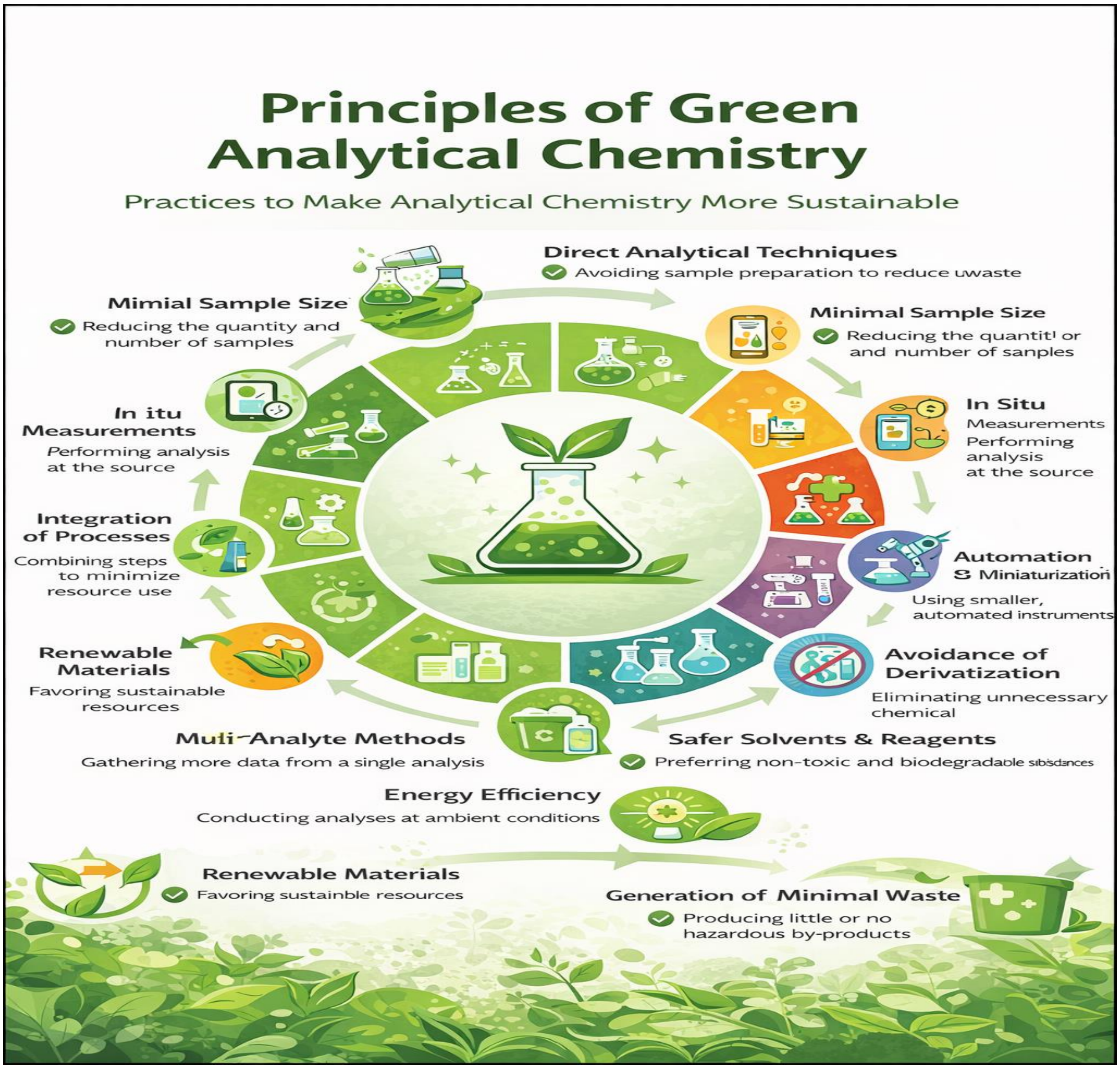

Fig. 1: Principles Green Analytical Chemistry.

2. THE SCOPE FOR GREEN ANALYTICAL CHEMISTRY INCLUDES

- Fundamental developments facilitating green analytical chemistry technologies.
- Development of chemical and biochemical sensors.
- Reducing time and energy
- Reuse of the devices will be emphasized to reduce waste.
- Alternative solvents, replacing hazardous compounds.
- Miniaturization, making it possible to reduce dramatically the amounts of reagents consumed and wastes generated
- Reducing or avoiding side effects of analytical methods.
- Environmentally friendly sample preparation techniques

- Solventless extraction techniques, the application of alternative solvents and assisted extractions both small and industrial scale
- On-site analytical instrument development and sampling protocols
- Flow cells
- Green Chemistry Education.[1]

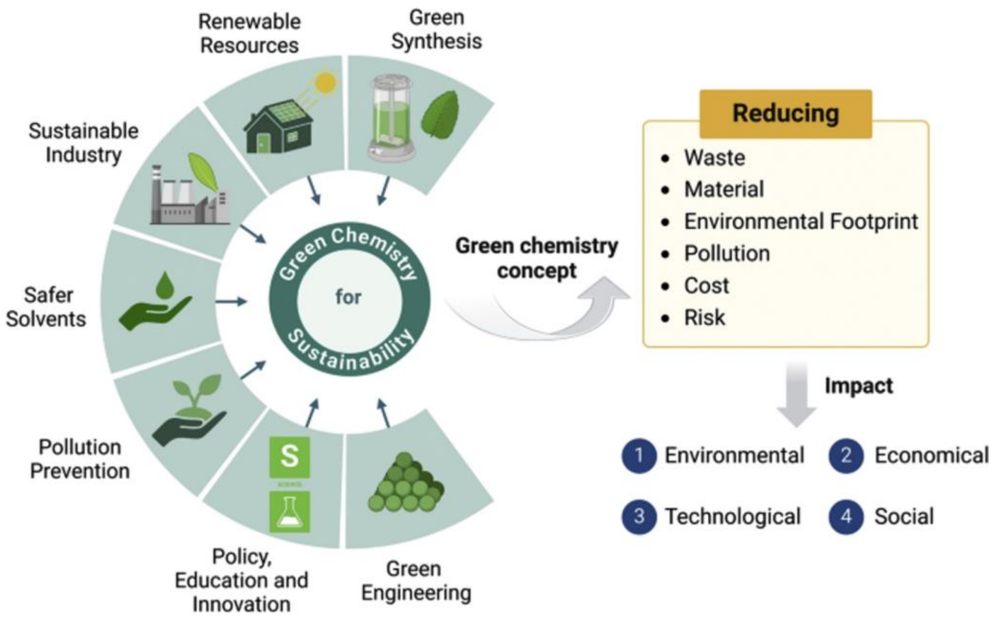

Fig. 2: The contributions of GChem to sustainability.

3. BASIC FOUNDATIONAL PRINCIPLES OF GREEN ANALYTICAL CHEMISTRY

Applying the concepts of green chemistry to the analytical process, green analytical chemistry is an outgrowth of the larger area of green chemistry. Making the entire analytical process as safe as possible, from sample preparation to data processing, is the ultimate goal. The key principles that drive eco-friendly analysis include:

3.1 Source Reduction: The most effective way to reduce waste is to prevent its generation in the first place. This means using smaller sample volumes, reducing the amount of reagents and solvents, and avoiding unnecessary steps in the analytical process. It's the core philosophy behind many green chemistry methods.

3.2 Energy Efficiency: Analytical tools and techniques can be very energy consuming. Green analytical chemistry aims to reduce energy usage by utilizing more efficient equipment, devising procedures with less heating or cooling, and investigating ambient-temperature alternatives.

3.3 Use of best Safer Solvents: Many traditional analytical methods rely on hazardous or toxic solvents. The green approach prioritizes the use of non-toxic, non-flammable, and biodegradable alternatives, such as water, supercritical carbon dioxide, or ionic liquids. There are several manageable ways to perform eco-friendly analysis by using ecofriendly solvents.

This not only makes the lab more of an environmentally safe lab but also significantly improves a researcher's safety for the critical research work.

3.4 Real-time Analysis: The ability to perform real-time analysis can prevent the need to take samples back to the lab, reducing transportation and the need for preservatives. It also allows for immediate decision-making, which is particularly valuable in field-based environmental monitoring.[2]

Table no. 1: Difference between traditional and green analytical method.

Principle	Traditional Method	Green Analytical Method
Sample Size	Milliliters or more	Microliters to Nanoliters
Solvent Choice	Hazardous solvents (e.g., chloroform, benzene)	Non-toxic alternatives (e.g., water, ethanol, ionic liquids)
Waste Generation	High volume of hazardous waste	Minimal waste, often non-hazardous
Energy Use	High (e.g., heating, vacuum pumps)	Low (e.g., room temperature methods)
Safety Profile	High-risk due to toxic chemicals	Low-risk, improved lab safety

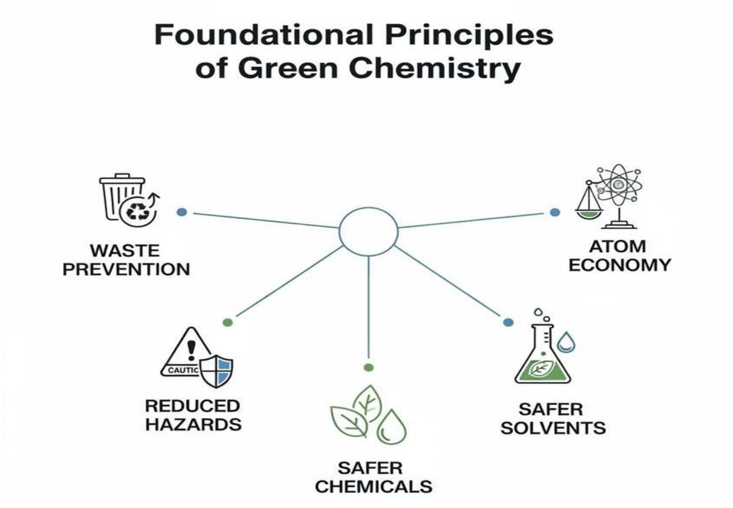

Fig. 3: Foundational principles of green chemistry.

Green Analytical Chemistry (GAC) is an evolving field that aims to reduce the environmental and health impacts associated with chemical analysis. Traditional analytical methods often rely on toxic reagents, generate large volumes of hazardous waste, and require significant energy consumption. In contrast, GAC focuses on designing analytical procedures that are safer, more efficient, and environmentally sustainable without compromising analytical performance.

The concept of Green Analytical Chemistry is derived from the broader framework of green chemistry and emphasizes minimizing the ecological footprint of analytical processes. It promotes the use of safer chemicals, reduction in sample and reagent quantities, and the development of energy-efficient techniques. Advances such as micro-scale analysis, automation, and solvent-free methods have significantly contributed to the growth of sustainable analytical practices.

4. IMPLEMENTATION OF GREEN CHEMISTRY METHODS: TECHNIQUES FOR ECO-FRIENDLY ANALYSIS

4.1 Miniaturization: This is the keystone of eco-friendly analysis. By reducing the scale of the analysis, from test tubes to microfluidic chips, labs can dramatically cut down on sample and reagent consumption. This not only minimizes waste but also lowers costs and speeds up analysis times. Lab-on-a-chip technology is a prime example of this principle in action.

Lab-on-a-chip (LOC) technology refers to miniaturized devices that integrate multiple laboratory functions—such as sample preparation, fluid handling, and detection—onto a single chip, typically only a few square centimeters in size. These systems use microfluidics to process tiny liquid volumes, enabling rapid, portable, and cost-effective analysis, often used for point-of-care diagnostics and research.[3]

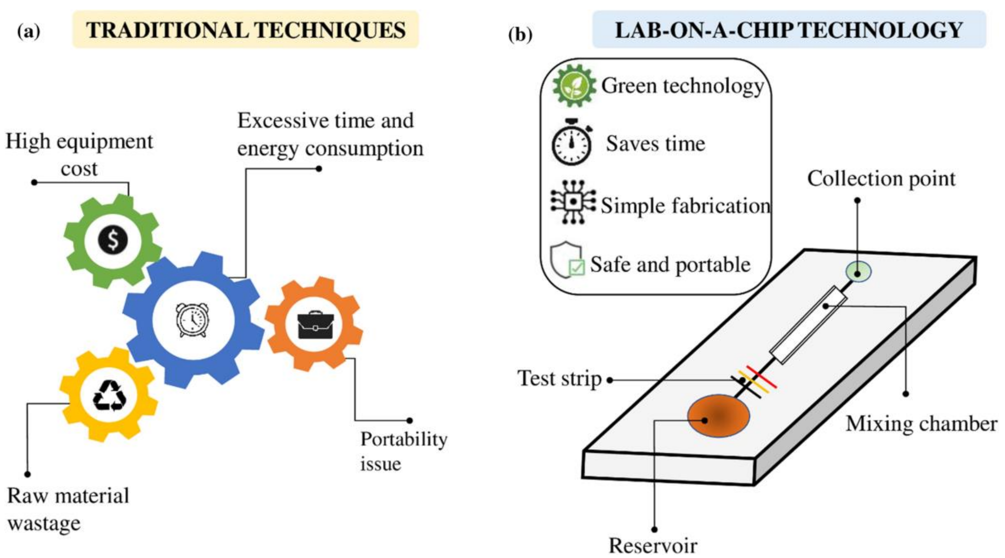

Fig. 4: Miniaturization Device.

4.2 Solventless or Reduced-Solvent Extraction: Traditional sample preparation often involves large volumes of organic solvents. Modern sustainable lab practices employ methods that eliminate or drastically reduce solvent use. Solid-phase microextraction (SPME) and supercritical fluid extraction (SFE) are excellent examples, where samples are extracted using solid fibers or supercritical fluids, respectively, with far less environmental impact.

4.3 Use of Alternative Solvents: When solvents are necessary, green analytical chemistry champions the use of benign alternatives. Water is the ultimate green solvent, and its use is increasing with the development of water-compatible chromatography columns. Bio-based solvents derived from renewable feedstocks, and non-volatile ionic liquids, which can often be reused, are also gaining popularity in creating an environmentally safe lab.

4.4 On-site and Real-time Analysis: Moving the analytical instrument to the sample source reduces the need for sample transportation, storage, and preservation. Portable spectrometers and sensors are making this a reality, leading to faster results and a reduction in the carbon footprint associated with sample logistics.

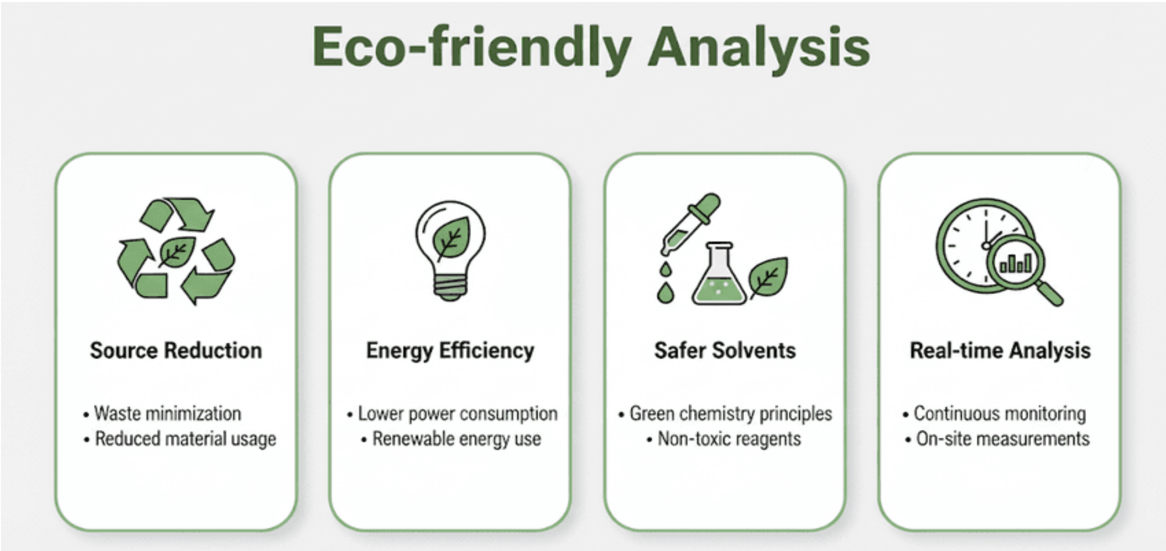

Fig. 5: Eco- friendly analysis.

5. ADOPTING SUSTAINABLE GREEN ANALYTICAL PRACTICES: BENEFITS AND CHALLENGES

Adopting sustainable lab practices offers numerous benefits that extend beyond environmental stewardship. For laboratory professionals, these methods often translate to tangible improvements in safety, cost, and efficiency. However, the transition is not without its challenges.

Benefits of Sustainable green analytical Practices

- **Enhanced Safety:** Using non-toxic solvents and reducing the generation of hazardous waste directly improves the health and safety of laboratory personnel.
- **Cost Savings:** Lower consumption of expensive reagents, solvents, and energy translates into significant operational cost savings over time.
- **Improved Efficiency:** Many green chemistry methods are faster and more automated than their traditional counterparts, leading to increased sample throughput and reduced turnaround times.
- **Better Public Image and Compliance:** Organizations that embrace green analytical chemistry can demonstrate a commitment to sustainability, which is increasingly important for public perception and regulatory compliance.

Challenges Sustainable green analytical Practices

- **Method Validation:** One of the primary hurdles is validating new eco-friendly analysis methods to ensure they provide results that are as accurate and reproducible as established, traditional techniques. This process can be time-consuming and requires careful documentation.
- **Initial Investment:** While long-term costs may be lower, the initial investment in new equipment, such as supercritical fluid chromatographs or specialized miniaturized devices, can be a barrier for some laboratories.
- **Training and Education:** The successful adoption of these methods requires lab professionals to be trained on new techniques and instruments. A cultural shift is needed to prioritize sustainability alongside traditional metrics like speed and accuracy.

6. TYPES OF GREEN ANALYTICAL CHEMISTRY METHODS

Green Analytical Chemistry (GAC) includes a range of analytical approaches that are classified according to their methodological strategies and practical applications. These methods aim to reduce environmental impact while ensuring reliable analytical performance.

6.1 Green Chromatographic Techniques

Chromatography is widely used in pharmaceutical analysis but often relies on hazardous solvents that generate significant waste. Green chromatography addresses this by improving sustainability and minimizing solvent use. Supercritical fluid chromatography (SFC) is considered a green analytical technique because it utilizes carbon dioxide (CO2) as the primary mobile phase instead of organic solvents. Supercritical CO_2 is non-toxic, has low viscosity and high diffusivity, allowing for faster separations and reduced solvent waste. As the world becomes ever more conscious of environmental sustainability, science continues to evolve to meet the growing demand for greener practices. With its widespread application in pharmaceuticals, environmental monitoring, food safety, and forensics, chromatography has a role to play in reducing the environmental footprint of the laboratory. Reversed-Phase Chromatography (RPC) can also be made greener by replacing harmful solvents such as methanol and acetonitrile with safer alternatives like ethanol, isopropanol, acetone, ethyl acetate, propylene carbonate, and water. These substitutions improve laboratory safety, reduce waste disposal costs, and lessen environmental impact without sacrificing performance. Additionally, Miniaturized Chromatography reduces solvent and sample volumes by over 90% compared to conventional LC, cutting time, cost, waste, and energy consumption. Beyond environmental and health benefits, miniaturization improves ion sensitivity, decreases dilution, and enhances mass spectrometric efficiency. Traditional chromatography techniques, particularly high performance liquid chromatography (HPLC), rely heavily on organic solvents such as acetonitrile and methanol. These solvents contribute to environmental pollution, are costly to dispose of, and pose health hazards to laboratory personnel. As a result, researchers are increasingly focusing on developing solvent-free techniques.

Another approach is ultrahigh-pressure liquid chromatography (UHPLC), which uses smaller particle sizes and higher pressures to achieve greater efficiency. UHPLC systems require significantly less solvent than conventional HPLC, making them a greener alternative while maintaining high sensitivity and resolution.

Green chromatography focuses on reducing solvent consumption and replacing hazardous solvents with environmentally friendly alternatives. Techniques such as ultra-high-performance liquid chromatography (UHPLC) and high-performance thin-layer chromatography (HPTLC) are widely employed due to their lower solvent requirements and improved efficiency.[4]

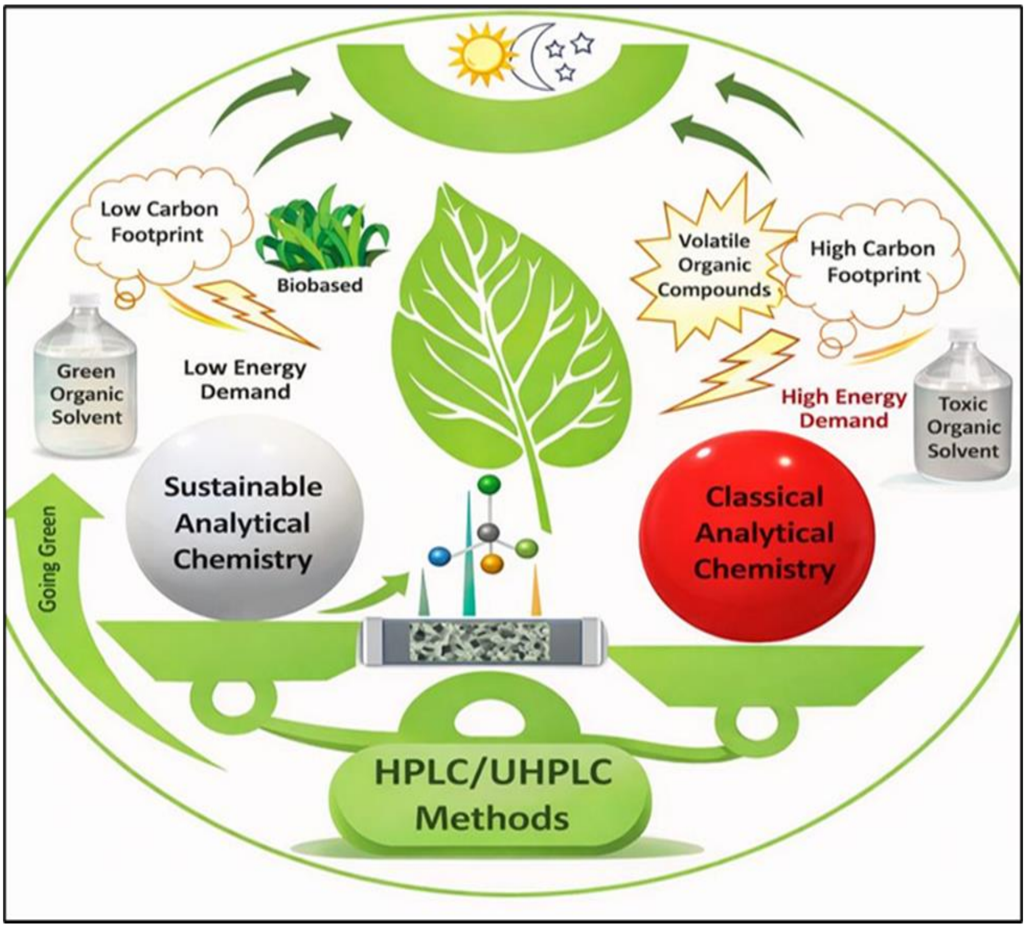

Fig. 6: Green Analytical Techniques.

6.2 Solid-Phase and liquid phase Microextraction: SPME and LPME leads to a substantial decrease in the amount of solvent and sample required, thus promoting sustainability. All these techniques enable the analysis of natural product compounds to be sensitive and selective, including flavonoids, phenolic compounds, alkaloids, terpenoids, and essential oils. It is an environmentally friendly sample preparation technique that minimizes reliance on hazardous solvents, aligning with green chemistry principles. With its very small extraction phase volume, the method produces minimal laboratory waste, requires little to no solvents, and offers fast, straightforward sample preparation. Its microextraction nature significantly reduces waste while enabling unique opportunities for in vivo sampling, avoiding labor-intensive procedures. The technique is easily automated, reducing manual handling and improving efficiency, making it highly practical for routine analysis. Additionally, SPME is well-suited for direct monitoring of environmental water and air, offering a simple, robust, and field-compatible option for on-site chemical analysis. These qualities make SPME and LPME an efficient, sustainable alternative to traditional extraction methods.

Microextraction techniques, such as solid-phase extraction (SPE) and dispersive liquid–liquid microextraction, are designed to significantly reduce solvent volumes while maintaining sensitivity and analytical accuracy. These approaches are particularly valuable for trace analysis.

6.3 Green Spectroscopic Techniques: Spectroscopic methods, including ultraviolet–visible (UV–Vis) spectroscopy, are considered green due to their minimal reagent consumption and reduced waste generation. These techniques often eliminate the need for extensive sample preparation and hazardous chemicals.

Near-Infrared (NIR) Spectroscopy is an inherently green method that reduces reliance on hazardous chemicals and solvents. It allows rapid, solvent-free analysis, such as checking solvent purity without sample preparation. By minimizing solvent use, NIR spectroscopy offers a sustainable alternative to traditional wet-chemistry methods. It also supports environmentally friendly recycling by improving sorting accuracy, reducing material demand, and lowering disposal costs through solvent recovery.[5]

Raman Spectroscopy is another eco-friendly approach designed to simplify analysis and shorten research times. It aids in crop monitoring, plant stress diagnosis, and sustainable agricultural practices. Raman spectroscopy enables real-time monitoring of solvent concentration during exchange or distillation, reducing solvent consumption and improving process efficiency. By eliminating delays linked to offline analysis, it saves reactor time, enhances process understanding, and supports industrial sustainability. Additionally, Raman spectroscopy facilitates recycling applications, such as precise large-scale sorting of waste plastics.

6.4 Voltametric and Electrochemical Methods: Voltammetry is prized for its simplicity, portability, affordability, and high sensitivity. Portable voltametric sensors enable fast, on-site analysis with minimal sample preparation. Advances in screen printing technology have made it possible to mass-produce low-cost, disposable screen-printed electrodes (SPEs), offering versatility, reproducibility, and reduced waste. Electrochemical methods also contribute to sustainability by replacing hazardous reagents with safer alternatives, thus reducing pollution. These methods are crucial for advancing green energy practices through efficient energy conversion and storage. For instance, fuel cells produce cleaner energy with fewer emissions via electrochemical reactions, while batteries enhance renewable energy storage, helping to balance the variability of solar and wind power. By reducing the environmental impact of synthesis and supporting greener energy technologies, electrochemical methods strongly align with the principles of Green Analytical Chemistry(GAC).[6]

6.5 Miniaturized Analytical Systems

The development of compact and portable analytical devices represents an important advancement in GAC. Miniaturized systems operate with smaller sample volumes, consume fewer reagents, and generate less waste, making them suitable for on-site and real-time analysis.

7. The three greenness assessment tools are briefly described here

7.1 NEMI (National Environmental Method Index): The Methods and Data Comparability Board (MDCB) developed the NEMI, which hosts the largest ecological analytical database. This tool provides free access to environmental methods through www.nemi.gov (accessed February 14, 2021). Keith et al. (2007) offered a detailed explanation of the instrument.

As illustrated in Figure 7, the NEMI is depicted as a circle known as the greenness profile, divided into four equal quadrants. The first quadrant represents PBT (persistent, bioaccumulative, and toxic), the second highlights acute toxicity, while the third and fourth correspond to corrosivity and waste generation, respectively. Each section can be shaded green to indicate compliance with green chemistry principles, or left blank if not.

The greenness profile accounts for critical parameters such as waste volume, pH, and the presence of substances with specific hazardous properties. This visual tool enables analysts to compare different analytical methods and evaluate their level of eco-friendliness and overall greenness.[7]

7.2 Analytical Eco-Scale Assessment (ESA): The Analytical Eco-Scale Assessment is a scoring system designed to evaluate how environmentally friendly an analytical process is. The scale begins with 100 points, representing the most eco-friendly method with no penalties. Penalty points are subtracted based on factors such as the use of hazardous solvents, excipients, additives, energy consumption, and other environmental impacts.

AES was proposed in 2012 as a semi-quantitative tool because it integrates descriptive and numerical data, and the obtained results enable researchers to make a reasonable estimation of the method's greenness profile. When assessing greenness using AES, the score calculation begins with a 100-point scale and deducts penalty points from this total. 100 points represent the ideal greenness, and penalty points are created based on parameters such as solvent and reagent amounts, energy consumption, and waste amounts. If the total score is higher than 75, it suggests that the method has excellent greenness. A total score between 50 and 75 indicates that the method's greenness is acceptable. If the total score is lower than 50, the method's greenness is inadequate. The main advantages of the AES tool are its ease of use, the provision of quantitative information on environmental impacts, and the evaluation of various environmental impacts. Although it appears to yield decisive results, it may struggle to distinguish the details of the analytical procedures. Additionally, the total AES score cannot be regarded as truly indicative of the cause of negative impacts; therefore, it becomes hard to determine the points that need improvement in the process. However, AES is an improvement over previously developed tool. AES tool is considered the most widely used tool with GAPI and AGREE.[8][9]

Penalty points are assigned according to the hazard level of chemicals involved. For instance, a chemical with no hazard pictogram receives zero penalty points (non-hazardous), while less hazardous chemicals are assigned one penalty point.

7.3 Green Analytical Procedure Index (GAPI): The Green Analytical Procedure Index, introduced by J. Płotka-Wasylka in 2018, is a modern tool designed to evaluate the environmental impact of analytical processes, covering every stage from sample collection to the final result. According to the GAPI framework, an analytical procedure typically begins with sample collection, followed by a phase that safeguards the sample from undesirable chemical or physical changes. The final phase involves the application of analytical techniques for detection and quantification. GAPI employs a pictogram to visually represent the ecological impact of each stage in the process. This pictogram uses a colour code green, yellow, and red to classify the degree of environmental friendliness, making it possible to quickly assess which stages are greener and which pose more environmental concerns.[10]

7.4 Analytical Greenness Calculator (AGREE)

The Analytical Greenness Calculator (AGREE) is a comprehensive and user-friendly evaluation method that provides an informative, easily interpretable result. Its assessment criteria are based on the 12 principles of Green Analytical Chemistry (GAC), which are integrated into a single 0–1 scale score.

- The most important advantages of the AGREE tool can be listed as follows:
- It is more comprehensive as it includes all the principles of green analytical chemistry.
- It is more flexible as it allows users to make some modifications.
- It allows easy analysis of the positive and negative aspects of the method thanks to the detailed pictogram.
- It gives both qualitative and quantitative results.
- The software is easy to use and gives fast results.

One advantage of AGREE is the availability of freeware software, making it highly accessible and simple to apply across different analytical contexts.[11][12]

7.5 Analytical method greenness score (AMGS)

AMGS calculator was introduced in 2019 by Hicks et al. and American Chemical Society Green Chemistry Institute Pharmaceutical Roundtable (ACS-GCI-PR). It is based on calculating a score by evaluating the parameters of cumulative energy demand of solvents, energy consumption, and waste production. Besides the score, a result based on three colors is obtained. AMGS tool is available online as a free program. AMGS is a quantitative tool that addresses many critical parameters and allows comparison. It is quite advantageous in terms of assessing environmental sustainability. However, the fact that it requires a lot of data entry to use the program makes it difficult to use.[13,14]

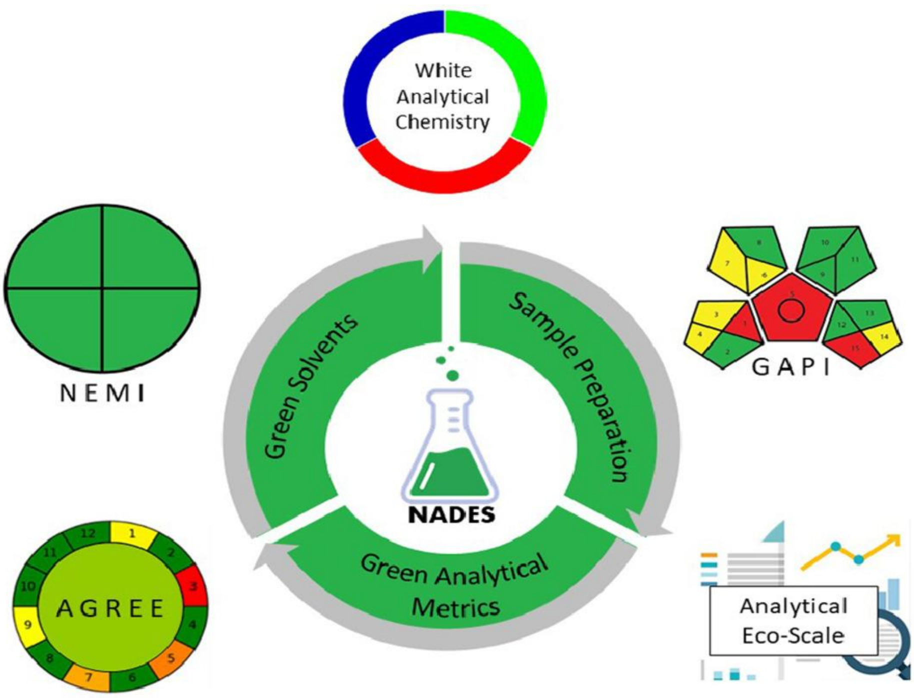

Fig. 7: Greenness assessment tools.

8. RECENT DEVELOPMENTS IN GREEN ANALYTICAL CHEMISTRY

8.1 Software's of Green Analytical Chemistry

The proposed tool is accompanied by a simple piece of software that facilitates the use of Complex GAPI for assessing the greenness of analytical procedures. It was developed in Python using the default 28 Tkinter library. The user selects parameters corresponding to both the pre-analysis processes and the sample preparation and analysis stages from drop-down menus, and a corresponding Complex GAPI pictogram is generated live for immediate reference. When ready, the pictogram can be saved as either a raster image (.png) or a vector graphic (.svg). The software is available under the open-source MIT license and can be downloaded from mostiedzy.pl/complexation. The code is made available in an open repository.

8.2 ECO-Footprint: In the early 1990s, Rees and Wackernagel devised an accounting tool called Ecological Food Enteral Footprint Analysis (EFA). It explains the quantity of a specific resource (ecosystem services) required for a specific level of consumption in an industrial activity or building project. The EF also explains how the ecosystem can absorb post-consumer waste to replenish all the resources used in a particular region for the production of goods and services. Global hectares (Gha) per person are used to express the EF measurement. If the EF value is lower, the industrial activities and population density in the area will be more environmentally friendly.

There are material footprints for energy, land, water, carbon, nitrogen, and phosphorus. A novel approach to estimating the general EF parameters. These approaches consider three main factors: built-up land, energy, and biological resource footprints. This approach was used to assess China's economic and technological developments between 1997 and 2011.

8.3 E-Factor: Based on the idea that the best solutions are usually the simplest, Sheldon developed a quick and simple metric called E (environmental factor) to evaluate the impact of industrial operations on the environment. The E-Factor is the total weight (in kilograms) of waste produced per kilogram of a product throughout an industrial or technological operation. The closer the E-factor number is to zero, the greener, more sustainable, and less wasteful the process will be. Therefore, it should be mentioned that depending on its potential uses, the E-Factor can be calculated with or without the process water.

The reported E-Factor values for a few selected industries of the chemical industry. This can also be used to evaluate how a certain industrial process, such the production of an electrical device, affects the environment. Compared to other chemical industry sectors, the pharmaceutical business has higher E-factor values. This is due to the fact that producing a very high-purity product necessitates a multi-stage reaction, which produces a lot of waste. Pharmaceutical manufacture also requires the use of extremely pure reagents.[17]

CONCLUSION

Green Analytical Chemistry (GAC) has emerged as a transformative approach that aligns scientific innovation with environmental responsibility. As the demand for sustainable practices continues to rise, the integration of green principles into analytical methods is no longer optional—it is essential. Tools such as the Analytical Eco-Scale provide practical and effective means to evaluate and improve the environmental performance of analytical procedures, guiding researchers toward greener alternatives.

By minimizing hazardous substances, reducing waste generation, and optimizing resource efficiency, GAC supports the broader goals of sustainable development and environmental protection. The adoption of its 12 guiding principles empowers chemists and researchers to design safer, more efficient processes while maintaining analytical quality and reliability.

Overall, this article emphasizes that green analytical chemistry is not only the need of the present but also a guiding light for the future. By embracing these sustainable practices, scientists and industries can contribute to environmental protection, support sustainable development, and ensure that future generations inherit a cleaner and safer world.

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