METHODS AND TOOLS FOR FUTURE EXPLORATION AND DECISION MAKING IN MULTIDISCIPLINARY AND FAST DEVELOPING TECHNOLOGICAL DOMAIN: A CASE OF NANOTECHNOLOGY

Dr. Nadezhda Gaponenko (Head of Department, Russian Institute of Economy, Policy and Law, Director of the Russian Node of the Millennium Project, AC/ UNU)

Extended abstract

Foresight methodology is in transition to a new paradigm; it is conditioned by the growing complexity of problems, accelerating rhythm of evolution and by the changes in the role of different actors in evolution. Nanotechnologies themselves produce the challenges to Foresight's methodology, which arise from and conditioned by the specific characteristics of this S&T domain. What are these specific characteristics? First of all it is an emerging, disruptive technology in an early very exploratory creative stage. Second, this is a fast developing multidisciplinary S&T domain, which is expected to change all sectors of economy, social needs and precondition the emergency of new markets and structural shifts in economy. Third, as a new emerging field its areas of application remain not well defined but it is already clear that the same scientific breakthroughs might be used in different sectors of economy. The consequences both beneficial and adverse of technological innovations' implementation in this field are not well explored as well as the impact of nanotech on other S&T domains. At last social values and cultural issues will have a special impact on nanotechnology development in the future. Thus methods and tools for the exploration of the future of nanotechnologies should meet both these specific characteristics of nanotech and fundamental changes in evolution. Actually this task might be divided into two ones; first, what methods and tools should be used for these purposes and what way they should be linked with each other; and, the seconds, what way to modify the selected methods for the nanotechnology Foresight program?

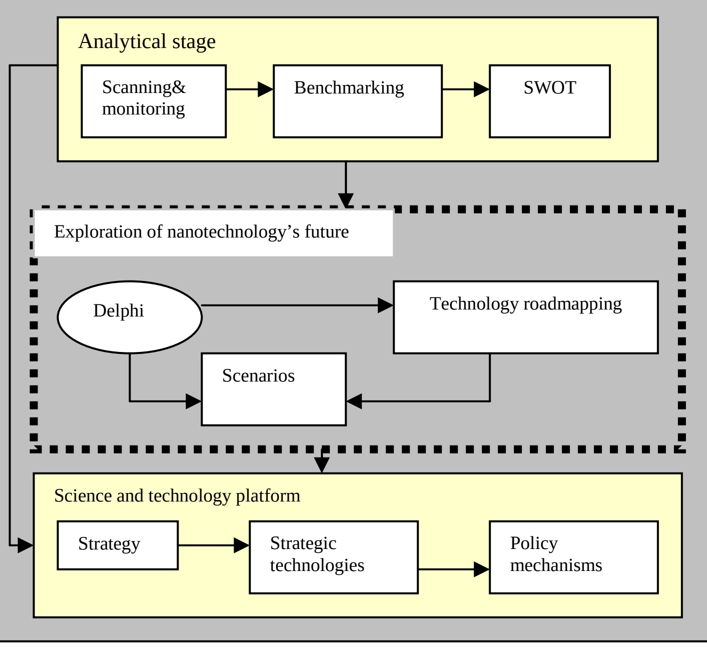
There are many different methods and tools used in Foresight studies. Any Foresight exercise may use one and only one of the methods, but the implementation of methods in combination often provides efficiency and makes the outputs more robust as far as any method has its advantages and the capabilities of any method are restricted. Therefore in practice most foresight exercises use a combination of methods, and it is the choice of which methods to combine that becomes the important question. How

some methods can be used in combination and how a number of methods and approaches, taken together, facilitate decision making in the Nanotech Foresight program? These issues we have put forward on the agenda in our methodology.

We think that in the solution of this issue one has to base on the specific characteristics of S&T domain first of all; in our methodological approach we tried to verify this assumption. One has to point out that the development of methodology for the National Nanotech Foresight Program is complicated by the lack of experience in methodological studies for the sectoral Foresight exercises for the emerging and rapidly changing domains like nanotechnologies. Formerly nanotechnologies were considered like one of technological domains in the National Foresight exercises. This is a valuable experience however specific characteristics of this domain could not be met this way. Therefore in the developed methodology we considered the specific characteristics of nanotechnology like a departure point.

Methodology includes three main stages: 1) analytical stage; 2) future exploration; 3) and implementation of outputs of the second stage for the decision- making, or rather for the setting national priorities and selecting technologies for the programming funding (see. Fig.1). One has to point out that foresight exercises' outputs might be used and should be used by private sector and R&D organizations for the strategic planning as well. This is also a challenge for the future studies and for the Foresight methodology as well; this means that it is already not enough to involve different stakeholders into foresight program; one has to produce outputs in the form which is clear for the private sector and other stakeholders and one has to produce information valuable for their strategic decisions. In our methodological approach we tried to meet this new challenge as well.

FIG.1. METHODS AND TOOLS



To avoid the limitation inherent in any method our methodology is based on the combination of the following methods and tools: scanning and monitoring (S&M), benchmarking, SWOT, Delphi, scenario approach, technological roadmapping (see Fig.1). Each of them plays its own role in the Foresight exercise but we think, that their combination serves like a tool for the comprehensive assessment of the state of the art and the future of nanotechnologies. The methodological approaches to the implementation of selected methods were also modified to meet both the specific characteristics of nanotechnologies and fundamental changes in evolution.

The task of analytical stage is the building of information base for the Foresight program as a whole and the providing the analyses of trends and emerging problems, strength and weakness, threats and emerging opportunities as well as the stand of different stakeholders to nanotech. Scanning and monitoring, benchmarking and SWOT we selected for the analytical stage to carry out the outlined tasks.

Scanning and monitoring plays a special role at the analytical part and for the Foresight Program as a whole. Since decisions and strategies are based on forecasts and forecasts are based on assumptions about the future, scanning the horizon is always prudent to identify trends which have been already formed and new developments that can challenge past assumptions or provide new perspective to future threats or opportunities. Environmental scanning provide the information base for the analyses of the state of the art and early warning about important changes and detect "weak signals" that indicate plans should be amended. No system will be able to eliminate all uncertainty; the objective of a scanning system is simply to find early indications of possibly important future developments to gain as much lead time as possible (Future research methodology, Millennium Project).

Environmental scanning is a systemic futures methodology that was developed by Aguilar in 1967 (Preble 1978, Preble et al 1988, Thomas 1980). One has to pint out that the environmental canning is one of the fundamental tasks of futurists and any Foresight exercise. The main rationale for environmental scanning is the same as for most of the futures methodologies, that is, the world and the operating environment for communities, organizations and individuals is increasingly turbulent and uncertain (Kast 1980, Witham 1991). It should be designed to feed the Foresight program and to provide inputs to all parts of the Program and to all methods and tools. The role of environmental scanning and monitoring is changing in Foresight studies. Fundamental changes in technological evolution first of all growing complexity of any issue and any system and rapid technological changes conditioned these changes.

We think that S&M should focus on three key issues important for any Foresight exercises: 1) trends and problems have been formed in the past as well as factors which conditioned them; 2) changes, which could take place in the future but already are visible today; 3) and weak signals. For the fast developing S&T domain like nanotechnology the identification of weak signals, small changes, which might be resulted in big challenges, is of critical importance.

These general considerations of the role of S&M in Foresight exercises and its main tasks are an important base for the methodological studies but they do not give the answer on the questions like: "What way to provide S&M for the National Nanotech Foresight program", "What kind of information should be collected and monitored to feed the Program?" These are still opened questions. We think that the nature of nanotechnology and specific features of their evolution gives some guiding line for the methodological studies in this part of Foresight program.

From the very beginning it was clear for us that first of all one has to select the principal domains for the S&M and after that to outline sub- domains, issues and if possible indicators. We selected the following domains: nanoscience and nanotechnology (i.e. monitoring of nanotechnology development themselves); economy; social and environmental issues; geopolitical changes; National Nanotech Foresight programs (methodological issues as far as methodology is in transition). Actually these principle domains fit for any other S&T domain, therefore more complicated issue is the selection of sub- domains and the identification of specific issues and indicators.

S&M of changes in *nanoscience and nanotechnology* should provide the information about the trends in nanoscience, R&D capacity development in different parts of the world, about the possible breakthroughs and their impact on economic development and solution of social issues, about the actions implemented in framework of science, innovation and technology policy. Information about the public and private investments in nanoscience and their distribution across different nanofields (nanomaterials, nanoelectronics, nanoenergy, and the like) is general but important information to start with. It gives the idea where innovations and competitors will come from. Today R&D organizations in nanoscience are not mapped properly and one may observer rather rapid emergency of new nanocenters as a result of policy actions or initiatives of universities and researches. The research organizations- leaders in different nanofields are also not mapped properly. This is one of the areas for the scanning and monitoring of changes. This information should show the world nanoscience map today, as well as what and who drives the changes and what are the directions of changes. This is valuable information not only for the analytical part of the Program but also for Delphi survey, for the scenarios and for the S&T platform development. Another important issue for the scanning and monitoring are science, innovation and policy mechanisms implemented by the counties to support nanoscience and nanotechnology development. These are also critical issues and there are not approved solutions as far as nanotechnology is a fast developing and interdisciplinary domain. This is valuable information for the Benchmarking and for the S&T platform development although it might be also useful for the Delphi questionnaire development.

The key issues for the scanning and monitoring are the identification and mapping of coming technologies and scientific breakthroughs with significant impact on economy, social sphere and environment as well as clarification the spheres of application of coming technologies; the National Foresight programs serve like a very important source of information for this purposes. At last valuable information for the National Nanotech Foresight is the number of scientific papers published in various nanofields and patent applications.

In economic domain we selected two sub- domains for the scanning and monitoring: the main economic problems, which might be solved successfully by the implementation of nanotechnologies and trends and actors at the global and regional nanotech markets.

Nanotechnologies, on the one hand, form new needs, new structure of demand and accordingly new markets but, on another hand, they provide new instruments for the solution of economic and social issues. Therefore economic and social problems play in some sense the role of drivers in nanotechnology evolution. Thus the monitoring of economic problems and clarification of factors conditioned the worsening of these problems becomes an important task of S&M.

Today nanotech market is at the initial stage of its development therefore nanotech companies are still not mapped properly as far as one may already observer rather rapid emergency of new companies in particularly spin- offs and start up. This is also an important field for the scanning and monitoring. This is valuable information for Benchmarking and SWOT as far as for scenarios and S&T platform development.

Social and environmental issues scanning and monitoring for the Nanotech Foresight program has also some peculiarities if compare to other S&T domains. The point is that cultural issues play a special role in nanotech evolution therefore the monitoring of measured implemented in different countries for the improving citizens' attitude to nanotech as far as cultural barriers emerged by the implementation of nano- innovations is an important task of S&M for the Nanotech Foresight program. In addition too nanotechnologies server not only like the instrument for the solution of social and environmental problems; it is expected that they could also provide a negative impact on peoples' health and environment. This issue has been just put on the agenda in many National Nanotech Initiatives but it has already became an important issue for the scanning and monitoring.

In transition to a new economic, social and technological order new geopolitical blocks are usually arise; it might be resulted in implementation of measures for the regional market protection, and the like. Therefore in the era of huge uncertainties and turbulence geopolitical issues monitoring becomes an important task.

The key role for the exploration and assessment of coming technologies plays ***Delphi***. Named after the Greek oracle at Delphi to whom the Greeks visited for information about their future, the Delphi technique is the best known qualitative, structured and indirect interaction futures method in use today (Woudenberg 1991). Essentially, Delphi is the name given to a set of procedures for eliciting and refining the opinions of a group - usually a panel of experts (Dalkey 1967, Brown 1968). Initially Delphi was developed for the accumulation of experts' knowledge, for the elimination of the impact of the most active/ respectable individuals on the panel as a whole and for the providing feedbacks between any member of the panel and a panel as a whole. It is a way whereby a consensus and position of a group of experts is reached after eliciting their opinions on a defined issue and it relies on the "informed intuitive opinions of specialists" (Helmer 1983:134). This collective judgment of experts, although made up of subjective opinions, is considered to be more reliable than individual ones (Johnson & King 1988, Helmer cited in Masini 1993). As Linstone and Turoff (1975, 3) write, "Delphi may be characterized as a method for structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem."

In a sense, the Delphi method is a controlled debate. The reasons for extreme opinions are made explicit, fed back coolly and without anger or rancor. More often than not, experts groups move toward consensus; but even when this does not occur, the reasons for disparate positions become crystal clear.

Today, we think that Delphi could contribute to the exploration of the future of nanotech much more that just a tool for the accumulation of experts' knowledge. Of course knowledge of experts about the future of nanotechnology are rather restricted and it remains an important mission of Delphi but it becomes dramatically important to provide the dialogue between the main groups of stakeholders. Therefore we tried to design Delphi- survey to provide dialogue (and learning process as well) between panel's members (different stakeholders) in terms of the future of nanotechnology, to outline both beneficial and adverse consequences of their implementation as well as to evaluate their impact, their spheres of application, barriers and to formulate policy mechanisms. We think that the panel should consist of four groups of respondents: corporations, academia, governmental officials and innovations' users. It is important to include the innovations' users into the panel as far as the role of cultural and social issues is high in nanotechnology evolution. Up to a point these four groups of respondents have different knowledge and interests about the future of nanotech we think that four questionnaires with common technological statements but different characteristics (indicators) should be developed. The task of academic researches is to evaluate the nanotechnology impact on the development of other S&T domains, their possible negative impact on population health and environment, to outline the likely scientific and technical barriers and to suggest S&T mechanisms as well as to estimate the gap (forestalling or tardiness) of the national R&D in compression to the world leaders. We think that corporations should evaluate market demand, market barriers, fields of nanotechnology application and the impact of nanotech on the competitiveness of the national companies as well as to formulate innovation policy mechanisms. The role of governmental officials is to estimate public demand, institutional and legislative barriers and to suggest policy mechanisms. At last innovations' users should evaluate coming technologies in terms of cultural barriers and their importance for the solution of social and environmental issues.

We hope that this approach provides opportunity to make a comprehensive assessment of nanotech, to accumulate knowledge of different stakeholders and innovations' users and to link science push and demand pull approaches.

As far as nanotechnology is an interdisciplinary and fast developing domain it might be very helpful to couple Delphi with multidisciplinary brainstorming workshop to outline what kind of scientific breakthroughs with significant impact on economy and social problems' solution could happen in the future. We think that that this workshop's outputs could serves like one of important input to the Delphi questionnaire.

In order to realize the idea of providing the dialogue between different stakeholders it was suggested in the second round of Delphi- survey to send the results of the first round calculated for each group of respondents to the members of four respondents' group. This way each group of respondents could learn the expectations of other groups; corporations, for example, could learn the expectations of innovations' users, governmental officials and scholars and make corrections in their own judgments on the base of this information. As far as the uncertainties in nano- field are dramatically high it is important for any group of stakeholders to learn the expectations of other groups.

Delphi outputs are proposed to use for the first round of technology prioritization. For this purposes the methodology suggests to use the following approaches: a) orientation on the consensus between different respondent's groups; b) realization of four stages of technology mapping using the criteria of technology importance (in terms of competitiveness at the world market, contribution to the social and environmental issues solution, impact on the other S&T domains' evolution and importance for the national defense sector) and likelihood; c) evaluation of possibility of technology implementation in different sectors of economy.

Delphi- survey outputs serve also like the input for the development of **technological roadmaps**. Methodology proposes to build roadmaps for different nanofiels (nanomaterials, nanobio, nanoelectronic, nanoenergy); it is expected that they will be used by policy- makers and scholars and serve like the input for the S&T platform development. The roadmap for sectors of economy is oriented on the implementation by corporations and like input for scenarios.

Scenarios play a special role in Nanotech Foresight exercise. They let to explore how nanotechnology could play in alternative worlds of external environment (geopolitical, economic, social, cultural). Scenarios are narrative descriptions of the future that focus attention on causal processes and decision points (Kahn 1967). Ged Davis presents scenarios as “coherent, credible stories about alternative futures”, and as uniquely capable of helping us created a shared understanding of possible changes, options, and decisions (Ged Devis, 2002, p.1). A scenario is a rich and detailed portrait of a plausible future world, one sufficiently vivid that decision makers can clearly see and comprehend the problems, challenges, and opportunities that such an environment would present. A scenario is not a prediction of specific forecast per se; rather, it is a plausible description of what might occur. Scenarios describe events and trends as they could evolve. Today scenario approach is used for the providing dialogue between different stakeholders and like powerful tool for the learning process.

The goal of generating scenarios is to understand the mix of strategic decisions that are of maximum benefit in the face of various uncertainties and challenges posed by the external environment. Scenario building, in conjunction with a careful analysis of the driving forces, fosters systematic study of potential future possibilities—both good and bad. This approach enables decision makers to grasp the long-term requirements for sustained advantage, growth, and avoidance of problems.

Scenarios are usually developed by the scenario development panel. The panel should be interdisciplinary and should include different stakeholders. What kind of experts should be invited to the panel in Nanotech Foresight program? This issue usually emerges just at the beginning of scenario development process. We think that experts in geopolicy, global and national economy, ecologist, experts knowledgeable in social and cultural issues and of course those, who understands the nature and the future of nanotechnology should be invited to the scenario development panel. In addition too, different groups of stakeholders should be represented in the panel: policy- makers, private sector, NGOs and scholars.

Usually scenario development process is information hungry, therefore it is important to accumulate the information from different parts of the Foresight program and offer it to the scenario development panel members before the workshop. The question is “What kind of information might be helpful for the scenario development panel?” S&M could feed the panel by the information about the geopolitical changes, economic, social and environmental trends and problems as well as trends have been formed in nanoscience and at the nano- market. Delphi produces a helpful information about expected barriers and suggested policy mechanisms. Technological roadmaps supply information about the coming technologies i.e. technological events, which could change the equilibrium at the market, mode of production in some sectors of economy as well as structure of demand and mode of consumption.

Many different approaches are used to construct scenarios, but all seek the same general ends: a set of descriptions of future conditions, encompassing a range broad enough to evoke meaningful polices. Further, most approaches involve producing future histories that seek to satisfy the criteria of internal consistency and plausibility. In the methodology we have outlined the following steps in scenario building: 1) driving forces and scenario worlds; 2) scenario logic; 3) narrative scenarios; 4) scenario quantification; 5) scenario writing and discussion.

At the first step it is important to identify and explore the driving forces that will shape the future and uncertainties and draw a line around the alternative future worlds. The development scenario skeleton is accomplished at the second step. We suggest to start the development of scenario skeleton with the identification of key problems, which will condition nanotechnology development in the future, and which are important for the decision making. It permits to focus scenarios on the principal issues important for the decision making. The key problems should be mapped using the criteria of importance and uncertainties and this way one can build the map of problems for visualization and implementation of this map for the building narrative scenarios.

The carefully exploration of driving forces and their mutual impact is another important issue for the development of scenario logics. At this step he qualitative analyzes of driving forces trends is provided in order do not switch the mind of experts on the quantification problems. It might be also helpful to draw the trajectory of driving forces and to identify the turning points as well as factors conditioned the abrupt changes in the trajectories of driving forces.

At last the development the time scale of events is the third task of scenario development panel at this step. The time scale starts with key event, which will condition the changes in the trends formed in the past or contrary which will enforce formed trends. One has to keep in mind that nanotechnology development in the future might be pushed by the worsening of some economic, social or environmental problems, therefore the key event could come from the economic, social and environmental spheres, or contrary the appearance of novel technologies could break the equilibrium at the market and in people’s mind. In both these cases the development of time scale should be linked with the technological roadmaps, but in the first case one has to analyze the impact of economic, social and environmental events on nanotech trajectory in the future (what technologies might be pushed), and in the second case one has to evaluate the impact of novel technologies on the external environment (on the economy, social and environmental spheres). Outputs of the second step of scenario development are short stories for all alternative scenario worlds. Each story should take into account critical drivers and uncertainties.

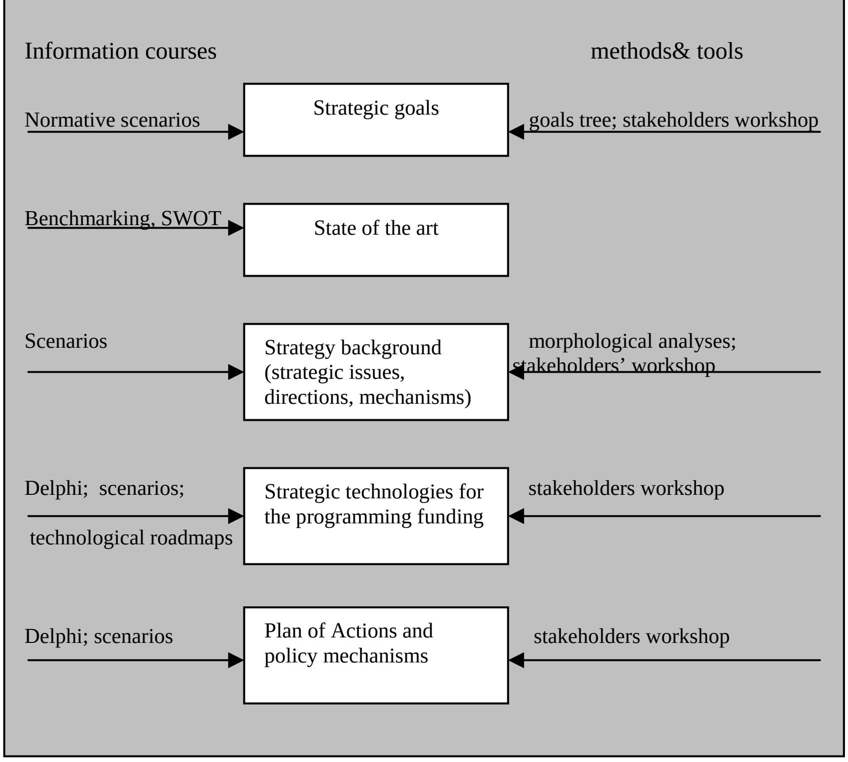
All information produced at the second step serve like a base for the narrative scenarios. Using the map of issues, time scale of events and short stories already developed as a guide, the scenarios are then described in sufficient detail. The time scale of events helps to flow from one event to another without loosing scenario consistency and plausibility and the map of problems gives a guide what kind of issues should be explored more detailed. It is better to start with the problems with high uncertainties; if they are explored in details than the study of problems with low uncertainties usually do not bring any problems. At this step the main trends, factors and motivations of different actors should be analyzed. A special attention should be paid to the turning pints in the technological trajectory and to the factors and actors which condition the abrupt changes in the trajectory. Very often scenarios suffer from the linearity of thinking of the scenario development panel but nanotechnology is a fast developing and nonlinear domain by nature. After the writing the alternative stories in details one has to put forward the issue of identification of strategic options.

Scenarios quantification is still a problem not only for nanotechnologies. For the fast developing domains like nanotechnology it is complicated by the lack of appropriate models. At this step scenario development panel should build the list of qualitative and quantitative indicators and to work hand in hand with the modeling group.

When scenarios are ready one has to discuss them at the workshops and seminars involving different stakeholders into the dialogue.

The outputs of analytical and future studies play like the inputs **for the development of the national S&T platform.** Fig.2. gives an idea about information sources and methods& tools used for this purposes. This way future studies we hope might be linked with decision-making. Science and Technology Platform is oriented on the formulation of strategic goals, selecting of strategic technology for the programming funding, development action plan and policy mechanisms for the supporting strategic technologies and for the building public- private partnership.

Fig.2. S&T Platform



To sum it up one has to point out that the developed methodological approach allows:

- to link science push and demand pull approaches;
- to provide dialogue and learning process between different stakeholders;
- to link future studies with policy- making;
- to collect the judgments of different stakeholders and innovations' users for the providing comprehensive assessment of coming nanotechnology;
- to select nanotechnology for the programming finding;
- to formulate policy mechanisms like dialogue between different stakeholders as well as to outline the fields for the public- private partnership;
- to form the information base for the corporations' strategic planning. The design of Foresight program like a dialogue forms also conditions for the building networks and public- private partnership.

Literature

Albright, R.A (2002) Roadmapping Perspective: Science-Driven Technologies. Global Advanced Technologies Innovation Consortium (GATIC) Workshop, Zurich, September 26

R. Bjil (1992) "Delphi in a future scenario study on mental health and mental health care" in Futures Vol 24, No 3, pp 232-250

Brown B (1968). Delphi Process: A Methodology Used for the Elicitation of Opinions of Experts The RAND Corporation, Santa Monica

Dalkey N (1967). Delphi The RAND Corporation, Santa Monica

Dalkey N & Helmer O. (1962). An Experimental Application of the Delphi Method to the Use of Experts The RAND Corporation, Santa Monica

Day L (1975). "Delphi Research in the Corporate Environment" in The Delphi Method: Techniques and Applications Linstone and Turoff (Eds) Addison-Wesley Publishing Company, London

Devis, Ged (1998) Creating Scenarios for Your Company's Future. Conference «Bringing Sustainable Development Down to Earth», New York, 28 April, 1998

Future Research Methodology. Scenarios. Millennium Project, American Council, United Nation University

Gordon, T. J. and Helmer, Olaf (1964) Report on a Long Range Forecasting Study, R-2982

Handbook of Knowledge Society Foresight (2003) EFILWC, Dublin, Ireland

Helmer, Olaf (1967). Analysis of the Future: The Delphi Method The RAND Corporation, Santa Monica

Helmer, Olaf (1994) "Adversary Delphi" in Futures Vol 26, No 1, 1994, pp 79-88

Helmer, Olaf (1983)"Looking Forward: A Guide to Futures Research", Sage Publications, Beverly Hills

Linstone H (1978). "The Delphi Technique" in Handbook of Futures Research Fowles J (Ed) Greenwood Press, Westport

Linstone H (1987). "Book Review of Issues Management by Coates J" in Technological Forecasting and Social Change Vol 32, pp 319-321

Harold Linstone & Murray Turoff, "Introduction" in The Delphi Method: Techniques and Applications Linstone and Turoff (Eds) Addison-Wesley Publishing Company, London, 1975

Ludlow J (1975). "Delphi Inquiries and Knowledge Utilization" in The Delphi Method: Techniques and Applications Linstone and Turoff (Eds) Addison-Wesley Publishing Company, London

Marien, M."Scanning: An Imperfect Activity in an Era of Fragmentation and Uncertainty" in Futures Research Quarterly, Fall, 1991

J. Martino "Methods of Technological Forecasting' in Assessing the Future and Policy Planning, 1973

E. Masini (1993) "Why Futures Studies?" Grey Seal, London

Schwartz P. (1991). The Art of the Long View Doubleday, New York

P. Thomas "Environmental Scanning - The State of the Art" in Long Range Planning, 1980, Vol. 13, No 1, pp 20-25

van Dijk J (1990). "Delphi Questionnaires Versus Individual and Group Interviews" in Technological Forecasting and Social Change Vol 37, pp 293-304

van Dijk J (1990). "Delphi Method as a Learning Instrument: Bank Employees Discussing an Automation Project" in Technological Forecasting and Social Change Vol 37, pp 399-407

F. Woudenberg "An Evaluation of Delphi" in Technological Forecasting and Social Change Vol 40, 1991, pp 131-150

Yuxiang C, Donghua Z Changgeng L (1990). "Applications of the Delphi Method in China" in Technological Forecasting and Social Change Vol 38, pp 293-305