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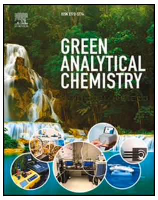

RGBfast – A user-friendly version of the Red-Green-Blue model for assessing greenness and whiteness of analytical methods

Paweł M. Nowak [a,*], Fabiana Arduini [b]

[a] Department of Analytical Chemistry, Jagiellonian University in Kraków, Gronostajowa 2, 30-387 Kraków, Poland
[b] Department of Chemical Science and Technologies, University of Rome Tor Vergata, via della ricerca scientifica, 000133, Rome, Italy

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ABSTRACT

A new version of the popular RGB model has been developed to meet the expectations of users of greenness and whiteness assessment metrics. It has been called "RGBfast" due to its simplicity and significant assessment automation. The criteria were limited to six key parameters that are easy to objectively express numerically, which combine various features of analytical method determining its functionality and sustainability. A customized Excel sheet applies the entire procedure itself after entering the appropriate input data. The assessment outcomes are presented in concise and easy-to-interpret tables, which can be used as pictograms. RGBfast enables reliable comparison of alternative procedures dedicated to the same purpose, thus can be a good support during the validation of new methods and literature reviews. As a case study, the model was applied to compare five methods for the determination of phosphate using different types of (bio)sensors. Subtle differences between them have been captured and analyzed. The mathematical structure of the model can be modified in the future, for example to take potential opportunities offered by artificial intelligence technology.

1. Introduction

The implementation of the idea of green analytical chemistry (GAC), i.e. the development of environmentally friendly and safe procedures and methodologies, is currently one of the main trends in analytical chemistry [1-5]. A reliable assessment of greenness is of key importance to prevent using phrases such as "my method is green" or "my method is greener than yours" as superfluous and benefit-oriented statements. Assessment is possible thanks to various metrics dedicated to this purpose [6-8]. Analytical Eco-Scale [9], GAPI [10], AGREE [11], and their extended versions [12,13], are the often used examples. Since each approach has its limitations, a reasonable solution seems to be the use of several different models at the same time, because their differences can complement each other, and together build a more comprehensive and objective image of greenness.

For several years, the idea of white analytical chemistry (WAC) has also been promoted [14], which expands the concept of GAC and indicates the need to achieve the best possible compromise between greenness and functionality. WAC refers to the Red-Green-Blue model of a light color, in which greenness is one of the three primary components of whiteness [15,16]. Red color is assigned to analytical aspects as trueness (previously called accuracy), precision, sensitivity, and blue is assigned to practicality and economics [17]. The overall quality of the method is expressed by whiteness. A whiter method is one that is more comprehensive and overall better, but at the same time not necessarily greener (note that a certain method may be highly green but not very functional in the red or blue area, so it will not represent the desired compromise).

Two versions of the RGB model are used to assess whiteness: RGB (first version from 2019) - which gives freedom in choosing the assessment criteria [15], and RGB 12 (second version from 2021) - which indicates 12 criteria divided into 4 red, 4 green, and 4 blue [14]. Both versions run in a formated and automated Excel spreadsheet. Unlike models such as Analytical Eco-Scale, GAPI, and AGREE, there are no rigid assessment guidelines. The appropriate number of points for each criterion, expressing how good is particular aspect, is awarded by the user. Thanks to this, the RGB model remains flexible in terms of the specificity of the assessed method and does not impose rigid expectations. The evaluator is obliged to apply the procedure objectively, adapting the rigor of assessing individual parameters to the nature of the

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Abbreviations: RGB, Red-Green-Blue; GAC, Green Analytical Chemistry; WAC, White Analytical Chemistry; CH, Chemical Hazard; LLMs, Large Language Models; AI, Artificial Intelligence.

* Corresponding author.

E-mail address: pm.nowak@uj.edu.pl (P.M. Nowak).

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method.

As one of us is the author of both versions of the RGB model, we keep up to date with its applications and comments from the users' community. Despite quite a lot of interest and many examples of use, some drawbacks of the model are raised. The most common criticisms include the relatively high complexity and time-consuming evaluation procedure, the lack of rigid rules and detailed guidelines for scoring individual criteria, as well as the possibility of manipulating the expected assessment results, leading to a decrease in objectivity.

Moreover, in the meantime, in cooperation with other specialists in the field of GAC, a new greenness indicator has been developed, called ChlorTox Scale [18] (more information about it in the Section 2.2), which seems to be a more objective approach than "simply counting" pictograms and the amount of reagents used. However, it has not yet been integrated into the RGB model.

It should be emphasized here that the implementation of the GAC and WAC ideas absolutely requires the use of reliable tools (metrics) that are based on hard data proving the individual features and quality of the developed methods, but at the same time they cannot be too complicated, and the evaluation procedure cannot be ambiguous. Therefore, we decided that it is high time to propose an improved version of the RGB model, which could be a tool of choice when assessing methods from the point of view of WAC in the forthcoming future.

Therefore, the purpose of this article is to present such new, improved version of the RGB model, called RGBfast, which includes ChlorTox Scale as one of the criteria. This version was developed based on the opinions and needs of users. The main advantages of RGBfast over previous versions are simplicity of use, transparency, automation of the assessment procedure, and limited freedom of manipulation.

2. RGBfast

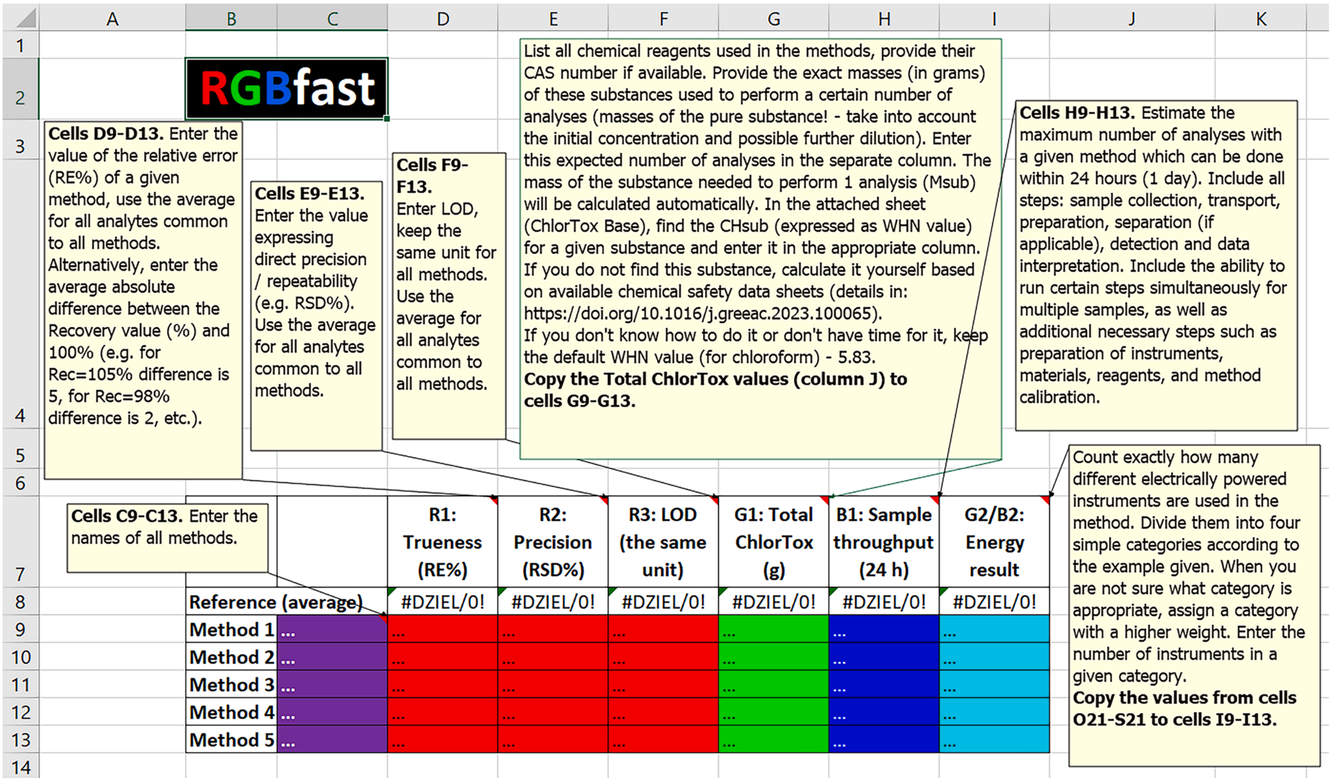
2.1. General information

As in the previous versions, the RGBfast model is based on an automated Excel spreadsheet containing a place to enter appropriate data, explanation of assessment guidelines, and presentation of assessment results in the form of an automatically formated tables/pictograms - see Fig.1. This spreadsheet is attached as a supplement to this article.

2.2. Selection of criteria

It is important to realize that the more we want to simplify the structure of the assessment model, the greater the risk that the model will not be reliable and credible. It is necessary to find a golden mean. Therefore, for optimizing criteria number, we decided to use six that are easy to quantify based on hard experimental data and to numerical expression. As will be explained in a moment, although their number may seem too small, they often refer to more than one feature of the method. Thus, they suffice to showcase the overall methods' greenness and whiteness.

In the case of red color, we chose three basic ones: trueness (R1) expressed in relative error or recovery, precision/repeatability (R2) expressed in the relative standard deviation of the analytical result obtained within one day, and LOD (R3) expressed as lowest detectable concentration (note that accuracy is understood herein as a combination of R1 and R2 criteria). This choice was dictated by the easy availability of this data in almost every publication presenting new chemical analysis methods. It is to be noted that the choice of other parameters, e.g. reproducibility or robustness, could pose the problem of availability of data for comparison and the lack of a universal measure allowing for "face-to-face" comparison if methods were validated using different



Cells D9-D13. Enter the value of the relative error (RE%) of a given method, use the average for all analytes common to all methods. Alternatively, enter the average absolute difference between the Recovery value (%) and 100% (e.g. for Rec=105% difference is 5, for Rec=98% difference is 2, etc.).

Cells E9-E13. Enter the value expressing direct precision / repeatability (e.g. RSD%). Use the average for all analytes common to all methods.

Cells F9-F13. Enter LOD, keep the same unit for all methods. Use the average for all analytes common to all methods.

List all chemical reagents used in the methods, provide their CAS number if available. Provide the exact masses (in grams) of these substances used to perform a certain number of analyses (masses of the pure substance! - take into account the initial concentration and possible further dilution). Enter this expected number of analyses in the separate column. The mass of the substance needed to perform 1 analysis (Msub) will be calculated automatically. In the attached sheet (ChlorTox Base), find the CHsub (expressed as WHN value) for a given substance and enter it in the appropriate column. If you do not find this substance, calculate it yourself based on available chemical safety data sheets (details in: https://doi.org/10.1016/j.greeac.2023.100065). If you don't know how to do it or don't have time for it, keep the default WHN value (for chloroform) - 5.83. **Copy the Total ChlorTox values (column J) to cells G9-G13.**

Cells H9-H13. Estimate the maximum number of analyses with a given method which can be done within 24 hours (1 day). Include all steps: sample collection, transport, preparation, separation (if applicable), detection and data interpretation. Include the ability to run certain steps simultaneously for multiple samples, as well as additional necessary steps such as preparation of instruments, materials, reagents, and method calibration.

Cells C9-C13. Enter the names of all methods.

Count exactly how many different electrically powered instruments are used in the method. Divide them into four simple categories according to the example given. When you are not sure what category is appropriate, assign a category with a higher weight. Enter the number of instruments in a given category. **Copy the values from cells O21-S21 to cells I9-I13.**

		R1: Trueness (RE%)	**R2: Precision (RSD%)**	**R3: LOD (the same unit)**	**G1: Total ChlorTox (g)**	**B1: Sample throughput (24 h)**	**G2/B2: Energy result**
Reference (average)		#DZIEL/0!	#DZIEL/0!	#DZIEL/0!	#DZIEL/0!	#DZIEL/0!	#DZIEL/0!
Method 1	...	...	...	...	...	...	...
Method 2	...	...	...	...	...	...	...
Method 3	...	...	...	...	...	...	...
Method 4	...	...	...	...	...	...	...
Method 5	...	...	...	...	...	...	...

Fig. 1. A screenshot of Excel sheet with the RGBfast model encoded showing the main table for data input. The assessment can be performed for 2–5 methods at the same time. To perform it, the values of six parameters are only needed. Guidelines for the individual columns are described in the comments. After entering the data, everything is automatic (the stage of awarding points has been eliminated). See the attached Excel sheet for more information (note that some parts of the sheet are not shown in this figure).

procedures.

In the case of greenness assessment, we decided to use the ChlorTox Scale [18] – criterion (G1). It is a quite new greenness indicator that allows to estimate the overall risk associated with the use of chemicals. Most importantly, each chemical reagent is considered individually and its contribution to the overall risk depends on both its quantity and the hazards it poses. The risk is estimated by comparison to the reference substance - chloroform:

$$\text{ChlorTox} = \frac{CH_{sub}}{CH_{CHCl3}} \cdot m_{sub} \tag{1}$$

Where the ChlorTox value, expressed in the mass of chloroform (g), reflects a degree of chemical risk associated with the substance-of-interest, considering its properties (hazards) and the amount used. $\mathrm{CH_{sub}/CH_{CHCl3}}$ represents a relative Chemical Hazard (CH) of using the assessed substance in relation to chloroform, assuming the same mass-to-volume concentration of both chemicals, and $\mathrm{m_{sub}}$ is a mass of the substance-of-interest needed to apply the method.

To facilitate the use of the ChlorTox Scale, the ChlorTox Base has recently been published [19], a database of approximately 700 chemicals characterized for hazards ($\mathrm{CH_{sub}}$ values) based on averaged information from chemical safety data sheets. This database has also been integrated with the Excel sheet containing RGBfast, making finding the appropriate $\mathrm{CH_{sub}}$ value very easy for model's user. If despite this there is no data in the database, it is recommended to estimate the missing values based on averaged data presented in the updated safety data sheets of given chemicals, or ultimately, to assign the value $\mathrm{CH_{sub}} = 5.83$, which corresponds to the reference substance – chloroform (it is highly toxic, so there is a small risk of underestimating the risk by assuming the same value for chloroform and the substance of interest). The details on how to get the appropriate $\mathrm{CH_{sub}}$ values from official safety data can be found in the literature [19].

The user of the RGBfast model should only have reliable data on the mass of a given reagent in a pure form which is needed to perform a certain known number of analyses. ChlorTox values are calculated automatically in an Excel spreadsheet. The assessment of the method depends on the sum of these values obtained for all reagents, i.e. Total ChlorTox. To conclude, the ChlorTox criterion combines two input data: the amount of reagents (translating into the amount of waste generated) and their hazards. Remarkably, because these two parameters are always calculated independently for each reagent, the assessment is much more objective than in previous versions of the RGB model where all reagents were treated holistically [14,15].

In our opinion, the use of the ChlorTox Scale as the main measure of greenness (although not the only one – see the next criterion), is crucial to ensure the reliability of RGBfast-based assessments. The advantage of this approach is the reliance on hard empirical data and the ability to indicate even small differences between methods. The ChlorTox Scale is continuous and does not require simplifying categorization, e.g. into reagents posing low, medium and high risk. Moreover, attention should be paid to the multi-aspect nature of this tool. Obtaining low ChlorTox values will be easier in the case of methods that are miniaturized, automated, do not require complicated sample preparation or derivatization steps, and which are economical in terms of the use of solvents or allow replacing hazardous solvents with green equivalents. In a word, ChlorTox as a parameter combines many green criteria (and many principles of GAC [4]), so it should not be considered as a single-aspect and narrowed view of greenness.

The next criterion concerns the estimated electricity consumption (G2/B2). This criterion is included in both the green attribute – because the production and supply of electricity entails a carbon footprint [20], and the blue attribute – because it can be used to model the cost intensity of the method. Firstly, downloading electricity from the grid generates costs, and secondly, there is a certain analogy between the complexity and advancement of research instruments, their energy demand and price. Noticeably, the most expensive instruments found in analytical laboratories, such as UHPLC-MS, CE-MS, GC–MS/MS, ICP-MS or NMR spectrometers, generally consume the most energy. Simple methods using uncomplicated, portable and cheap equipment are usually characterized by relatively low or very low energy consumption.

To simplify the assessment, research and laboratory instruments have been divided into five categories with different energy consumption, which have been assigned different weights: weight 0 – category 0 (methods based on smartphones or microelectronic devices like laptops, whose energy consumption for measurements is negligibly small), this category is not listed in the Excel sheet as it is insignificant for the assessment outcome; weight 0.5 - category I (pH-meter, balance, magnetic stirrer, etc.), weight 1.5 - category II (small centrifuge, laboratory evaporator, grinder, heater, etc.), weight 3.0 - category III (fume hood, large centrifuge, chromatograph, spectrophotometer, fluorimeter, electrophoresis instrument, etc.) and weight 10 - category IV (systems coupled with mass spectrometry, e.g. LC-MS/MS, ICP-MS, NMR spectrometer, etc.). The criterion is assessed very simply, just by counting the instruments used by the method in each category. Of course, it should be emphasized that this approach is a certain simplification. Division into arbitrary categories does not replace direct measurement of the energy consumption of a given instrument at a given time. Moreover, this criterion does not cover all costs associated with the method, e.g. the price of reagents and materials. A more detailed approach, including direct energy measurement and cost estimation for each material and instrument, would significantly complicate the assessment procedure. Moreover, referring to the price is not easy because it changes over time, depending on the manufacturer and country of distribution. By proposing such approach, as we believe, probably the good compromise between simplicity and maintaining scientific value can be reached.

The last, sixth criterion is sample throughout (B1). This blue parameter is assessed by accurately estimating the maximum number of analyses/measurements that can be performed using a given method during 24 h of continuous operation. The estimate should include additional steps, such as calibration and instrument preparation, and assume maximum throughput at each step. For example, if the sample preparation technique allows certain steps to be performed simultaneously for multiple samples, this should be taken into account. Intermediate stages that require manual work and processing of research material should also be included, e.g. preparation of buffers, dilution of samples, centrifugation, etc. Thanks to this, this criterion takes into account several aspects: the duration of individual stages, e.g. extraction, centrifugation, chromatographic separation; automation and integration of individual stages of analysis, e.g. online techniques will be preferred over offline ones; and the miniaturization of equipment, which promotes sample throughput. Like ChlorTox (G1) and energy (G2/B2), sample throughput is therefore also a multi-faceted criterion.

To sum up, the RGBfast model considers six criteria, the three red criteria (R1-R3) are the main validation parameters crucial for assessing the analytical effectiveness of the method. The three remaining green-blue criteria (G1, B1, G2/B2) are multi-faceted, covering such features of the method as the amount of reagents and waste, chemical hazard, potential carbon footprint, energy and instrument costs, duration of individual stages of analysis and the degree of automation and integration of the procedure. In relation to previous versions of the RGB model, some aspects were omitted, but thanks to this the assessment procedure could be significantly simplified.

2.3. *Mathematic rules*

The basic assumption of the RGB model regarding the need to take into account the specificity of the method remains unchanged. However, in this version a solution was adopted that allows the assessment procedure to be automated and to avoid the often questioned stage of subjective awarding of points. The key in the current approach is the assumption that at least two methods with similar specificity are always assessed, e.g. dedicated to the same analytes and a similar sample matrix. The values of the relevant criteria are compared to the arithmetic average obtained for all compared methods, which depends on the methods' specificity. There is an appropriate mathematical rule allowing the assessment results (*Scores* values) to be narrowed down to 0–100 in each case (Eq.2):

$$Score = 100 \cdot \frac{1}{1 + \frac{Result}{Average\ result}} \tag{2}$$

Where *Result* is the value of a given parameter for the assessed method, and *Average result* is the arithmetic average for all methods. It is worth remembering that in the case of each criterion, the higher the *Result* value, the worse the characteristics of the method, i.e. it may be a greater error, worse repeatability (higher RSD), higher LOD, greater chemical risk (ChlorTox), greater energy consumption and worse sample throughput (the inverse of the number of analyses within 1 day). Adopting this formula allows for a simple interpretation of *Score*. When the criterion is rated as close to ideal and the *Result* value is extremely low in comparison to *Average result*, the *Score* is close to 100; when *Result* and *Average result* show the same value, *Score* is 50; when *Result* is worse (higher) than the *Average result*, the *Score* is <50 (note that $Score=0$ is unattainable in practice, the method would have to be infinitely bad).

The saturation of a given primary color and whiteness are calculated as the geometric average of the corresponding *Score* values (Eq.3-6):

$$Redness = \sqrt[3]{Score_{R1} \cdot Score_{R2} \cdot Score_{R3}} \tag{3}$$

Where R1 – trueness, R2 – precision, R3 – LOD.

$$Greenness = \sqrt[3]{{Score_{G1}}^2 \cdot Score_{G2/B2}} \tag{4}$$

Where G1 – ChlorTox, G2/B2 – energy.

$$Blueness = \sqrt[3]{{Score_{B1}}^2 \cdot Score_{G2/B2}} \tag{5}$$

Where B1 – sample throughput, G2/B2 – energy.

$$Whiteness = \sqrt[9]{Score_{R1} \cdot Score_{R2} \cdot Score_{R3} \cdot {Score_{G1}}^2 \cdot {Score_{B1}}^2 \cdot {Score_{G2/B2}}^2} \tag{6}$$

The green-blue criteria have double significance because they are multi-aspect and combine several important features of the method. In addition, thanks to this, all primary colors have the same contribution to whiteness (1/3). The use of the geometric average at this stage is very important – consistency and good balance of the method's potential without significant drawbacks are rewarded. For example, the arithmetic average of the sets (1,4,10) and (5,5,5) is the same – 5, and the geometric average is approximately 3.4 for the first and 5 for the second. A better result was obtained for the second set, where the values show less variation. In the first set, the value "1″ may constitute a significant bottleneck of the method, excluding its use. The adopted model is therefore consistent with the WAC idea that rewards the search for an optimal compromise between red, green and blue attributes [14].

2.4. Interpretation remarks

One can easily conclude that the assessment results are intrinsically relative, because they depend on the selection of reference methods for comparison (*Average result* value in Eq.2). Moreover, it is impossible to assess only one method without any reference. Are these significant limitations? It is important that we realize what purposes greenness and whiteness metrics are currently used for. Typically, it is a comparison of different methods dedicated to the same purpose. The RGBfast model is very suitable for such a task. The adopted mathematical rules make it possible to highlight the differences between the compared methods of similar specifics and being mutual alternatives. The assessment is based on hard experimental data, assuring outcomes are reliable.

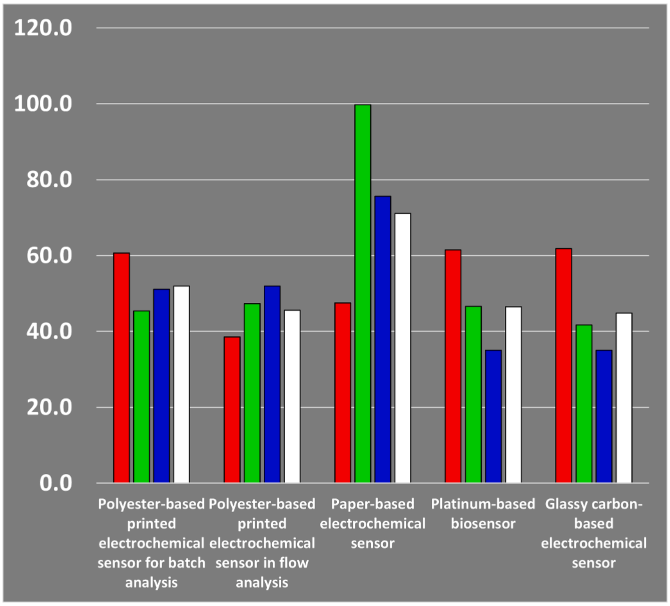


Fig. 2. Comparison of the five sensor-based methods for determining phosphate in terms of the saturation of red, green, blue colors, and resulting whiteness as a holistic assessment.

Admittedly, to propose specific parameter values that would always guarantee a given outcome, e.g. $Score = 50$, it would be necessary to perform time-consuming deep literature surveys on very varied types of analytical methodologies. Otherwise, proposed guidelines could be questioned. Some hope for the future in this aspect is the use of artificial intelligence (AI), especially Large Language Models (LLMs). Perhaps in the near future it will be possible to use the capabilities of LLMs to analyze the text of numerous publications and descriptions of analytical methods in order to obtain required statistical data, essential to proposing the desired values of criteria respecting the method's specificity. It is a perspective for further development of the RGBfast model.

Another issue is the use of appropriate terminology. In a recently published article, we devoted a lot of attention to the theoretical analysis of the “greenness” concept, pointing out three different interpretations of the "state of being green": purist, pragmatic, and formal [21]. Now it is only worth mentioning that there is no single correct interpretation, each of them has its advantages and disadvantages. The RGBfast model clearly indicates which method appears more/less green or white, which method appears best of all (the greenest or whitest), but does not assume any specific interpretation of the "state of being green or white". In other words, the RGBfast model does not explicitly state that "some method appears generally green or white", this would require certain assumptions that were deliberately avoided to provide the user with a freedom of choice how they want to see greenness and whiteness as a state.

3. Demonstration of using RGBfast

To demonstrate the performance of the RGBfast model, we selected five phosphate determination methods based on different types of (bio) sensors [22-26]:

i/ii) polyester-based printed electrochemical sensors used in batch [22], or in flow condition [23], in which the phosphate reacts with molybdate in acid solution to form phosphomolybdate complex. This complex is then reduced at the screen-printed working electrode modified with carbon black nanomaterial;

iii) a paper-based printed electrochemical sensor based on the same principle as previously reported, but with the advantage that the paper works as reservoir, because all reagents (few μL) are loaded on the paper by drop casting [24]. The addition of sample dissolves the reagents allowing for the measurement;

iv) a platinum-based biosensor using maltose phosphorylase, mutarotase, and glucose oxidase as biocomponents, entrapped in an inorganic laponite clay [26];
v) a glassy carbon-based electrochemical sensor modified with ammonium molybdate(VI) tetrahydrate−chitosan film to detect phosphate at pH=2 under degassed conditions [25].

The obtained assessment results are shown in Figs.2 and 3, all data are also available in the attached supplement (Excel sheet).

The obtained results clearly indicate that the third method, using paper-based sensor, is both the greenest and the whitest one. It obtained by far the highest saturation values for green (99.8) and blue color (75.6), while the red criteria were rated worse than three other methods. Its whiteness reached 71.

The paper-based sensor is characterized by worse precision and LOD values than the arithmetic mean for the entire methods' set, which is why its redness does not exceed 50. In terms of this RGBfast assessment, these shortcomings are however compensated by other criteria. Particularly noteworthy is the very high ChlorTox rating, close to 100, which results from the very low use of hazardous substances, considering the few µL of reagents required. It is also worth highlighting that this type of sensor can be incinerated after use, reducing further the residues. Regarding energy demand, it has been used with a portable potentiostat in connection with a laptop (it can also be used with smartphone-assisted potentiostat). Remarkably, both smartphone and laptop are classified as electric devices of category 0, and hence are not included in the assessment of energy demand. A great rating of this criterion (100/100), also indicates its general cost-efficiency. The sample throughput criterion was also rated the best of all methods, which proves that it is also the fastest, but the difference is not as spectacular as in the case of the previous two parameters.

Second in terms of whiteness (52), is the method using a polyester printed sensor for batch analysis. Its greatest advantages are a very low LOD value and low energy consumption (the only additional instrument powered by electricity – in respect to the paper-based sensor – is a magnetic stirrer classified in category I). The remaining methods show a similar whiteness, not exceeding 50, which means that they seem overall worse than the two previously mentioned methods. It is worth emphasizing that the method using a polyester printed sensor in flow analysis shows redness lower than greenness and blueness, contrary to the other two remaining methods. The analytical criteria of the platinum-based biosensor and glassy carbon-based sensor, namely precision and LOD, are the strongest advantage. The biggest disadvantage of these methods is in turn the blue attribute. In this case, both sample throughput and energy consumption have been relatively poorly assessed by the model (these methods require quite time-consuming preparation and additional electric devices like degasser).

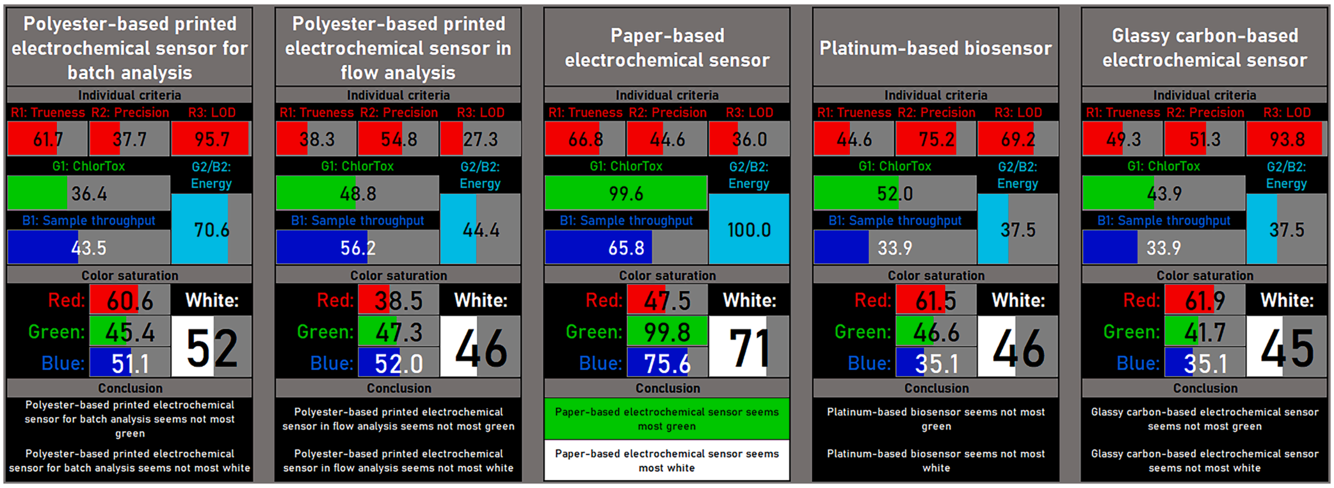
To sum up, the method based on the paper sensor received undoubtedly the most positive outcome. It is most consistent with the GAC and WAC ideas, thus being a great example of combining savings in the use of hazardous reagents, energy and practical utility. Its analytical criteria also seem satisfactory. However, the relatively high LOD value may be a bottleneck for this method in certain circumstances. In such a case, the best alternative seems to be the method with a polyester printed electrochemical sensor for batch analysis. Otherwise, the porosity of the paper can be exploited to further pre-concentrate the sample, as previously demonstrated in the case of a paper-based device for silver ions detection in water samples [27].

It is important to realize that compared to traditional methods, e.g. colorimetric titration or chromatography, all methods considered herein will show most probably a high greenness due to the low consumption of reagents. The purpose of this comparison, however, was to narrow the spectrum only to sensor-based methods and to demonstrate possible differences between them. This goal has been achieved, it has been proven that sensors can differ significantly from each other, and choosing the optimal one for a given application is not obvious.

4. Conclusions

The RGBfast model seems us much easier in use and more transparent than the previous versions. Its simplicity was achieved at the cost of reducing the number of assessment criteria and introducing a new mathematical rule which bypasses the need to award points externally (by user). Therefore, the resulting picture is not so comprehensive but suffices for analyzing crucial green parameters and how they correspond with a general usability (red and blue attributes). The mathematical rule assuming calculation of an arithmetic average of all compared methods as the reference point can be modified to better represent the users' expectations. An interesting option for developing model in this context would be the application of LLMs based on AI methods, to perform deep literature analysis and establish more objective reference points than relative average.

The presented data evidently show that analytical methods based on sensors can vary from each other, and that even subtle differences can be captured and analyzed with the RGBfast. As the use of electrochemical sensors, especially paper-based ones, is very often associated with environmental friendliness, they constitute a valuable alternative of classical methods based on large-scale devices. Apart from (bio)sensing tools, RGBfast is appropriate to assess and compare other analytical methods. Indeed, the inspection of the key green, red, and blue criteria



	Polyester-based printed electrochemical sensor for batch analysis	Polyester-based printed electrochemical sensor in flow analysis	Paper-based electrochemical sensor	Platinum-based biosensor	Glassy carbon-based electrochemical sensor
Individual criteria					
R1: Trueness	61.7	38.3	66.8	44.6	49.3
R2: Precision	37.7	54.8	44.6	75.2	51.3
R3: LOD	95.7	27.3	36.0	69.2	93.8
G1: ChlorTox	36.4	48.8	99.6	52.0	43.9
G2/B2: Energy	70.6	44.4	100.0	37.5	37.5
B1: Sample throughput	43.5	56.2	65.8	33.9	33.9
Color saturation					
Red:	60.6	38.5	47.5	61.5	61.9
Green:	45.4	47.3	99.8	46.6	41.7
Blue:	51.1	52.0	75.6	35.1	35.1
White:	52	46	71	46	45
Conclusion	Polyester-based printed electrochemical sensor for batch analysis seems not most green Polyester-based printed electrochemical sensor for batch analysis seems not most white	Polyester-based printed electrochemical sensor in flow analysis seems not most green Polyester-based printed electrochemical sensor in flow analysis seems not most white	Paper-based electrochemical sensor seems most green Paper-based electrochemical sensor seems most white	Platinum-based biosensor seems not most green Platinum-based biosensor seems not most white	Glassy carbon-based electrochemical sensor seems not most green Glassy carbon-based electrochemical sensor seems not most white

Fig. 3. Automatically formated tables/pictograms obtained for the compared methods using the RGBfast model.

can be done easily and quickly.

To conclude, we believe that RGBfast can be a valuable supporting tool in various applications. We recommend its use to quickly assess and compare methods dedicated to the same or similar analytical purpose. However, the previous versions of the RGB model may still be more useful in some applications that require greater flexibility of the model. It is however always advisable to conduct a parallel assessment using other metrics, e.g. GAPI [10,12] or AGREE [11,13] models for assessing greenness, or BAGI [17] for assessing blueness. This would make the comparison more detailed and provide more objective conclusions regarding the selection of the optimal methodology.

As for the future perspective, we believe that the introduction and popularization of RGBfast may contribute to an increase in the quality of scientific publications referring to the WAC idea, because it is based on more objective and transparent foundations. Thanks to this, WAC may gain many new supporters. Another interesting idea is the relatively easy possibility of implementing RGBfast in other fields, e.g. for the evaluation of chemical synthesis methods. We plan to work on this implementation in the near future.

Associated content

Supporting Information. The ready-to-use Excel worksheets for method assessment with instructions, containing also some additional data (ChlorTox Base).

CRediT authorship contribution statement

Paweł M. Nowak: Writing – original draft, Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Fabiana Arduini:** Writing – original draft, Resources, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data shown in the attached Excel sheet

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.greeac.2024.100120.

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