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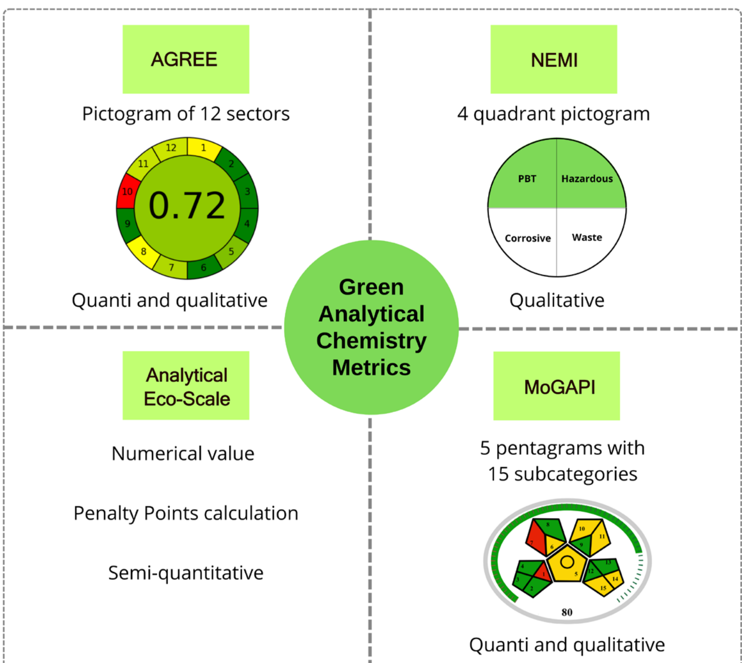
REVIEW

Overview of the Greenness' Metrics used to Evaluate Analytical Methods

Amanda Mohr*, Brendha Lang Camboim, Andreas Sebastian Loureiro Mendez, Cássia Virginia Garcia, Martin Steppe

Faculdade de Farmácia, Universidade Federal do Rio Grande do Sul Av. Ipiranga, 2752, 90610-000, Porto Alegre, RS, Brazil



The main goal of Green Analytical Chemistry (GAC) is to reduce the use of hazardous chemicals and waste generation in analytical procedures without compromising method performance. Over the years, several metrics tools were introduced to measure the environmental impact and greenness of analytical procedures. In this context, this paper aims to present an overview of the most used GAC metrics in analytical chemistry, highlighting their criteria, advantages, disadvantages, and comparing their applicability. After extensive research, the metrics selected to be addressed were: National Environmental Method Index (NEMI), Analytical Eco-scale, Modified Green Analytical Procedure Index (MoGAPI), and Analytical GREEnness Metric (AGREE). NEMI is one of the oldest GAC metrics, describing the greenness of the method by a simple pictogram. Analytical Eco-Scale is based on subtracting penalty points from a total score of 100 points. MoGAPI uses a pictogram made up of fifteen categories and a total score to display the greenness of the analytical procedure. AGREE is represented as a circular pictogram divided into 12 parts, where each part corresponds to a principle of GAC. Each discussed metric has its own advantages and disadvantages; however, AGREE stands out as the most widely used and comprehensive GAC metric, applicable to several techniques. Although time-consuming, ideally, the best approach is to apply all metrics in combination to gain as much information as possible.

Keywords: GAC metrics, NEMI, AGREE, MoGAPI, Analytical Eco-Scale

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INTRODUCTION

Over the last few decades, great interest has been raised about the impact of chemicals on the ecosystem.[1] The concept of Green Chemistry emerged in 1990 as the use of chemistry techniques and methodologies that reduce or eliminate the use or generation of hazardous substances.[2] Later, in 1999, following this idea, the term Green Analytical Chemistry (GAC) was proposed, and since then, it has been increasingly applied to minimize health and environmental impact.[3] In 2013, the Twelve Principles of GAC were proposed, with the main goal of reducing the use of hazardous chemicals and waste generation in analytical procedures without compromising method performance.[4-8]

In the field of the chemistry industry, several routine analyses are conducted, from production to quality control of the final product, leading to large amounts of waste generation. Different analytical techniques are employed daily, such as chromatography, spectroscopy, mass spectrometry, and electrochemical analysis, which vary in terms of hazardous chemicals use, chemical consumption, energy consumption, and waste generation.

Therefore, there has been concern about the environmental impact of these analyses and the use of green chemistry. To measure this impact and identify points for improvement in analytical methods, specific metrics have been developed. In this way, besides applying the concepts and principles of GAC, these appropriate evaluation tools are important to conclude whether the analytical procedure can be considered green and its degree of greenness. Over the years, several metrics tools were introduced to measure the greenness of analytical procedures.[9,10] Some of these metrics are: National Environmental Method Index (NEMI),[6] Analytical Method Volume Intensity (AMVI),[11] Analytical Eco-Scale,[12] HPLC-EAT (Environmental Assessment Tool),[13] Green Analytical Procedure Index (GAPI),[14] modified GAPI (MoGAPI),[15] Analytical Method GREEnness Score (AMGS),[16] Analytical GREEnness Metric (AGREE),[17] ChlorTox Scale,[18] and Blue Applicability Grade Index (BAGI).[19]

All the aforementioned metrics combine a score or a coloring pictogram result relating to the degree of greenness of the analytical procedure. Therefore, they can differ in their criteria, content, qualitative or quantitative approach, applicability on sample preparation, and specificity to certain instrumentation.[20,21] Some of them are not widely applied because they focus on particular evaluation parameters, such as the calculation of waste generation (e.g., AMVI), are specific to certain techniques (e.g., HPLC-EAT and AMGS), or are considered complex to use (e.g., ChlorTox Scale). In addition, authors tend to apply the most known metrics to their methods, as they are more established than other metrics and cover more analytical procedures.

In this context, this paper aims to present an overview of the most used GAC metrics in the analytical chemistry field, highlighting their criteria, advantages, disadvantages, and comparing their applicability. For that, extensive research was done about the studies published in the GAC metrics thematic, selecting review and research articles in different databases. As inclusion criteria, it was considered the most widely and generally used metrics once they can be applicable to the majority of analytical procedures. They were NEMI, Analytical Eco-Scale, MoGAPI, and AGREE. Thus, metrics that were less used or more specific were not addressed in this review. Additionally, a case study was conducted applying the four metrics addressed in this paper in an analytical method to compare and discuss the results obtained.

National Environmental Method Index – NEMI

One of the oldest GAC metrics is NEMI, where the greenness of the method is described by a pictogram divided into a four-quadrant circle. The quadrant will be considered and colored green if: (I) none of the reagents are defined as persistent, bioaccumulative, and toxic (PBT) by the Environment Protection Agency's Toxic Release Inventory (EPA-TRI); (II) none of the reagents are considered a hazardous waste by the EPA-TRI (according to the D, F, P, or U lists); (III) the pH of the sample lies in the range of 2 - 12; (IV) the generated waste is less than 50g. Otherwise, if one of these items is not met, the quadrant remains white. Thus representing only a general qualitative tool.[6,9,14,20,22]

The main advantage of NEMI is their simple and easily read representation. Despite their simplicity, no software is available for inputting the data; therefore, it requires a manual process to obtain the pictogram figure. Another disadvantage is the time-consuming process of searching for every compound in the EPA-TRI lists.[10,21,23,24] A while later, a modified-NEMI was proposed, which included a color scale and more assessment details, becoming a semi-quantitative approach.[1] Although the improvements in the modified-NEMI, few studies have reported their application.[25,26] Nowadays, NEMI is usually applied along with other quantitative metrics.[27-31]

Analytical Eco-Scale

Analytical Eco-Scale is a GAC metric based on subtracting penalty points (PPs) from the total score of ideal green analysis of 100 points. The final score allows us to classify the method as excellent (> 75 points), acceptable (75 – 50 points), and non-green (< 50 points). The higher the score, the more environmentally friendly the analytical procedure is.[5,10,12,21,24]

The assignment of the PPs takes into account the hazard and amount of chemicals used, energy consumed by instruments, waste generation, and occupational hazard, as shown in Table I. The metric has no software for calculation, involving a manual process and providing a semi-quantitative result.[1,23,32]

Table I. Analytical Eco-Scale PPs calculation

Parameters	Criteria	PPs*
Hazard	None	0
	Warning	1
	Danger	2
Amount of chemical	< 10 mL (g)	1
	10-100 mL (g)	2
	> 100 mL (g)	3
Energy consumption	≤ 0.1 kWh per sample	0
	0.1 - 1.5 kWh per sample	1
	> 1.5 kWh per sample	2
Waste generation	None	0
	< 1 mL (g)	1
	1 - 10 mL (g)	3
	> 10 mL (g)	5
	Generated waste has a recycling process	0
	Generated waste has a degradation process	1
	Generated waste has a passivation process	2
	Generated waste has no treatment	3
Occupational hazard	Procedure does not release vapors into the environment	0
	Procedure releases vapors into the environment	3

*PPs: Penalty Points

The main advantages of Analytical Eco-Scale are that different aspects of the environmental impacts are evaluated, and it has well-defined criteria for evaluation. The main disadvantage is that the score does not provide information about which were the causes of the PPs, making difficult the improvement and optimization of the process. In fact, from the score, without further information, it is difficult to critically evaluate the procedure and to find the critical points in which to intervene.[12,24]

Furthermore, the PPs are calculated by multiplying the parameter chemical hazard and amount of chemical used, as the influence of hazardous substances depends on their amount.[10,12] However, when assigning a hazard PP to a chemical, the metric simply asks to multiply the number of pictograms with the word symbol of “warning” or “danger”. So, the Analytical Eco-Scale does not consider the type of pictogram used and the severity or hazardous aspect. This can be problematic as some pictograms may indicate more severe hazards than others.[9,21] Table II shows an example of PPs calculation to evaluate an UFLC method for the determination of Omarigliptin in tablets.[33] Table III demonstrates some examples of hazard symbols and their meaning that can be found in some reagents and solvents. Table IV illustrates examples of the amount of energy consumed by some equipment used in the laboratory routine.

Recently, some studies applied the Analytical Eco-Scale to evaluate the greenness of their methods in combination with other metrics.[34-38] Only a few studies were found applying the Analytical Eco-Scale alone and claiming to be “eco-friendly”.[39,40]

Table II. PPs* used to evaluate an UFLC method for determination of Omarigliptin in tablets

			PPs*
Chemicals			
	Hazard	Amount	
Ammonium acetate	0	1	0**
Methanol	6	1	6**
Phosphoric acid	4	1	4**
Instruments			
UFLC			0
Balance			0
Sonicator			0
Total waste (1 - 10 mL)			3
Waste Treatment passivation			2
No vapours released			0
			Σ15
Analytical Eco-Scale Total Score: 85			

*PPs: Penalty Points; **Total Penalty Points = Hazard PP x Amount PP.

Table III. Reagent hazard symbols and their meanings

Meaning	Symbol	Example
Flammable		Acetonitrile
Toxic		Methanol
Health Hazard (eg, sensitisers, carcinogens)		Methanol
Corrosive		Phosphoric acid
Moderate Hazard (eg, harmful if inhaled or in contact with skin, causes eye irritation)		Phosphoric acid

Table IV. Amount of energy consumed by equipment

Equipment	Amount of energy
Raman	
Optical microscope	
Titration	<0.1 kWh per sample
UV-VIS spectroscopy	
UPLC	
HPLC	≤ 1.5 kWh per sample
GC	
GC-MS	> 1.5 kWh per sample
LC-MS	

MoGAPI

Proposed in 2018 by Płotka-Wasylka, GAPI uses a pictogram made up of five pentagrams divided into subsections to display the greenness of the analytical procedure.[14] Recently, in 2024, a modified GAPI tool (MoGAPI) has been developed to address some limitations of the former GAPI metric. The modification implemented a total score to enable comparison between methods and a new software to simplify and expedite its application.[15]

The MoGAPI, as well as the former GAPI, evaluates the environmental hazards of the entire analytical methodology using five colored pentagrams. Each pentagram comprehends a specific step of the procedure: sample handling, type of method, sample preparation, reagents and solvents used, and instrumentation, which are further divided into 15 subsections.[10,15,21]

The subsections are color-coded as green, yellow, and red to indicate the severity of their impact. Green signifies that the subsection is satisfactory and requires no further action. Yellow indicates that there may be minor issues that need to be addressed, while red highlights major problems that demand immediate attention. Additionally, if a circle is placed in the center of the pictogram, it indicates that the method is both qualitative and quantitative.[1,9,23,24] The criteria of MoGAPI and the fifteen subsections are shown in Table V, and the pictogram is illustrated in Figure 1.

Table V. MoGAPI parameters description

			Color (Points)		
Category	**No.**	**Subsection**	**Green (3)**	**Yellow (2)**	**Red (1)**
Sample handling	1	Collection	In-line	On-line or at-line	Off-line
	2	Preservation	None	Chemical or physical	Physicochemical
	3	Transport	None	Required	–
	4	Storage	None	Normal conditions	Special conditions
Method type	5	Direct or indirect	No sample preparation	Simple procedures	Extraction required
Sample preparation	6	Scale of extraction	Nano	Micro	Macro
	7	Solvents/reagents used	None	Green solvents/ reagents	Non-green solvents/reagents
	8	Additional treatments	None	Simple	Advanced
Reagents and solvents	9	Amount	< 10 mL (< 10 g)	10 – 100 mL (10 – 100 g)	> 100 mL (> 100 g)
	10	Health hazard (NFPA health hazard score)	0 or 1	2 or 3	4
	11	Safety hazard (NFPA flammability or instability score)	0 or 1	2 or 3	4
Instrumentation	12	Energy	≤ 0.1 kWh per sample	≤ 1.5 kWh per sample	> 1.5 kWh per sample
	13	Occupational hazard	None (Hermetic sealing)	–	Vapors to the atmosphere
	14	Waste	< 1 mL (< 1 g)	1 – 10 mL (1 - 10 g)	> 10 mL (> 10 g)
	15	Waste treatment	Recycling	Degradation, passivation	No treatment

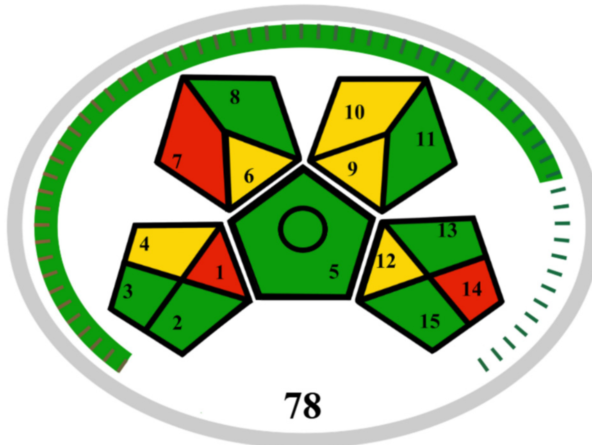

Figure 1. Illustrative MoGAPI pictogram.

Among the advantages of MoGAPI is that the color-system pictogram allows an easy perception of the greenness of each subsection and clearly indicates the weakest points of the procedure. The implementation of the total score provided an overall assessment of the method's greenness, further facilitating visualization and comprehension. This straightforward overview is especially useful for comparing different analytical methods based on their overall scores, especially when the analytical steps differ significantly. Moreover, MoGAPI covers many aspects of the procedure, allowing a more precise assessment of the green profile. Software is also available to directly input the method parameters and result in the pictogram.[9,15]

Although MoGAPI tries to cover the entire analytical process, its functionality can be difficult. Also, some categories can be difficult to fill in correctly into the software, like the concepts of sample preparation in-line, on-line, at-line, and off-line. Another disadvantage is that the subsection amount of reagents and chemicals used and the amount of waste considers the same label for a wide range of volumes.[1,10,21,32]

In 2021, the Complementary Green Analytical Procedure Index (ComplexGAPI) was introduced to assess the sample preparation of the method. It includes an extra hexagonal part that covers the preliminary activities involved in sample preparation and analysis.[41] Since its development, GAPI has been widely used in the literature along with other metrics.[42-47] Despite being very recent, there are already reports of the application of MoGAPI.[47-50] Additionally, a few studies applied the metric alone[51,52] or used the ComplexGAPI.[53-55]

AGREE

Developed in 2020, AGREE is the most widely used metric. It is represented as a circular pictogram divided into 12 parts, where each part corresponds to a principle of GAC. The input of the 12 parts is individually transformed into a score range of 0–1, and a final score is obtained by calculating the average of the parts. Depending on the scores obtained, each part is colored from dark green (score 1) to red (score 0), indicating the impact of each principle.[1,23,24,32]

Additionally, a specific weight is allocated to each part by software default, but that can also be changed by the user. In the pictogram, the length of each part reflects the specific weight assigned.[21] The resulting pictogram is like a clock shape, with a final score colored in the center surrounded by all the 12 parts, also colored,[17] as shown in Figure 2. Therefore, the metric provides both qualitative and quantitative results.[20] Table VI summarizes the criteria for assigning the scores based on the 12 principles of GAC.

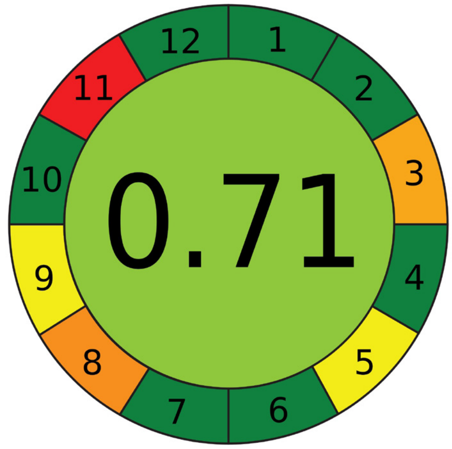

Figure 2. Illustrative AGREE pictogram.

The main advantage of AGREE is its comprehensive approach, as it covers all 12 principles of GAC, which makes the assessment more robust. Another advantage is that the assessment can be easily performed with user-friendly software that automatically generates the pictogram. The pictogram has an easy interpretation, with both color and numeric results, allowing the user to determine the overall greenness of the analytical procedure quickly. Moreover, the color scheme varies according to the score range of 0-1 rather than being restricted to the conventional colors of green, yellow, and red.[9,17,21]

As a disadvantage, it can be confusing and quite difficult to allocate and understand the weighting of the 12 parts.[1,10,20] Another difficulty is to correctly input the information on the software, some parts like the sampling procedure step could be difficult to understand, being recommended to read the original article of AGREE by Pena-Pereira, 2020.[17] Furthermore, one related issue is the lack of CAS data for some reagents in the derivatization part; this could be overcome by software updates and alternatively allowing the user to input the missing data manually.

Several authors have used the AGREE metrics.[56-61] A lot of studies applied this metric alone.[62-68] In 2022, the AGREEprep was introduced, designed to evaluate the greenness of the sample preparation process.[1] However, still few studies have applied it.[69,70]

Table VI. 12 criteria of AGREE assessment

No.	Principle/part	Condition	Score
1	Sample pretreatment	Remote sensing without sample damage	1.00
		Remote sensing with little physical damage	0.95
		Non-invasive analysis	0.90
		In-field sampling and direct analysis	0.85
		In-field sampling and on-line analysis	0.78
		On-line analysis	0.70
		At-line analysis	0.60
		Off-line analysis	0.48
		External sample pre-and treatment (reduced number of steps)	0.30
		External sample pre-and treatment (large number of steps)	0.00

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Table VI. 12 criteria of AGREE assessment (continued)

No.	Principle/part	Condition	Score
2	Amount of sample	Ultra-microanalysis (<1 mL or g)	1.00
		Micro-analysis (1–10 mL or g)	According to equation
		Semi-microanalysis (10–100 mL or g)	
		Macro-analysis (>100 mL or g)	
3	Instrumental position	In-line	1.00
		On-line	0.66
		At-line	0.33
		Off-line	0.00
4	Method's steps	3 or less	1.00
		4	0.80
		5	0.60
		6	0.40
		7	0.20
		8 or more	0.00
5	Level of automation and miniaturization	Automatic, miniaturized	1.00
		Semi-automatic, miniaturized	0.75
		Manual, miniaturized	0.50
		Automatic, not miniaturized	0.50
		Semi-automatic, not miniaturized	0.25
		Manual, not miniaturized	0.00
6	Derivatization	No derivatization applied	1.00
		Derivatization applied	According to equation
7	Amount of waste	≤ 0.1 (mL or g)	1.00
		10 (mL or g)	0.40
		25 (mL or g)	0.25
		100 (mL or g)	0.1
		Any other amount	According to equation
8	Number of analytes/hour	70	1.00
		50	0.9
		10	0.5
		1	0.0
		Any other number of analytes	According to equation
9	Energy consumption/sample	<0.1 kWh	1.0
		0.1–1.5 kWh	0.5
		>1.5 kWh	0.0

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Table VI. 12 criteria of AGREE assessment (continued)

No.	Principle/part	Condition	Score
10	Renewable source reagent	No reagents	1.0
		All reagentes are bio-based	1.0
		Some reagents are bio-based	0.5
		None of the reagents are from bio-based sources	0.0
11	Toxic reagents used	No	1.0
		Yes	According to equation
12	Number of threats to operator	0	1.00
		1	0.80
		2	0.60
		3	0.40
		4	0.20
		5 or more	0.00

DISCUSSION

The increased concern with environmental issues and the incentive to apply GAC principles in procedures emerge the need to create metrics to assess the greenness of methodologies. As a result, various tools such as NEMI, Analytical Eco-Scale, MoGAPI, and AGREE have been proposed. Those metrics are applicable to several methodologies used in analytical chemistry. Their use is very important because it allows us to identify more clearly the specific steps and reagents and solvents of the methodology that have the greatest negative environmental impact. In general, a GAC metric should give easily readable results. Also, the criteria should include several parameters such as waste generation, waste treatment, the hazard of the chemicals, use of renewable source chemicals, the safety of the analyst, energy consumption, and sample preparation.

GAC metrics have been extensively researched and applied since their creation, highlighting their significance in demonstrating the environmental impact of analytical methods. The use of a metric translates into paper publications, and through the amount of papers published applying the metric is possible to measure its utilization. After researching the metrics addressed, it is remarkable the increased number of papers published in recent years (Figure 3). Back in 2019 and 2020, only NEMI and Analytical Eco-Scale were applied, and the concept of GAC metrics was still in its beginning. Later, GAPI and AGREE were created and well-accepted by the researchers. As seen in Figure 3, the paper's publication applying NEMI, Analytical Eco-Scale, GAPI, and AGREE are being used in constant increase, demonstrating their importance. Interestingly, most of the works presented in Figure 3 employed the Liquid Chromatography (LC) technique. Although greener techniques exist, such as ultraviolet-visible spectroscopy and capillary electrophoresis, which consume lower reagents and solvent amounts, LC remains a popular technique. Still, efforts have been made to develop greener LC methodologies and evaluate their environmental impact through the use of the GAC metrics.

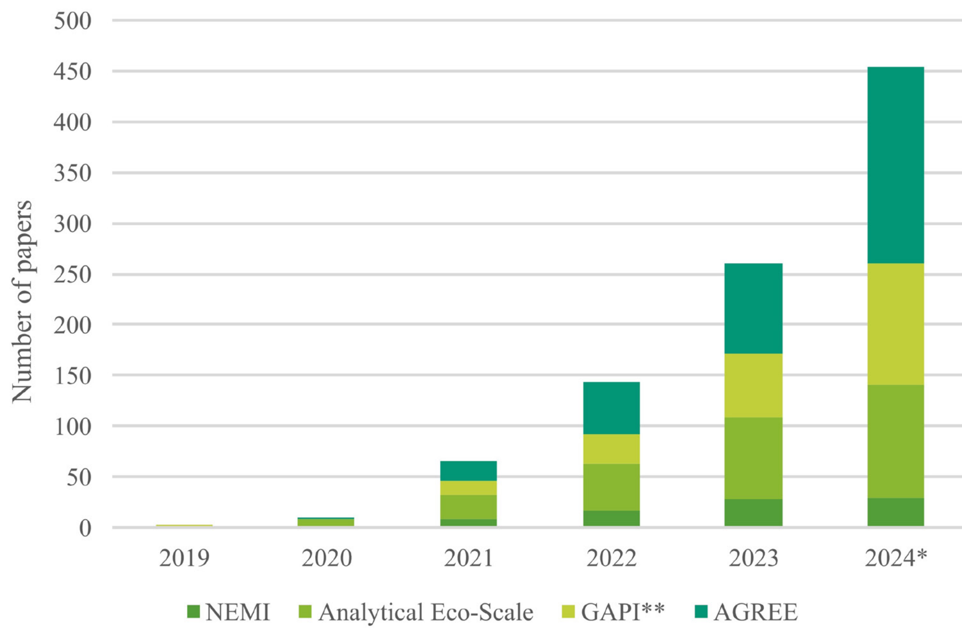

Figure 3. Number of papers using NEMI, Eco-Scale, GAPI and AGREE over the years. Note: *Results up to november 2024. **Results of MoGAPI were also included. Data obtained in Scopus, keywords: "corresponding metric" + green metric.

As a historical timeline, NEMI was the first GAC metric reported, then the Analytical Eco-Scale, GAPI, and AGREE. Two versions of sample preparation tools were also created, the ComplexGAPI and AGREEprep. In 2024, a modification of GAPI was developed, the MoGAPI. Also, a recent metric, namely BAGI, was reported focusing on the White Analytical Chemistry and has been proposed as a complementary to the GAC metrics already established. For this reason, BAGI was not deeply discussed.

To further discuss and compare the GAC metrics, a case study was conducted applying the four metrics addressed in this paper in a previously developed UFLC method for pharmaceutical quantification of the drug Omarigliptin.[33] The results obtained from the four metrics are shown in Figure 4. The application of NEMI resulted in three out of four green quadrants, demonstrating the eco-friendly nature of the method. The hazardous quadrant was not labeled green since the methanol and phosphoric acid used in the mobile phase are considered hazardous waste by the EPA-TRI. The Analytical Eco-Scale total score obtained was 85, classifying the method as excellent greenness. Ten penalty points were assigned to the hazardous and amount of methanol and phosphoric acid used. The total waste per analysis of the method was 1.32 mL, and for that, 3 penalty points were assigned due to the waste being in the range of 1 - 10 mL. Finally, the method received 2 penalty points for the passivation waste treatment.

In the MoGAPI assessment, most categories were considered green, and only two were red in the pictogram. The red categories were due to offline sample preparation and the use of non-green solvents. The yellow categories were received because the sample preparation involves simple procedures and is on a micro-scale, the solvents methanol and phosphoric acid have a health and safety hazard of 3, and similar to the Analytical Eco-Scale, the waste generated has passivation treatment and is on the range of 1 – 10 mL. The method had a total score of 80 and was considered green.

Unlike the other metrics, the AGREE pictogram has a color scheme that varies according to the score received in each category. The case study method only received one absolute red color because none of the solvents used were from bio-based sources. Some of the categories were colored as weak green and weak yellow due to the sample pretreatment being off-line, the amount of waste per analysis of 1.32 mL, only 1 analyte is determined in a single run, the use of approximately 0.43 mL of toxic solvents, and the chemicals used are flammable and explosive. The method achieved an overall AGREE score of 0.72, indicating its environmental friendliness. In general, the four metrics yield similar results, suggesting that the method can be considered green. However, the complexity level differs among the metrics, and for a more comprehensive and robust evaluation, they should be used combined.

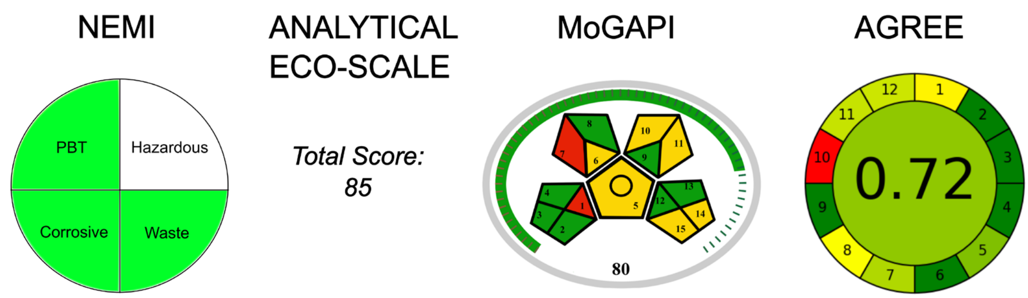

Figure 4. Results of the case study showing the application of the NEMI, Analytical Eco-Scale, MoGAPI and AGREE in an UFLC method for the determination of Omarigliptin.[33]

As illustrated in the case study, NEMI is the only qualitative metric, despite their very easily readable pictogram, it does not show much information and has been replaced by the most new and complete metrics. Analytical Eco-Scale is considered a semi-quantitative approach. It stands out compared to NEMI due to its detailed discussion of the analytical procedure, considering more parameters, and providing an assessment of the greenness as a numerical value. Nevertheless, the main issue of both metrics is the manual and time-consuming process to acquire the necessary information about the chemicals used in the analytical method.

The MoGAPI combines the visual impact of the colored pentagrams with an accurate overall score. The improvement of the total score enabled the metric to give a more accurate and objective comparison between methods instead of just evaluating each step separately. In addition, MoGAPI offers several advantages over Analytical Eco-Scale because it covers a wide range of the analytical procedure aspects, and it gives not only a numerical value but also some colored qualitative information, making MoGAPI more robust. However, none of these metrics consider each one of the 12 principles of GAC.

AGREE is the only metric that has the advantage of including all the 12 principles, previously not considered. It also gives both quantitative and qualitative results, similar to the MoGAPI, and has an easy visualization pictogram. This can explain the fact that AGREE is the most GAC metric applied alone without other complementary metrics. An overview of the GAC metrics is represented in Table VII.

Table VII. Overview of the GAC metrics

GAC metric	Outcome data	Representation	Advantages	Disadvantages
NEMI	Qualitative	4 quadrant pictogram 	Simple and easily read representation.	Requires manual process to obtain the pictogram; Time consuming.

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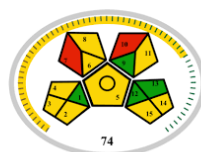
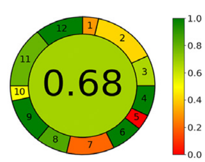
Table VII. Overview of the GAC metrics (continued)

GAC metric	Outcome data	Representation	Advantages	Disadvantages
Analytical Eco-Scale	Semi-quantitative	Numerical value	Evaluate different aspects of the environmental impacts; Well-defined criteria of evaluation.	Lack of information about which were the causes of the PPs; Difficult to critically evaluate the procedure.
MoGAPI	Quantitative and qualitative	5 pentagram with 15 subcategories 	Color-system allows an easy perception of the greenness; Clearly indicates the weakest points; Total score facilitates comprehension; Covers many aspects of the procedure.	Difficult functionality; Consider the same label for a wide range of volumes.
AGREE	Quantitative and qualitative	Pictogram of 12 sectors 	Easily performed using the software; Automatically generated pictogram; Easy to visualize the weightage; Consider all the 12 principles of GAC.	Confusing to allocate and understand the weighting; Lack of explanation about the terms in Sampling Procedure step.

Nowadays, a change must be made in the evaluation of analytical methodologies. Not only usual parameters are required when assessing the analysis performance and conducting practical studies, but also it must be considered the environmental impact and the sustainability level of analytical techniques. The analytical researchers should know the impact that the process causes on the environment, to limit hazards discharged into the ecosystem. So, the GAC parameters should be evaluated during the construction and planning phase of the analysis. For this, it is worthwhile and important to apply the GAC metrics.

CONCLUSIONS

It was possible to conclude that over the years the GAC metrics have improved and are increasingly being applied. All of the metrics discussed have their own particularities, advantages, and disadvantages. After analysing all the metrics, we observed that AGREE is the most complete and most used GAC metric on its own. In addition, its pictogram is the most encompassing, being the only one that covers all 12 principles. It has an easy comprehension as the color scale allows a better visualization and understanding of the method's greenness profile. The MoGAPI now also provides an easy visual overview of the environmental impact and safety of the method, along with a total score assigned to each method. Moreover, although it is very time-consuming, ideally the best approach is to apply all the metrics in combination to gain as much information as possible, ensuring a comprehensive evaluation of the environmental impact. It is important to note that measuring greenness is not just about determining the quantity of waste but also considering all factors involved in the methodology. Also, the current GAC metrics need further improvements to enhance their user-friendliness and provide quantifiable reference values. So, it can be expected that more enhanced metrics emerge in the future.

Conflicts of interest

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