CHAPTER 1

Past, Present and Future of Green Analytical Chemistry

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1.1 Green Analytical Chemistry Data

Nobody could imagine at the end of the last century the wonderful success that green analytical chemistry (GAC) would achieve. In fact, preliminary proposals in this field spoke about environmentally friendly conscientious analytical chemistry[1] or an integrated approach of analytical methods,[2] the former being referred to in the title of the editorial in the first special issue devoted to clean analytical methods, published in the Royal Society of Chemistry journal *The Analyst* in 1995.

It could be considered that as analytical chemistry involves relatively small volumes of chemicals compared with synthetic and industrial chemical activities, the deleterious side effects of analytical methods would not be of great concern. However, the importance of analytical measurements, recognized by Paul Anastas in his books on green chemistry (GC),[3,4] and the fact that analytical chemistry methods are used extensively in both academic and application laboratories, made this subject of special relevance in everyday activities.[5] As a result, GAC has experienced tremendous growth since the end of the twentieth century. In fact, from 1995 to 2000 only 27 papers were published on this topic and the main part of those concerned only clean or

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sustainable methods, not using the term ‘‘green’’ directly. In 2001, Jacek Namieśnik published the paper ‘‘Green analytical chemistry – some remarks,’’ including for the first time the term green analytical chemistry in the title.[6] This contribution was followed in 2002 by ‘‘Some remarks on gas chromatographic challenges in the context of green analytical chemistry’’ (Wardencki and Namieśnik)[7] and a paper by Joseph Wang entitled ‘‘Real-time electrochemical monitoring: Toward green analytical chemistry’’[8] in the electroanalytical field. Despite this, it is important to note that up to 2019 fewer than 60 papers have been published that included the complete term green analytical chemistry in the title. However, some efforts have been made in studies of the theoretical aspects of GAC and this will improve the development of green methods in the present century.

Figure 1.1 shows the evolution of the literature on green analytical methods from data obtained from the Web of Science Core Collection database considering the presence of the terms ‘‘green analytical chemistry’’, ‘‘green analytical method’’, ‘‘clean analytical method’’ or ‘‘environmentally friendly method’’. From the comparison of these data with those included in the book *Green Analytical Chemistry: Theory & Practice*,[9] published in 2011, it can be concluded that the impact of this subject on the analytical literature of this century has been substantial, especially after the publication in 2010 of the first book on GAC by Mihkel Koel and Mihkel Kaljurand entitled *Green Analytical Chemistry*.[10]

Up to 2007, only 29 review papers were published on general GAC or special topics closely related to it, such as miniaturization, sensors, less aggressive sample preparation techniques to the environment, flow analysis

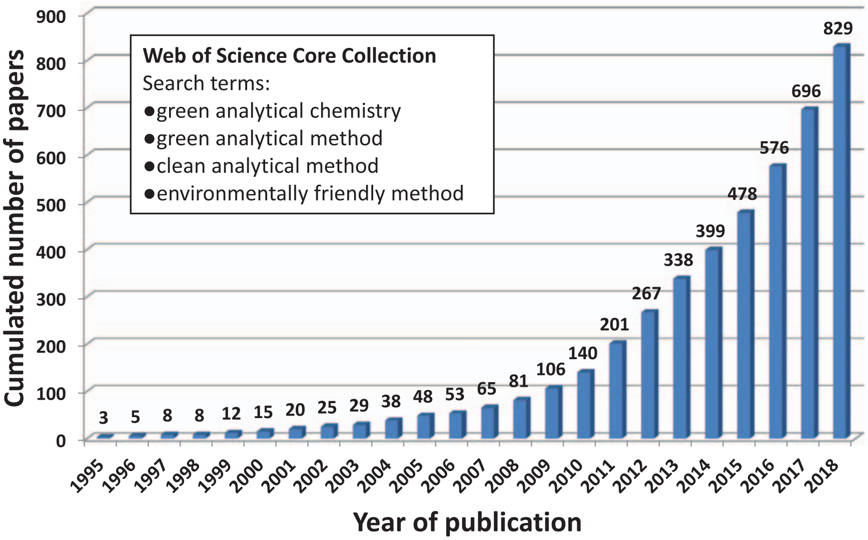


Figure 1.1 Evolution of the literature on green analytical chemistry from 1994 to 2018.

or green aspects of special application fields such as gas chromatography, electrochemical methods, spectroscopy, plasma-based techniques and ionic liquids.[9] In fact, in only 12 of the published reviews was the term ''green analytical'' included in the title. Along with this progress in publications concerning GAC, the evolution of the number of times these papers have been cited is also evident, as can be seen in Figure 1.2, indicating an exponential increase in the citations of the papers considered in Figure 1.1. The most cited papers relating to GAC are listed in Table 1.1.[5,8,11–26] As can be seen, most of them correspond to reviews published in the journal *Trends in Analytical Chemistry* (*TrAC*), including studies related to GAC fundamentals and greener metrics or applied techniques evaluated from the point of view of GAC. The importance of papers relating to sample preparation concerning the use of microextraction techniques and the large number of citations received per year (taking into consideration that the absolute number of citations per year and not the cumulated number is presented) are noticeable.

Concerning authors publishing papers on GAC, Spain, Brazil, Poland, the USA and China are the countries that have contributed the most from 1994 until now, with *Talanta*, *Trends in Analytical Chemistry*, *Journal of Chromatography*, *Analytica Chimica Acta*, *Analytical and Bioanalytical Chemistry*, *Analytical Methods* and *Microchemical Journal* being the most common journals for publication, with more than 35% of the total contributions. This clearly supports what Professor Kaljurand said about GAC: ''Authors try to be environmentally friendly, editors and journals love the term and green is easily understood by the whole of society, thus we can expect a great future for GAC'' (M. Kaljurand, personal communication).

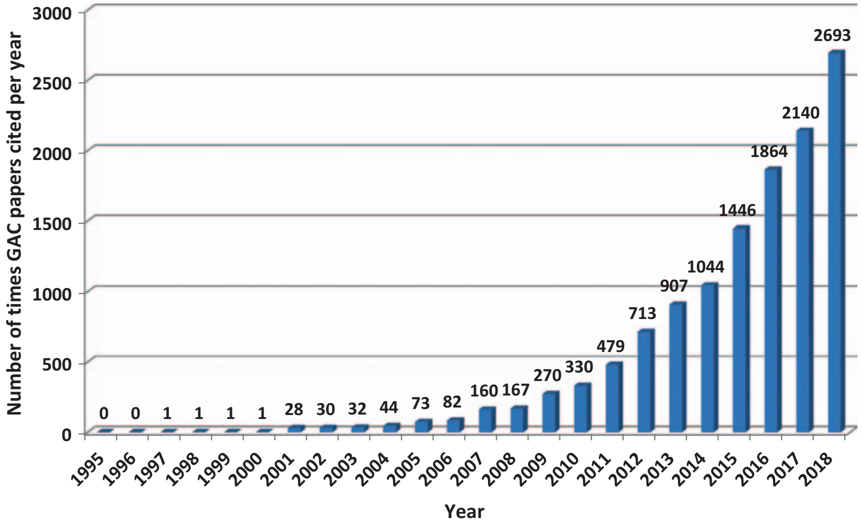


Figure 1.2 Number of times the papers relating to green analytical chemistry considered in Figure 1.1 have been cited.

Table 1.1 Most cited papers relating to green analytical chemistry.

No.	Title	Authors	Journal	Year	Total[a]	Average[a]	Ref.
1	Green analytical chemistry	Armenta, S.; Garrigues, S.; de la Guardia, M.	*TrAC, Trends Anal. Chem.*	2008	454	37.8	11
2	The 12 principles of green analytical chemistry and the SIGNIFICANCE mnemonic of green analytical practices	Gałuszka, A.; Migaszewski, Z.; Namieśnik, J.	*TrAC, Trends Anal. Chem.*	2013	331	47.3	12
3	Cloud point extraction as a procedure of separation and pre-concentration for metal determination using spectroanalytical techniques: A review	Bezerra, M. D.; Arruda, M. A. Z.; Ferreira, S. L. C.	*Appl. Spectrosc. Rev.*	2005	267	17.8	13
4	Green analytical methodologies	Keith, L. H.; Gron, L. U.; Young, J. L.	*Chem. Rev.*	2007	204	15.7	14
5	Green chemistry and the role of analytical methodology development	Anastas, P. T.	*Crit. Rev. Anal. Chem.*	1999	200	9.5	5
6	Recent advances in dispersive liquid–liquid microextraction using organic solvents lighter than water. A review	Kocurova, L.; Balogh, I. S.; Sandrejova, J.; Andruch, V.	*Microchem. J.*	2012	192	24.0	15
7	Determination and speciation of mercury in environmental and biological samples by analytical atomic spectrometry	Gao, Y.; Shi, Z.; Long, Z.; Wu, P.; Zheng, C.; Hou, X.	*Microchem. J.*	2012	153	19.1	16
8	Liquid-phase microextraction techniques within the framework of green chemistry	Pena-Pereira, F.; Lavilla, I.; Bendicho, C.	*TrAC, Trends Anal. Chem.*	2010	151	15.1	17
9	Green analytical chemistry in sample preparation for determination of trace organic pollutants	Tobiszewski, M.; Mechlinska, A.; Zygmunt, B.; Namieśnik, J.	*TrAC, Trends Anal. Chem.*	2009	148	13.5	18

10	Greening analytical chromatography	Welch, C. J.; Wu, N.; Biba, M.; Hartman, R.; Brkovic, T.; Gong, X.; Helmy, R.; Schafer, W.; Cuff, J.; Pirzada, Z.; Zhou, L.	*TrAC, Trends Anal. Chem.*	2010	147	14.7	19
11	Recent developments and future trends in solid phase microextraction techniques towards green analytical chemistry	Spietelun, A.; Marcinkowski, L.; de la Guardia, M.; Namieśnik, J.	*J. Chromatogr. A*	2013	145	20.7	20
12	Modern trends in solid phase extraction: New sorbent media	Płotka-Wasylka, J.; Szczepańska, N.; de la Guardia, M.; Namieśnik, J.	*TrAC, Trends Anal. Chem.*	2016	143	35.8	21
13	Real-time electrochemical monitoring: Toward green analytical chemistry	Wang, J.	*Acc. Chem. Res.*	2002	140	7.8	8
14	Analytical eco-scale for assessing the greenness of analytical procedures	Gałuszka, A.; Konieczka, P.; Migaszewski, Z. M.; Namieśnik, J.	*TrAC, Trends Anal. Chem.*	2012	134	16.8	22
15	Green analytical chemistry – theory and practice	Tobiszewski, M.; Mechlińska, A.; Namieśnik, J.	*Chem. Soc. Rev.*	2010	121	12.1	23
16	Green chemistry and the evolution of flow analysis. A review	Melchert, W. R.; Reis, B. F.; Rocha, F. R. P.	*Anal. Chim. Acta*	2012	116	14.5	24
17	Vibrational spectroscopy provides a green tool for multi-component analysis	Moros, J.; Garrigues, S.; de la Guardia, M.	*TrAC, Trends Anal. Chem.*	2010	116	11.6	25
18	Compressed fluids for the extraction of bioactive compounds	Herrero, M.; Castro-Puyana, M.; Mendiola, J. A.; Ibañez, E.	*TrAC, Trends Anal. Chem.*	2013	115	16.5	26
19	Miniaturized solid-phase extraction techniques	Płotka-Wasylka, J.; Szczepańska, N.; de la Guardia, M.; Namieśnik, J.	*TrAC, Trends Anal. Chem.*	2015	114	22.8	27
20	Application of ionic liquids for extraction and separation of bioactive compounds from plants	Tang, B.; Bi, W.; Tian, M.; Row, K. H.	*J. Chromatogr. B*	2012	110	13.8	28

[a] Total = number total of times cited. Average = average number of times cited per year.

Table 1.2 Books relating to green analytical chemistry.

Year	Authors/Editors	Title	Publisher	Ref.
2010	M. Koel and M. Kaljurand	*Green Analytical Chemistry*	Royal Society of Chemistry	10
2011	M. de la Guardia and S. Armenta	*Green Analytical Chemistry: Theory & Practice*	Elsevier	9
2011	M. de la Guardia and S. Garrigues (eds)	*Challenges in Green Analytical Chemistry*	Royal Society of Chemistry	29
2012	M. de la Guardia and S. Garrigues (eds)	*Handbook of Green Analytical Chemistry*	John Wiley & Sons	30
2014	Inamuddin and A. Mohammad (eds)	*Green Chromatographic Techniques: Separation and Purification of Organic and Inorganic Analytes*	Springer	31
2017	E. Ibañez and A. Cifuentes (eds)	*Green Extraction Techniques: Principles, Advances and Applications*	Elsevier	32
2019	M. Koel and M. Kaljurand	*Green Analytical Chemistry, 2nd edition*	Royal Society of Chemistry	33
2019	J. Płotka-Wasylka and J. Namieśnik (eds)	*Green Analytical Chemistry: Past, Present and Perspectives*	Springer Nature Singapore Pte Ltd.	73

In fact, one of the reasons for the success of GAC in applications laboratories, but also at the academic level, is that green methods are, in general, less expensive than classical methods. This is an added value that is welcomed by the scientific community. It explains the fact that many journals have devoted special issues to GAC that reveal the growth in this field and the permanent interest of editors and authors. In the same context, it is not astonishing that the first book devoted to GAC, as indicated previously, was published in 2010[10] and that, as can be seen in Table 1.2, nowadays there are many books available[9,10,29–33] and some of these are undergoing new editions, whereas from 1996 to 2007 books and journals devoted to green topics concerned just green chemistry.

In short, the data reported on GAC evidence today's interest in the field and the growth of the literature that has dramatically changed the mentality about the consumption of energy and reagents, modified many of the habits in laboratories and provided new activities devoted to minimizing or detoxifying analytical waste, providing a change of the paradigm from chemurgy to ecological chemistry, as was expounded by Professor Hanns Malissa in 1987.[34]

1.2 The Reasons for the Success of GAC

The attitude of the general population towards the environment, with the exception of a small number of politicians, has been modified in the last 20 years owing to the problems created by the environmental impact of human activities on climate change. The evidence for the limits of the human and social development of our societies, the reduction of fossil fuel reserves and the new challenges created by plastic and solid residues in general, gas emissions into the atmosphere and pollution of sweet water reservoirs, including the effect of human activities on polar ice, have moved many people to have serious concerns regarding environmental protection. In such a frame, it is clear that any activity related to environmentally friendly laboratories should be welcomed, and GAC is no exception.

The concern about the deleterious side effects of many reagents, extensively used in the past in our laboratories, has moved authors, referees and editors to think seriously about the replacement of toxic compounds with innocuous materials or, at least, with less harmful products, and this also involves worries about the safety of method operators and environmental damage. Therefore, nowadays many efforts are being devoted to searching for new renewable feedstocks to be used as reagents and solvents, such as agrosolvents,[35] and to incorporate smart materials that are able to improve the sensitivity and selectivity of sample preparation methods.[36] In short, it can be concluded that GAC has provided new ideas and objectives for basic research and hence it does not concern ecological opposition to the use of chemicals. On the contrary, GAC involves the deep evaluation of new alternatives and, because of that, the new mentality has evidenced clever solutions in the face of chemical problems and put the spotlight on the resolution of problems and new challenges and not at all on a fundamental ecologism that cannot provide correct answers at the level of consumer needs.

The mixture of a pragmatic point of view and an ethical compromise with environmental sustainability has given prestige to the so-called green analytical methods which, ultimately, provides correct solutions at the required accuracy, sensitivity, selectivity and precision levels without side effects for operators and the environment.

On the other hand, the efforts made to move from off-line batch determinations in the laboratory to point-of-care and *in situ* analysis or remote sensing of target analytes provide strong reductions in the consumption of reagents and waste generation and also energy demands, and all of this reduces the method costs, thus offering cheaper alternatives that are greatly appreciated by companies and applications laboratories. Thus, as Professor Farid Chemat said: ‘‘green analytical chemistry could also be called poor analytical chemistry’’ (F. Chemat, personal communication), and this point of view is close to the common use of vanguard methodologies[37] in green analytical methods rather than costly conventional rearguard analytical systems and the extended use of screening methods suitable to provide an appropriate level of information in a short time, once again contributing to decreasing methodology costs.

Summarizing, it is not at all astonishing that GAC was developed after the popularization in the 1970s of flow methodologies, because they contributed to the adoption of method automation, taking advantage of flow injection analysis (FIA),[38] sequential injection analysis (SIA),[39] lab-on-a-valve (LoV)[40] and lab-on-a-chip[41] and multicommutation[42] developments to reduce the consumption of samples and reagents and minimize operator manipulation and waste generation.

Automation is, basically, a very useful tool to integrate, in a single manifold, all the steps required in analytical methods and to minimize operator and environmental risks. Further, the addition of a waste treatment step after analyte determination has evidenced that chemical problems could be solved with an extra bit of chemistry[43] and, once again, this opens up new perspectives for basic and applied research.

An additional reason for the importance of GAC methods comes from the efforts to make available the advantages of analytical chemistry to isolated and less developed societies, making extra efforts to move from sophisticated methods, based on the use of high-cost instrumentation, to the modelling of signals obtained with relatively low-cost and readily available instruments. Based on the use of chemometrics and direct measurements, it is possible to develop fast and cheap methods, using a series of samples well characterized by reference methodologies as calibration standards.[44] Thus, extensive data modelling and the use of lower cost instruments and free-of-charge software available in the cloud have extended the analytical tools and the availability of these methodologies to a large number of beneficiaries and users.

All the aforementioned reasons are summarized in the scheme in Figure 1.3, which shows that reasons for moving to GAC concern knowledge advancement together with ethical and economic reasons.

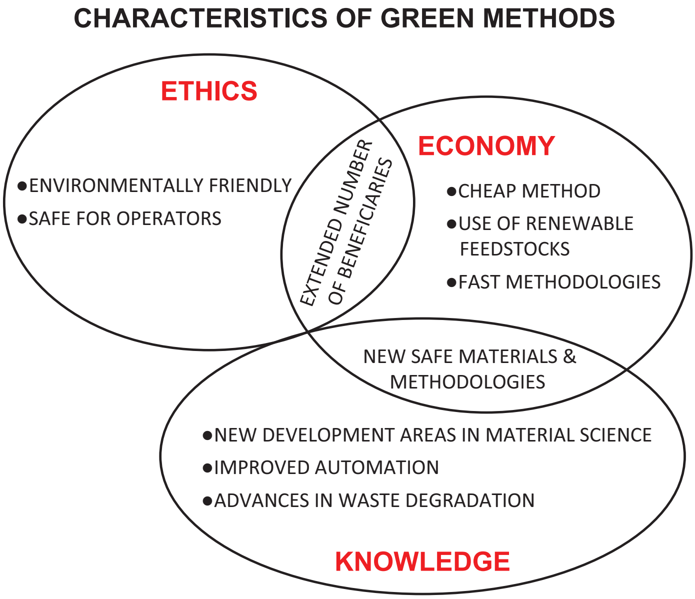


Figure 1.3 Reasons for the success of green analytical chemistry.

1.3 Theoretical Developments in GAC

At the end of the twentieth century, the ''Twelve Principles of Green Chemistry'', defined by Anastas and Warner,[4] oriented alternative research on sustainable chemistry. Of these principles, the 11th was devoted to the need for real-time analysis to prevent pollution, but many of these analyses could be directly translated to the requirements of GAC methods, hence avoiding derivatizations, if possible, is a common point between the GC and GAC principles established by Gałuszka, Migaszewski and Namieśnik in 2013[12] and also the use of renewable feedstocks and the reduction of risks, waste and energy consumption (see Table 1.3).

In fact, the so-called SIGNIFICANCE mnemonic can be considered an excellent translation to the everyday work in analytical chemistry of the main principles of Anastas, independently of the fact that GC put the stress on catalytic methods and GAC must try to be adapted to the user's needs, and well crystallized the four priorities of GAC established by Namieśnik in 2001,[6] regarding (1) elimination or reduction of reagents and solvents, (2) reduction of emissions, (3) elimination of toxic reagents and (4) reduction of labour and energy, and our own six basic strategies for greening analytical chemistry, established at that time, concerning (1) direct analysis of untreated samples, (2) alternative sample treatments, (3) miniaturization and automation, (4) on-line decontamination, (5) search for alternative reagents and (6) evaluation of energy consumption.[9]

The aforementioned theoretical approaches, together with efforts to evaluate method greenness (see Chapter 11 for additional details), have

Table 1.3 Principles of green chemistry *versus* principles of green analytical chemistry.

Green chemistry		Green analytical chemistry	
1	Prevent waste	**S**	Select direct analytical techniques
2	Design safer chemicals and products	**I**	Integrate analytical processes and operations
3	Design less hazardous chemical syntheses	**G**	Generate as little waste as possible and treat it properly
4	Use renewable feedstocks	**N**	Never waste energy
5	Use catalyst not stoichiometric reagents	**I**	Implement automation and miniaturization of methods
6	Avoid chemical derivatizations	**F**	Favour reagents obtained from renewable sources
7	Maximize atom economy	**I**	Increase safety of operator
8	Use safer solvents and reaction conditions	**C**	Carry out *in situ* measurements
9	Increase energy efficiency	**A**	Avoid derivatizations
10	Design chemicals and products to degrade after use	**N**	Note that sample number and size should be minimal
11	Analyse in real time to prevent pollution	**C**	Choose multi-analyte or multi-parameter methods
12	Minimize the potential for accidents	**E**	Eliminate or replace toxic reagents

contributed to the regularization and systematization of GAC in university courses and laboratory practice, thus creating a new generation of analytical chemists for the future.

1.4 Practical Application of GAC

One of our objectives when in 2011 we started the production of books related to GAC was to extend the ideas from our laboratory to as many research teams as possible involved all around the world on these kinds of problems and, for example, the number of authors varied from two in the 2011 Elsevier book[9] to 24 in the Royal Society of Chemistry book also published in 2011[29] and to 50 in the 2012 Wiley book.[30] In the last book mentioned there were contributors from India, Poland, Estonia, Taiwan, Argentina, Italy, Japan, Iran and Brazil, thus clearly showing that, in addition to Spanish laboratories, there was general worldwide interest in the subject.

Figure 1.4 shows the general distribution of papers published from 2007 in different fields of GAC, including spectroscopy (atomic and molecular), electroanalytical methods and separation methods, covering chromatography and electrophoresis techniques. Methods based on imaging treatment are also included.

From the reported published papers, it can be concluded that the most numerous is the group concerning fundamentals, which include papers relating to the principles of GAC, green metrics and those, mainly reviews, regarding sample preparation and the use of extraction techniques. A detailed study of the evolution of the contributions on GAC indicated that prior to this century electroanalysis, electrophoresis and especially

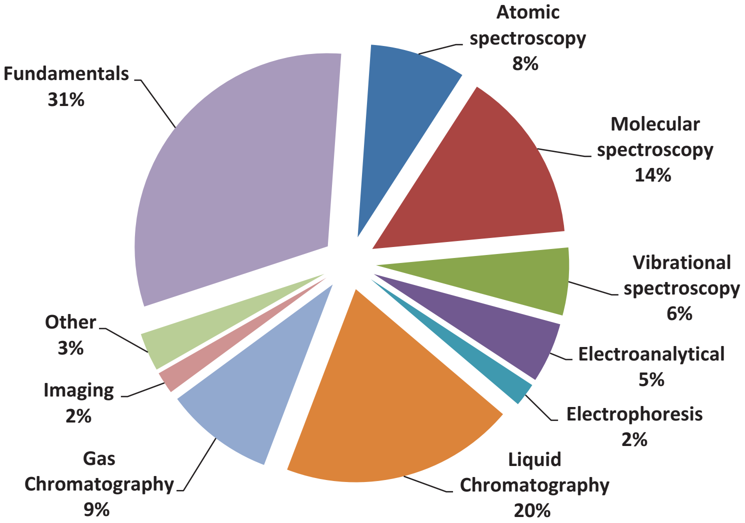


Figure 1.4 Distribution of green analytical chemistry publications as a function of the instrumental field involved in the period from 2007 to 2019.

molecular spectroscopy were the main techniques considered. Molecular spectroscopy continues to be the most common greener alternative technique. From 2010 there has been an increase in papers relating to other techniques, such as atomic spectroscopy and chromatography, particularly liquid chromatography, and also a proliferation of studies relating to sample preparation, especially focused on extraction techniques. This trend continued to grow in the following years so that currently most of the studies relating to GAC concern sample preparation and the use of chromatographic, molecular spectroscopic and electroanalytical techniques, with the progressive incorporation of applications based on image processing through the direct use of cameras and smartphones or devices coupled to them.[45]

From recently published papers, it can be also concluded that there is a general trend of authors to use remote sensing or direct methods, without involving any chemical modification of samples or analyte extraction. However, greening the analytical methods also involves reducing the consumption of reagents and energy in traditional methods, reducing and/or degrading the generated wastes and, in short, enhancing the so-called environmentally friendly characteristics of methods in addition to preserving the main features of the methods. Achieving the appropriate levels of accuracy, sensitivity and selectivity required for making decisions continues to be a basic requirement of being green.[46]

1.5 The Future: A Democratic Analytical Chemistry Paradigm?

In recent years, the conceptual advancement on GAC has moved in parallel with efforts to incorporate new screening tools and low-cost tools to solve analytical problems.

In 1975, the pioneering work on FIA[47] and the use of microwave ovens for sample digestion[48] paved the way for methodological improvements of available methods for both analyte detection and sample preparation and also evidenced the possibility of finding appropriate low-cost solutions. Thus, the use of readily available inexpensive apparatus favours the development of methods suitable for use all around the world and in spite of the level of laboratory budgets.[49]

Regarding sample preparation, the use of closed reactors showed that pressure, temperature and reagents were the main variables for assuring the complete extraction of target analytes and correct matrix removal or partial matrix decomposition. In recent years, it has been demonstrated that in addition to classical hard digestion methodologies, such as dry ashing and wet ashing, the use of microwave-assisted methods[50] and soft energy technologies such as ultrasound-assisted procedures[51] provided efficient heating systems that permitted the quantitative recovery of target analytes, with a strong reduction of matrix effects during the measurement step together with reductions in analyte losses and contamination, also increasing the possibilities for metal speciation.[52] Additionally, these alternative digestion methods provided relatively low-cost tools in terms of both equipment and energy consumption. On the other hand, modern sample treatment alternatives were also highly compatible with the automation of systems, thus offering well-integrated methodologies.[53]

In recent years, the search for the design of point-of-care tools has taken advantage of the reduction of the power supply requirements of microwave ovens to make possible the in-field extraction of essential oils from plants,[54] and these treatments could be also adapted for in-field mineral analysis of solid samples based on closed reactor digestion and the use of colorimetric assays.

Another recent advance in sample preparation concerns the use of hard cup espresso machines to improve fast analyte extraction (of the order of less than 100 s), based on the use of relatively high temperature and pressure conditions,[55] and this is an important contribution that permits analytical problems to be solved with inexpensive and worldwide readily available instrumentation.

Hence it can be concluded that new tools for sample preparation provide low-cost and sustainable methodologies that have also reduced drastically the time, labour and costs of sample preparation. Additionally, the advantages concerning the main analytical features of selectivity and, in some cases, sensitivity that were improved by the new approaches must also be taken into consideration.

In the list of new tools to make analytical determinations easier, the use of portable devices for air quality control,[56] lateral flow analysis sensors[57] and, in general, bio(chemical) sensors[58] provides point-of-care low-cost alternatives to rearguard methods.

A good example of the changes introduced into analytical chemistry by the development of the aforementioned green tools concerns the extended use of image processing methods. Both general sample parameters[59] and specific sample characteristics[60] could be determined for natural samples without any chemical or physical damage, just based on the treatment of images obtained by using digital and smartphone cameras.[45] Additionally, image treatment methods together with simple colorimetric assays and/or paper chromatography[61,62] or gel electrophoresis[63] improve the sensitivity and selectivity of these *in situ* determinations.

The advances in chemometrics (see Chapter 10) together with the use of the available software permits a move from costly and expensive instrumentation to the use of low-cost, readily available and point-of-care methodologies, which could change the perspective of analytical chemistry[64–68] even though the use of powerful rearguard methodologies is required in most cases for a complete characterization of samples to be used for calibration purposes.

On the other hand, the Internet and the tremendous development of social networks will provide new data distribution approaches without any time delay between data acquisition and data distribution, leading, at the same time, to great possibilities for fast decision-making but also creating problems to confirm true information.[49] Thus, as indicated in Figure 1.5, the democratic analytical chemistry (DAC) concept has moved from the extension of benefits to the main aspects of data production.

In fact, analytical chemistry throughout the world at the human scale looks very promising as an added-value side effect of GAC that will move from a main objective of being safe and sustainable to a new perspective in order to be beneficial for the whole population and all practitioners.[69]

The adoption of the term ‘‘democratic analytical chemistry’’ (DAC) to describe the new perspective[49,70] was made taking into account not only the advantages but also the risks involved in the new situation. Figure 1.6 compares some of the deleterious aspects of classical methods of analysis, described as old concepts that provided pretentious ideas about analytical science and analytical chemists, and the fact that in the new scenario created by DAC the availability of low-cost instrumentation and easy and fast measurements, free access of software in the cloud, the tremendous development of on-site and point-of-care data acquisition with speed-of-light data sharing through the Internet will create a new frame of solidarity and globalization that will provide open diffusion of data and opinions. In this respect we are absolutely convinced that it has tremendous advantages but also involves many risks.

Figure 1.7 summarizes the main risks associated with the misuse of readily available instrumentation, inexperienced data acquisition and the irresponsible generation and distribution of false analytical information. From the lack of representative or inexperienced data to the misuse of true data and distribution of false data, all these mistakes or bad attitudes can

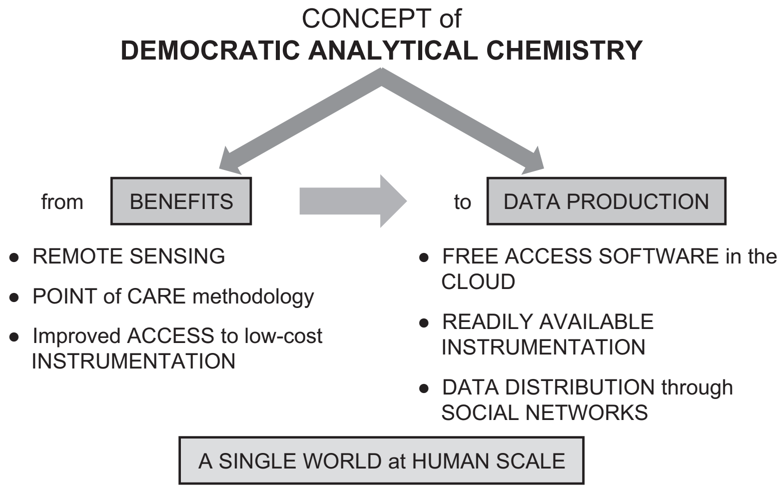


Figure 1.5 Concept of democratic analytical chemistry (DAC).

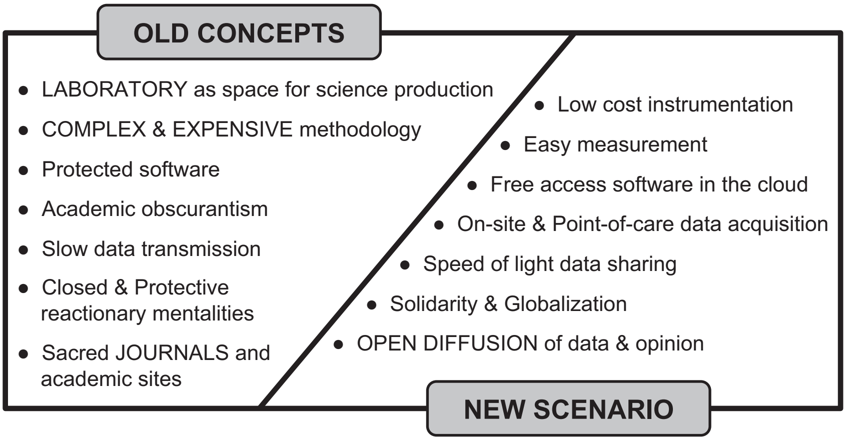
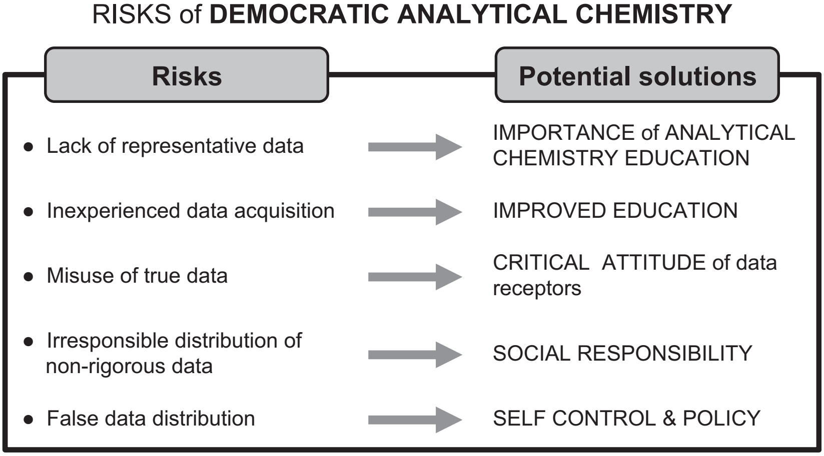


Figure 1.6 The change of scenario provided by democratic analytical chemistry compared with classical analytical chemistry.



RISKS of **DEMOCRATIC ANALYTICAL CHEMISTRY**

Risks		Potential solutions
Lack of representative data	→	IMPORTANCE of ANALYTICAL CHEMISTRY EDUCATION
Inexperienced data acquisition	→	IMPROVED EDUCATION
Misuse of true data	→	CRITICAL ATTITUDE of data receptors
Irresponsible distribution of non-rigorous data	→	SOCIAL RESPONSIBILITY
False data distribution	→	SELF CONTROL & POLICY

Figure 1.7 Risks and potential solutions of problems related to the advancement of democratic analytical chemistry.

dramatically affect both the trueness of analytical results and the prestige of our discipline. In view of the aforementioned risks, education and analytical chemistry education, together with self-control and social responsibility of operators[71,72] and the critical attitude of data receptors, could be the main potential solutions to the risks of democratic analytical chemistry. Additionally, the development of a simple and clear analytical chemistry language is necessary so as to be able to transmit technical analytical information to the general population, without a requirement for an adequate level of technical knowledge, in order to avoid misunderstandings that can create unjustified alarm situations.

From a social point of view, it is important to highlight the contribution that the developments based on the principles of GAC can provide for society in important matters such as clinical analysis and diagnosis or environmental control with clear implications for improving the quality of people's lives and the environment. The development and widespread use of fast, cheap and portable techniques in less developed countries, but also in those who call themselves first world but lack social and universal models of healthcare and base their policies on services provided in the health sector by private companies, may help governments to offer adequate health programmes to the entire population in a social and responsible way, avoiding the commercial interests of private companies. Portable systems for the control of parameters such as blood glucose, or smart watches that control other clinical and vital parameters, can support democratic access to the improvement of the quality of life of the population and improving their health. In the same sense, having adequate methods that allow *in situ* environmental control in a generalized and sustainable manner will allow rapid and efficient decision-making, such as establishing limitations in the traffic of cities and controlling domestic emissions and urban spills, among others.

In short, we are absolutely convinced that GAC has provided the principles for a new DAC frame in which (1) screening methodologies and fast methodologies will provide elements for preliminary decision-making, (2) the use of readily available and low-cost apparatus and instrumentation will increase the number of data acquisition personnel and multiply the eyes that look at an analytical problem and (3) the expanding social networks will improve the speed of communication of data and results. However, it seems clear that additional efforts will be required to educate well the new analytical chemistry operators and to put real data at the service of communities. This is the challenge and we must strive to provide correct answers to the multiple problems and risks in the future.

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