Available online at www.sciencedirect.com
ScienceDirect
Technological Forecasting & Social Change 73 (2006) 1013–1027
Technological Forecasting and Social Change

Text mining as a valuable tool in foresight exercises: A study on nanotechnology

Marcio de Miranda Santo, Gilda Massari Coelho *, Dalci Maria dos Santos, Lélio Fellows Filho

Center for Management and Strategic Studies – CGEE, SCN Quadra 2, Bloco A, Ed. Corporate Financial Center, 11° andar, Sala 1102, CEP 70712-900 Brasília-DF-Brazil

Received 1 April 2006; received in revised form 28 May 2006; accepted 31 May 2006

Abstract

Since its inception in 2001, the Center for Management and Strategic Studies (CGEE) has as its main activity the conduct of foresight studies in support of the decision making process related to the establishment of ST&I policies and activities in Brazil. The methodology used by the center combines quantitative and qualitative methods. Explicit and tacit knowledge is mobilized in the process of developing complementary or differentiated visions of the future.

Most of the studies conducted by CGEE begin with data monitoring activities, making use of text mining techniques. One case study carried out by CGEE on the field of nanotechnology is presented. In this case, text mining was used at the first stage followed by qualitative techniques. Results were used to guide government agencies to fund nanotechnology R&D to help raise the competitiveness of several sectors of the Brazilian economy.

Keywords: Foresight; Science, technology and innovation; Future studies; Methods and techniques; Text mining; Nanotechnology

1. Introduction

Science, technology and innovation (ST&I) is the road ahead that provides “true answers” about the future. Research and development (R&D) activities must operate under a well structured policy in order to effectively promote a better and safe world for all. In that sense, it is crucial to know how an adequate

* Corresponding author.
E-mail address: gilda@massari.net (G.M. Coelho).

0040-1625/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2006.05.020

knowledge management strategy can help decision and policy makers from industry, government and the academy to share ideas in a participatory process towards a sustainable future. New methods, techniques and tools have been developed during the last years, using the explicit and tacit knowledge available, not to forecast how the future will be, but to understand which are the drivers, variables and choices, as well as the best ways for shaping the future.

The Brazilian Science, Technology and Innovation (ST&I) system has made significant progress in terms of research and development coupled with organizational and institutional changes in the last decade. Currently, Brazil possesses a relatively strong and consolidated scientific base that is being used strategically for the promotion of social transformation and economic development. On the other hand, there is a clear understanding that science and technology will only play a central role in improving Brazilian society through continued efforts, at all levels. Considering the high degree of risk and uncertainty related to the innovative process, it is necessary to construct ways to guarantee society permanent participation to maintain support of the policies related to ST&I development. Articulation of a national system of innovation requires the government

- to harmonize technological and industrial policies
- to provide for a better ST&I structure and governance, focused on strategic issues and with broader participation of government, academy and private sector representatives,
- to disseminate technologies with favorable social-economic impact.

Considering the increasing complexity of the decision making process, the speed of technological changes and their economic and social impacts, and market interdependence, it is obvious how greatly a given decision making body depends on an efficient system of knowledge management. To understand the complexity including potential risks and threats in a given future dimension is not a trivial undertaking and involves the analysis of realities and situations that take into account many factors of both a social and technical nature. Foresight stands out as an important tool to be used in planning activities and other decision making processes, both in the public and private sectors, since it allows for the anticipation of technological ruptures and for the identification of trends, discontinuities, new perspectives and opportunities in a given time horizon. New models and tools for future analyses and studies are currently considered crucial for the development of institutions, countries and regions [1]. Foresight offers ample possibilities to identify and take advantage of opportunities; to investigate and understand the nature of risks; to neutralize and minimize the effects of the risks; and to find ways to provide a rapid reaction to mitigate the problems once they start to unfold.

The utilization of forecasting/foresight methods and techniques to support decision making and the establishment of S&T policies is a relatively recent development in Brazil. This is an outcome of deep changes in the international scenario, particularly in aspects related to the globalization of the economy and the acceleration of technological changes, which makes it mandatory for the country to reach higher levels of S&T development. The capacity to anticipate the future has become an element of extreme importance to increase the competitiveness of Brazilian companies and the country itself.

2. Brazilian strategies on science, technology and innovation (ST&I)

Brazilian investments on Science, Technology and Innovation have historically come from government and with the ever growing number of ST&I institutions that have been created in the last decades, the financial resources have naturally been stretched to the limit. In order to allow the national innovative and learning capability to keep its growth it was necessary to make changes and establish new strategies for ST&I. This has led to a series of initiatives conducted by the Brazilian government and, among them, we can point out:

- The creation of Sector Funds to support ST&I programs and projects, one of the essential elements for shaping up new national policies for science, technology and innovation considering that the financial resources will be steadily available to finance and stimulate scientific and technological development promoting the integration between industry and R&D centers. The first Sector Fund was launched in 1999 and now there are 16, including oil and gas, information technology, energy, water resources, among others. In practical terms, the financial resources of the S&T Sector Funds come from a percentage of the revenues from the respective private sectors. They are collected by regulatory agencies and go straight to the Sector Funds managed by the Ministry of Science and Technology-MCT [2].
- The so-called National Innovation Law [3], which was recently adopted (10/11/2005), aims at removing the legal constraints that are hindering the development of joint scientific and technological projects by public and private institutions for fostering innovation in industry. This law also encourages support to small technological based-companies and the promotion of small business associated with technological incubators within R&D centers.
- The 2nd Brazilian Conference on Science, Technology and Innovation and the publication of the "Green" and the "White" books on ST&I, summarizing the strategic choices to promote science, technology and innovation in the country [4,5]. The strategic guidelines have defined routes, indicated work methodologies to obtain good and concrete results, pointed out the main opportunities and vulnerabilities, focusing especially on those that, for broad spectrum and pervasive effects on the R&D infrastructure as a whole, could modify the perspectives of the national innovation system. Those guidelines are being reviewed, in a process that involves public consultation and the realization of sector and regional conferences. The 3rd Brazilian Conference was held in November, 2005.

One of the recommendations of the 2nd Brazilian Conference on ST&I, in 2001, was the creation of the Center for Management and Strategic Studies – CGEE. Its main objective is the development of prospective studies in science and technology as well as the evaluation of economic and social impacts of scientific and technological policies, programs and projects.

3. Future studies methodological approach

CGEE future studies methodological approach was based upon the perception that decision making emerges via a negotiation among multiple stakeholders. This perception is the key point of the methodology known as foresight, which can be defined as a "process that leads to a more complete understanding of the forces that shape the future and that must be considered in the formulation of policies, planning and decision making" [6]. This approach aims at linking the present decisions and actions to a strategic perspective, coping with future possibilities for the construction of commitments around national priorities on science, technology and innovation.

Based upon concepts developed by the European Union, CGEE considers foresight as an activity that connects three different dimensions in the same process: thinking, debating and shaping the future. The diversity of communication channels and the need for an effective coordination of these three different levels stress the importance of setting up a well-structured governance body for the whole exercise [7].

There are a number of available alternatives to explore the future of science, technology and innovation described in the literature, ranging from simple denominations to families or conceptual structures [1]. As a result, techniques developed for very specific objectives are rather commonly used to answer broad and complex questions, leading to weak results and contributing to discredit this field. Most frequently, a combination of methods and techniques is required, which includes qualitative and quantitative ways to monitor trends with ample room for consultation and participation of key stakeholders, a typical characteristic of foresight-based approaches.

The methodological approach designed to guide foresight in CGEE is presented in Fig. 1. It takes into account the methodological structures proposed by Horton [8] and Conway and Voros [9], as well as practical orientations contained in the Handbook of Knowledge Society Foresight [10] and in Godet [11].

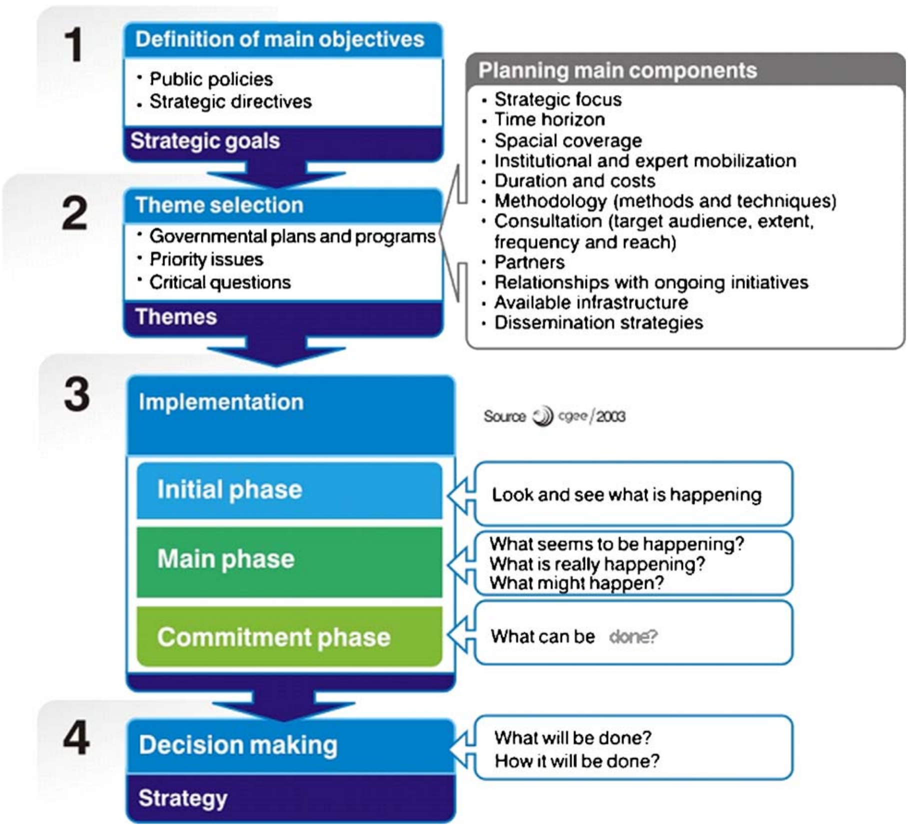

Fig. 1. The methodological approach designed to guide foresight in CGEE.

The CGEE approach considers that many forms of analyzing the future of science, technology and innovation coexist and can be mobilized, alone or in combination with others, to fulfill the needs of a given situation. New methods need to be explored to take full advantage of information resources and new approaches to complex systems. The methodological approach is open to accommodate several technology future analysis (TFA) forms and innovations from other domains, in order to better inform the decision making process in the field of science and technology.

4. Understanding the CGEE approach

Foresight studies constitute powerful assistants in planning and managing uncertainty levels. Their effectiveness is intrinsically linked to the choice of an adequate methodological proposal and detailed planning which includes: a correct delimitation of the scope of the issue under investigation, including its strategic focus and geographical coverage; the time horizon; available expertise, both individual and institutional; the choice of the methodology; the target audience; the establishment of partnerships; the relationship with ongoing related initiatives; the dissemination strategies; the available infrastructure, duration and costs involved. A very important step is the constitution of a stakeholders network, able to articulate and reach the necessary consensus and commitments aiming for the implementation of the identified plan of action.

The management of foresight exercises in CGEE tries to follow the theoretical model, considering four great sets: definition of objectives, theme selection, implementation and decision-making. The implementation of a foresight exercise is divided in three phases. Each phase adds value in relation to the previous one creating a chain that turns information into knowledge and knowledge into strategy. Each phase has a higher level of complexity, diminishing the uncertainty level and increasing the potential of contribution of the results to the decision making process.

In the *initial phase*, the main question is: *What is happening?* This phase corresponds to the identification of the current situation, and involves the collection, organization and summary of the available information on the theme or subject under analysis, using for this purpose studies, diagnosis, analyses and intelligence systems. In other words, this phase involves mainly the collection and analysis of the explicit knowledge available. Different techniques and methods are employed in this phase. In general, more than one technique or method is used, to obtain distinct or complementary visions on the same subject. It is rather in this phase that text mining techniques are employed.

In the *main phase*, the questions are: *What seems to be happening? What is really happening? What should be happening?* During the main phase, processes of translation and interpretation concerning the current trends and the future possibilities occur, using forecast and foresight techniques, as Delphi, expert panels, scenarios, etc. In this phase the broad participation of experts, groups of interest and decision makers allows for the strengthening of formal and informal networks and for the creation of opportunities for collective learning, making feasible a more qualitative vision of the question. The expected result is a better collective understanding of the involved issues and possibilities offered by the future. It represents the integration of tacit knowledge into the process.

The third phase is the *phase of commitments*, when the main question is: *What can be done?* In this phase, participants (mainly decision makers) are asked to think on how to implement the alternatives identified in the previous phases, building up and consolidating consensus where possible and mapping controversial points, which will require a more elaborated implementation strategy. It also represents an

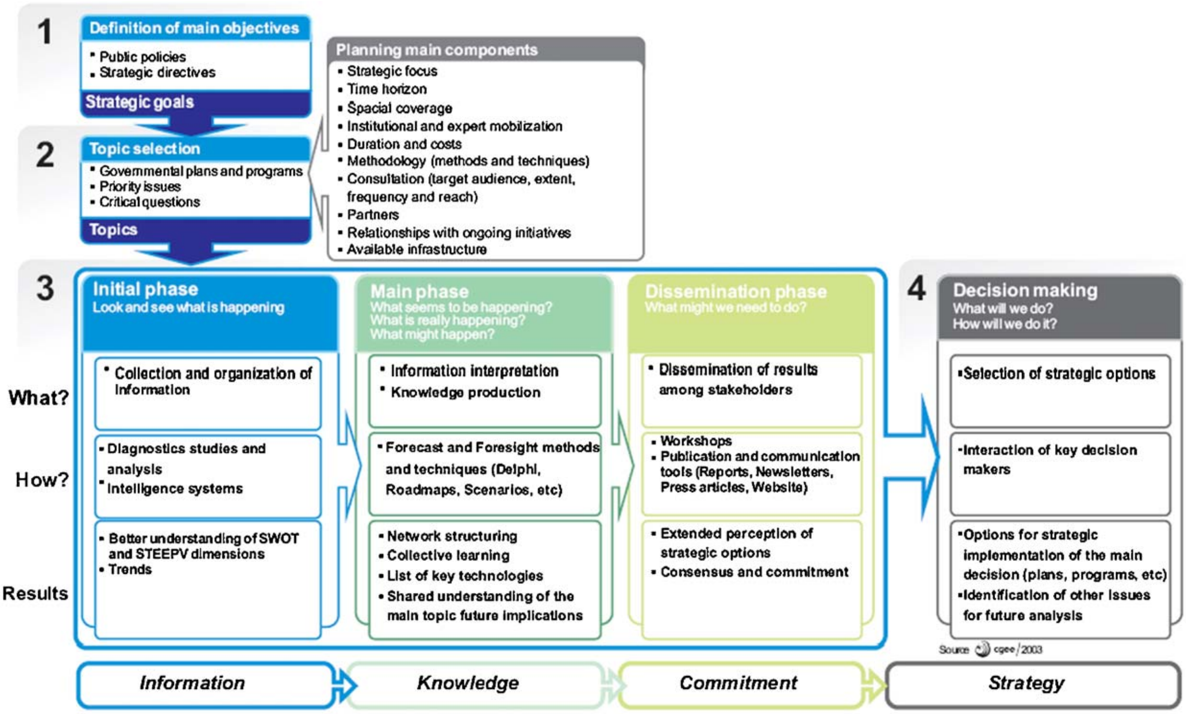

Fig. 2. The expanded model of the methodology in use by CGEE.

opportunity to convey non-classified results to a broader audience, through the dissemination of information via Internet or by means of publications, seminars, conference, etc. The expected result is the transformation of the accumulated knowledge into strategies and proposals, expanding the perception of strategic options among decision makers.

The foresight exercise ends when a final debate with decision makers is established in order to provide answers to what will be implemented and how. It is important to have feedback from decision makers on issues that will deserve an additional in-depth analysis, focusing on themes that were not visible at the beginning of the exercise. Despite the designation of a specific phase for the development of commitments and other intangible factors, it is important to stress that commitment is something to be developed during the whole process with the gradual participation of key decision makers at distinct decision levels (Fig. 2).

5. Text mining as a valuable tool in foresight exercises

Many new or potential tools, currently used in future studies, have resulted from advances in information technology and information science. Among them, stand out scientometrics and bibliometrics, tools used traditionally by the information science experts to measure scientific productivity and to identify science and technology networks [12]. Today, both principles are used in technological forecasting, together with a combination of machine learning, statistical analysis, modeling techniques and database technology to find patterns and subtle relationships in data and infer rules that allow to identifying future trends.

According to Porter and Cunningham [13], "social scientists have applied methods of content analysis for decades. Counting scientific publication activity dates back at least to the pioneering work of Derek de Solla Price (1963)… With the advent of electronic text sources and analytical software, content analysis has matured into text mining… Data mining seeks to extract useful information from any form of data, but common usage emphasizes numeric data analysis…Text data mining or text mining exploits text sources of various sorts".

One of the most important aspects of bibliometric analysis is that it goes beyond the experts' biases, allowing the discovery of new facts and patterns that sometimes are not perceived due to the limit of knowledge or prejudiced visions. Some authors point out certain limitations of bibliometric analysis [14,15], considering that not all R&D activities are published or patented: much of the activity of technological development is not included either in journals, conferences, papers or patents in a timely fashion; the counting of publications does not distinguish the quality from its content; each institution has its own patenting policy; and there is no perfect system of classification and indexation of publications.

Besides these limitations, there are other essential points for obtaining good results in text mining [12]:

- Knowledge of the subject under study: it is important to have a good knowledge of the subject to define the search strategy in databases and analyze its results.
- Knowledge of the databases to be used: to know their contents and their structure, their level of standardization and the existing possibilities of data recovery are factors that define the success or failure of the task. The lack of standardization, for example, sometimes makes good text mining impossible due to low trustworthiness of the data.
- Knowledge of patent information: if patents are under study, it is important to know about the patents information structure, since they have rules of their own. According to Dou et al. [16], patent is a wide field, where techniques, products, applications and legal considerations are strongly mixed. This is also a field most of the time dedicated to industry people and, for example, the academic community does not cite patents very much. Nevertheless, patents are a unique source of information since most of the data and information published in patents are not published elsewhere.
- Definition of search strategy: it is an essential step and it is linked to the three previous ones, that is: knowledge of the subject and knowledge of databases and patents. The use of restricted or extremely ample terms, for example, can lead to results that induce to errors of evaluation.
- Usage of analytical tools: it is important to have good text mining softwares and also to really know how to use them. Some commercial databases are beginning to provide analytical tools together with the search facilities, but they still have limited possibilities.
- Results analysis: experts must analyze the results trying to extract the best interpretation of the histograms, matrices and networks looking for strategic information.

The usage of text mining techniques must, necessarily, involve the experience of information professionals and of domain experts to be successful. The knowledge of information professionals on the available information sources, their contents and structure, and the opinion of experts to define the search strategy and to interpret the results are crucial for the quality of the final work.

CGEE methodology includes the use of text mining as a tool to map a given area or to identify trends. It is mostly used in the initial phase, where there is a need to have a good knowledge of the subject and bring up new questions. It has been used in some of the prospective exercises carried out by the Center and some of the results obtained by the "Prospective Study on Nanoscience and Nanotechnology" are presented below. This text mining exercise was the first step and contributed with several inputs that allowed a deeper look into this field in Brazil, using other methods and techniques, mainly expert opinion, Delphi consultation, workshops, and patent analysis.

6. Prospective study on nanoscience and nanotechnology using text mining techniques[1]

Nanotechnology is being pointed out as a highly innovative technology, since it deeply modifies the production of a diversified gamma of industrial products. Materials manipulation in nanometric scale brings up new possibilities to explore the functionalities of molecular architectures, through the control of optical, electronic and reactivity properties.

Many areas will suffer impacts caused by Nanoscience and Nanotechnology (N&N), as health, chemistry and petrochemicals, computing, energy, agribusiness, metallurgy, textiles, environmental protection, among others. The multidisciplinary integration involving abilities in chemistry, physics, biology and electronics, is another aspect to be valued.

The prospective exercise on N&N was a demand from both the Nucleus of Strategic Affairs of the Presidency of the Republic and the Ministry of Science and Technology (MCT), responsible for the Nanoscience and Nanotechnology Development Program.

The initial focus was on the technical and scientific advances worldwide and the identification of macro indicators of the development of N&N, from 1994 to 2004, in the following sets of countries:

- Key countries: United States, France, Germany, Japan, Canada, Spain.
- Emerging competitor countries: Brazil, India, China, Australia, South Africa, Korea, Singapore, Malaysia, Israel, Mexico.

The text mining study involved:

- Scientific papers bibliometric analysis on international level;
- Patent bibliometric analysis on international level;
- Mapping human resources capabilities in Brazil.

In the article, we will only present the results related to bibliometric analysis on scientific papers, which was made on the Web of Science database of the Institute of Scientific Information, covering the period from January 1994 to April 2004. It is important to say that, due to the gap between an article publication and its inclusion on a database, the data about 2003 and 2004 present some distortions, particularly the last one, since it covers only the period from January to April 2004.

In order to have an updated vision (although a general one) of N&N evolution worldwide, Fig. 3 presents the results of a search made in October, 2005, in the Web of Science database, considering the

[1] The scientific coordinators of the exercise "Prospective study on nanosicence and nanotechnology" were Prof. Oswaldo Alves and Fernando Gallembeck, from Campinas State University (Unicamp). The text mining study was coordinated by Prof. Adelaide Antunes, from Federal University of Rio de Janeiro (UFRJ).

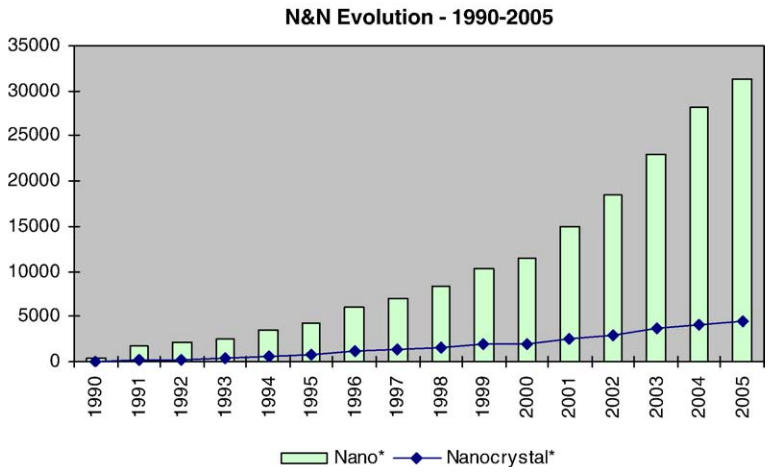

Fig. 3. Worldwide N&N evolution—1990–2005.

keyword "nano*". Although already included in nano*, a separate search was made for "nanocrystal*", since it presented the largest number of occurrences in the study carried out in 2004, in order to verify how its growth compared to nano*.

As to the search strategy adopted for the N&N prospective study, instead of using only the general terms "nanoscience" or "nanotechnology", it was decided to use a list of terms related to both of them but that would give more focus to data recovery and information analysis. The definition of the keywords was made considering a sampling in the main magazines that publish articles about N&N, as well as some specifications made by experts in the area. The general vision of the development of nanoscience and nanotechnology presented includes the results obtained searching all the keywords for all the considered countries, and spans the period from January, 1994, until April, 2004. The keywords used for the search strategy, as well as their occurrences, are presented in Table 1. They represent a view of topics of research in N&N and how much attention they are receiving in the scientific literature.

139,618 articles were recovered, representing the worldwide research production, considering the selected keywords. Approximately 40%, that is, 55,704 articles, was published by the key countries and 14%, that is, 19,644 articles, by the competitor countries.

This general view shows that the keywords – nanocrystalline/nanocrystal, nanoparticles, nanostructured/nanostructures, quantum-dot, fullerenes, nanotubes, nanotubes carbon, nanocomposite, nanoscale, and nanowires – are responsible for almost 83% of the occurrences. Fig. 4 illustrates this situation and its analysis shows that research activities, in global terms, are strongly concentrated in the production of nanoparticles and in their use in the production of new nanostructured materials. Although some of these categories are hard to distinguish from each other, this categorization helped to identify the most used denominations and gave inputs to other studies on the subject, carried out by CGEE.

A broader view of research in key countries confirms the perception – built by the media and scientific literature – that there is a predominance of the scientific production by the United States. Its scientific production (21.769 articles) is almost double that of Japan (10.883), which stands in second place (Fig. 5).

Table 1
A general view of N&N worldwide production—keywords and occurrences

Keyword	Number of articles	Keyword	Number of articles
Nanocrystalline/nanocrystal	19939	Spintronics	397
Nanoparticle	18869	Nanoparticulate	362
Nanostructured/nanostructures	14052	Nanotribology	234
Quantum-dots	12746	Nanoplatterning	226
Fullerenes	12591	Nanodroplets	219
Nanotubes	11519	Nanobelts	158
Nanotube carbon	9108	Nanoscience	156
Nanocomposite	7012	Nanoelectromechanical systems (NEMS)	130
Nanoscale	6462	Nanohybrids	89
Nanowires	3906	Nanoengineered/nanoengineering	76
Quantum-wires	3774	Nanoporosity	76
Nanosize/nanosized	3036	Nanocatalyst	70
Quasi-crystals	2423	Nanofilters	64
Nanoindentation	1892	Nanometrology	37
Nanotechnology	1699	Nanophotonics	33
Nanorods	1243	Nanotemplates	31
Nanospheres	1219	Nanonetwork	15
Nanomaterials	1201	Nanobiology	13
Nanophase	1142	Nanomedicine	13
Nanofibers	855	Bionanotechnology/nanobiotechnology	9
Nanofabrication	751	Nanocorns	5
Nanolithography	734	Nanodrugs	2
Nanopowders	559	Nanosieves	1
Nanoelectronics	474		

The same view relating to competitor countries shows that China stands out among this group, with a scientific production that represents half that of the USA, and rivals Japan. It is 3.7 times bigger than Korea and 9.5 bigger than Brazil (Fig. 6).

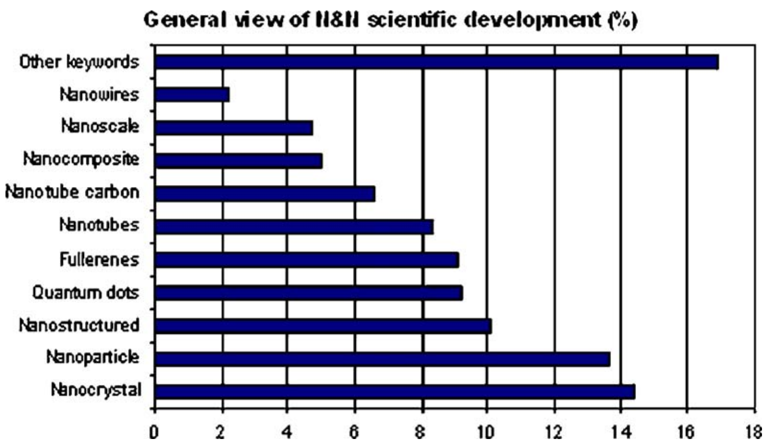

Fig. 4. General view of N&N scientific development—1994/2004.

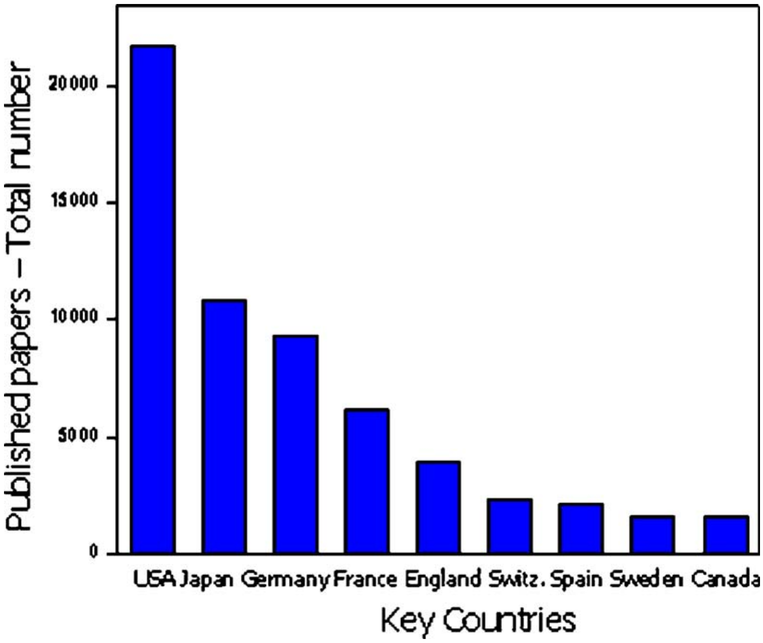

Fig. 5. N&N scientific production in key countries.

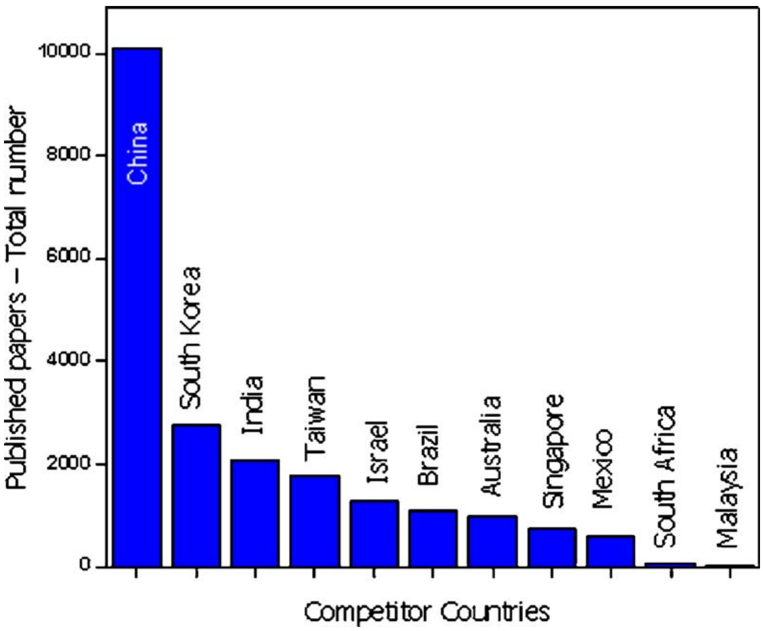

Fig. 6. Scientific production in competitor countries (1994/2004).

Table 2
Top keywords in key countries, competitor countries and Brazil

Key countries	Competitor countries	Brazil
Nanocrystal	Nanocrystal	Quantum-dot (32.0%)
Nanoparticle/nanoparticulate	Nanoparticle/nanoparticulate	Nanoparticle/nanoparticulate (22.6%)
Quantum-dot	Quantum-dot	Nanocrystal (18.3%)
Fullerenes	Fulerenos	Nanotubes (11.0%)
Nanotubes	Nanotubes	Nanostructured (6.2%)
Nanowires	Nanowires	Nanomaterial (5.3%)

The top keywords shown in Table 2, presented above, are research subjects in all the key countries since 1994. The only exception is nanotube, which only appears from 1998 on. As a matter of fact, the keywords – nanocrystal, nanoparticle/nanoparticulate and quantum-dot – belong to the same thematic area, as do the terms nanowire, fullerene and nanotube. The same top keywords appear in key and competitor countries. When the Brazilian production is considered alone there are differences in the priority subjects.

Fig. 7 shows clearly the great contribution of China to scientific research in N&N in the group of competitor countries. In 1994, its scientific production was 141 articles and it went up to 2187 in 2002, corresponding to a growth rate of more than 1500%. Another relevant observation is the Brazilian performance: in 1994 its production was 11 articles and in 2002 it was 297, representing a growth rate of 2700%. Although it represents a great effort and growth, this comparison shows that Brazil should focus on areas where it has comparative advantage and try to differentiate from the policies adopted by other emerging countries.

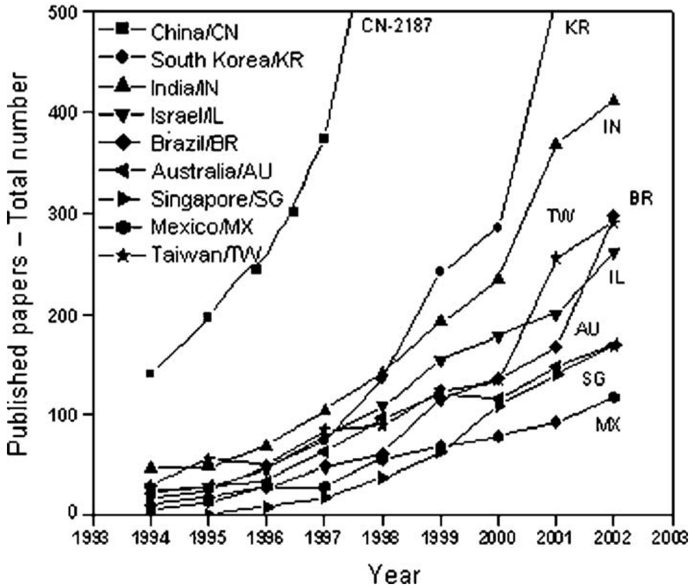

Fig. 7. Zoom of the evolution of N&N in competitor countries (1994/2002).

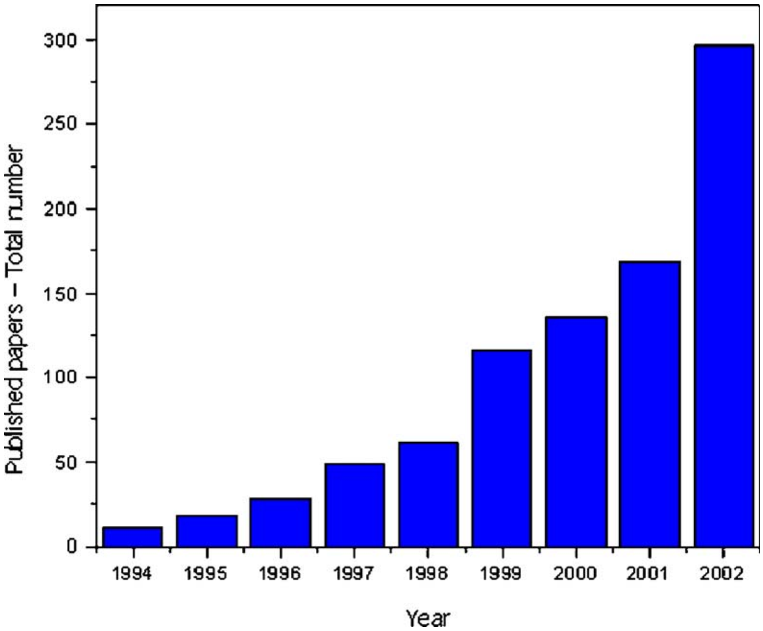

Fig. 8. Brazilian scientific production on N&N—1994–2002.

From 1994 to 2004, Brazil published 1066 scientific papers on N&N—2002 corresponded to approximately 28% of that total. Fig. 8 presents the evolution of the number of papers published by Brazilian authors.

7. Conclusions: key points and lessons learned

The creation of visions of the future to anticipate emergent opportunities, potential threats and to indicate trends and priorities is vital for the success of the innovation process. This requires permanent monitoring of the environment and refinement of perceptions of the impacts of a given decision on the future of nations and companies.

Kostoff et al. point out that "the maximum potential of the DT (data tomography) and bibliometrics combination can be achieved when these two approaches are combined with expert analysis of selected portions of the database." [17] CGEE's experience shows that including expert opinion is essential to obtain good results.

The efficient choice and use of different techniques stand out as vital to comply with problem specifics. Emphasis on participatory approaches, establishment of communication networks, with both horizontal and vertical communication channels, together with quantitative methods like text mining, help to reduce the risk of developing biased views. It can also increase commitment as the process unfolds. Another important point relates to the need to create new tools and approaches that can deal with multidisciplinarity. Methodological flexibility is necessary to address the increased complexity of themes associated with the innovation process. Through cooperation with researchers and practitioners, CGEE has developed and implemented a methodology that is designed to add value to available information and knowledge towards the development and implementation of future-oriented strategies on science, technology and innovation.

Foresight does not define rigid policies and strategies, but rather helps decision makers to implement them in a more appropriate and robust way in times of change and uncertainty, with ample flexibility to adapt those to distinct realities. Considering all the projects in development, we can say that Brazil is actively conducting foresight studies with the intention of improving its competitive edge in the global economy. We intend to establish more efficient foresight methods specific to Brazilian needs.

References

[1] A.L. Porter, et al., Technology futures analysis: towards integration of the field and new methods, Technol. Forecast. Soc. Change 71 (3) (2004) 287–303.
[2] Fundos Setoriais de C&T. Available at: http://www.mct.gov.br/Fontes/Fundos/info/geral.htm. Access on: 10/18/2005.
[3] Regulamentação da Lei de Inovação. Available at: http://www.inovacao.unicamp.br/report/inte-decreto-inovacao051011.shtml. Access on: 10/18/2005.
[4] C.G. da Silva, L.C.P. de Melo, Ciência, tecnologia e inovação: desafio para a sociedade brasileira; Livro Verde, MCT/ABC, Brasília, 2001.
[5] Ministério da Ciência e Tecnologia, Livro Branco da Ciência, Tecnologia e Inovação, MCT, Brasília, 2002.
[6] K. Cuhls, H. Grupp, Alemanha: abordagens prospectivas nacionais, Parcerias Estratég. 10 (2001) 76–104.
[7] D.M. Santos, M.M. Santos, A atividade de foresight e a União Européia (EU), Parcerias Estratég. 17 (2003) 165–192.
[8] A. Horton, Forefront: a simple guide to successful foresight, Foresight: the J. Future Stud. 1 (1) (1999) 5–9.
[9] M. Conway, J. Voros, Implementing Organizational Foresight: a Case Study in Learning from the Future, in Probing the Future: Developing Organizational Foresight in the Knowledge Economy, 2002.
[10] I. Miles, M. Keenan, J. Kaivo-Oja, Handbook of Knowledge Society Foresight, Prest, Manchester, 2002.
[11] M. Godet, Creating Futures—Scenario Planning as a Strategic Management Tool, Economica, Washington, 2001.
[12] G.M. Coelho, C.H. Silva, Prospecção tecnológica em patentes no setor de óleo e gás, in Anais do 4° Workshop Brasileiro de Inteligência Competitiva e Gestão do Conhecimento. Salvador, 2003.
[13] A.L. Porter, S.W. Cunningham, Tech Mining: Exploiting New Technologies for Competitive Advantage, John Wiley & Sons, Hoboken (New Jersey), 2005.
[14] A.L. Porter, M.J. Detampel, Technology opportunities analysis, Technol. Forecast. Soc. Change 49 (1995) 237–255.
[15] A.L. Porter, Innovation forecasting using bibliometrics, Compet. Intell. Rev. 9 (4) (1998) 11–19.
[16] H. Dou, J.M. Dou, B. Maninna, G.M. Coelho, Análise de patentes visando a competitividade tecnológica e a inovação, in Knowledge Management Seminar, São Paulo, , 2004.
[17] R.N. Kostoff, T. Braun, A. Schubert, D.R. Toothman, J.A. Humenik, Fullerene data mining using bibliometrics and database tomography, J. Chem. Inf. Comput. Sci. 40 (1) (2000) 19–39.

Marcio de Miranda Santo holds a PhD in Genetics and Plant Breeding, University of Sao Paulo, Brazil. He has a Post-Doctorate in Genetic Resources access and Visiting Scholar Ownerships, Harvard University, USA. He is currently Executive Director of Center for Management and Strategic Studies – CGEE and was director of the Research and Development National Research Center for Genetic Resources and Biotechnology - CENARGEN/EMBRAPA. Address: SCN Quadra 2, Bloco A, Ed. Corporate Financial Center, 11° andar, sala 1102, CEP 70712-900 Brasília-DF-Brazil, Phone: 55-61-3424 9600, e-mail: mmiranda@cgee.org.br.

Gilda Massari Coelho holds a DSc in Information and Communication Science, University of Marseille (France). She is Director of S and G Gestão Tecnológica e Ambiental, a consulting firm on the management of technology, information and environment. She is also a consultant for the Center for Management and Strategic Studies – CGEE. Her main research interests are related to technology foresight, competitive intelligence and information systems for decision making. She was responsible for the creation of the first post-graduation course on competitive intelligence in Brazil. Address: Rua Primeiro de Março, 23 s.1204, CEP 20010-000-Rio de Janeiro-RJ-Brazil, Phone: 55-21-2252-8151, e-mail:gilda@massari.net.

Dalci Maria dos Santos holds a MSc in Physics, Federal University of Minas Gerais (Brazil). Currently she is Technical Advisor of Center for Management and Strategic Studies – CGEE. Her main experience and research interests are related to Planning in Science and Technology, particularly foresight in science, technology and innovation and management of technology. Address: SCN Quadra 2, Bloco A, Ed. Corporate Financial Center, 11° andar, Sala 1102, CEP 70712-900 Brasília-DF-Brazil, Phone: 55-61-3424 9600, e-mail: dmsantos@cgee.org.br.

Lélio Fellows Filho is currently CEO Advisor of Center for Management and Strategic Studies – CGEE. He is also Coordinator of the Latin American Network for Prospective Studies of the Ibero-American Program on Science and Technology for Development (CYTED). He graduated in Metallurgy at Federal University of Rio de Janeiro and his main research interests are management of technology, technology foresight and public policy. Address: SCN Quadra 2, Bloco A, Ed. Corporate Financial Center, 11° andar, Sala 1102, CEP 70712-900 Brasília-DF-Brazil, Phone: 55-61-3424 9600, e-mail:lelio@cgee.org.br.