Identifying expected areas of future innovation by combining foresight outputs

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Abstract

Purpose – *This paper attempts to examine the efficacy of combining outputs from a foresight exercise by different methods to get information for discussion on strategies of sustainable growth through science and technology. It seeks to address the combination of outputs in an objective manner to identify expected areas of future innovation toward the desired future as well as related areas that are supposed to play a key part.*

Design/methodology/approach – *Three investigative studies using the Delphi method, scenario and workshop were conducted independently in consideration of four global or national challenges. The points of the studies are interdisciplinary or diversified discussion and a mission-oriented approach. Information from the Delphi method and scenario is converged using text mining to position scientific and technological areas in a big picture.*

Findings – *Combining outputs reveals the whole picture of scientific and technological areas, including specific areas and common factors to be promoted toward the desired society. The result shows that green-related and life-related areas are two major areas where future innovation is expected. ICT, management and globalization are common factors that would be critical to promote innovations in these areas.*

Originality/value – *This paper is a case study of combining outputs at the last stage of a national foresight exercise to identify areas where future innovation is expected. It suggests the potential of combining outputs by capitalizing on the full value of the information obtained.*

Keywords *Foresight, Combination, Delphi method, Scenario, Innovation, Sustainable development, Forward planning*

Paper type *Case study*

1. Introduction

The situation surrounding science and technology has undergone a radical change in recent years. The world faces a number of complex problems, such as climate change and population problems, and each country also has its own specific issues, for example rapid aging of the population or economic stagnation. Expectation for innovation through scientific and technological development is building up in this situation, and many countries have shown a clear tendency to place special focus on science and technology policy in their innovation strategies. Science and technology policy are often discussed, including the creation of values in society, social or economic conditions for their promotion, and reform of stakeholders' way of thinking. In the USA, ''A Strategy for American Innovation: Driving towards Sustainable Growth and Quality Jobs'' was formulated in 2009 (Executive Office of the President, 2009), which was revised as ''A Strategy for American Innovation: Securing our Economic Growth and Prosperity'' in 2011 (National Economic Council, 2011). The European Commission released ''Innovation Union'' as a flagship initiative in Europe 2020 (European Commission, 2010). In Japan, the status of science and technology policy in the national grand strategy has changed significantly as its GDP growth rate stagnates in the face of intensified international competition and a falling birth rate and aging population.

Since 1996, science and technology policy has been carried out under the Science and Technology Basic Plans, which are formulated every five years. In the Second and Third Basic Plans, which started in 2001 and 2006 (Government of Japan, 2001, 2006), strategic prioritization was the basic principle in drawing up related policies except for those related to basic research. In conjunction with this principle, a call for innovation through scientific and technological development was first mentioned clearly in the Third Basic Plan.

Against the backdrops mentioned above, expectations are growing high in Japan, calling for the fruits of science and technology to contribute toward addressing global or national challenges. In the Fourth Basic Plan (Government of Japan, 2011) the focus on a problem-solving approach becomes more apparent: solving global or national issues through the effective application of science and technology. In this situation, the idea of placing special focus on particular fields has to be phased out, while the following themes will be central in discussions in the days to come:

- the fusion of several areas in science and technology;
- collaboration with the humanities and social science; and
- the promotion of science and technology viewed as an integral part of social-system reformation.

Converging technologies, collaboration or fusion of several fields (nanotechnology, biotechnology, information technology, and cognitive science) have been given attention since the mid-2000s. This indicates that science and technologies are becoming interrelated and need to be converged, and converging technologies focus on human performance or the social or economic dimension (National Science Foundation, 2002, 2005; European Commission, 2004). It is expected that converging technologies will trigger innovation and lead to the solution of social issues in the future.

Foresight has changed its role according to these changes: it aims to provide an overview of future impacts on our society in broader contexts. Foresight activities in Japan have also changed their objectives. Their main role was to identify key or emerging technologies, looking into the development of science and technology and the expected changes in society. Currently activities aim to discuss innovations that have the potential to change society for the better. Strong emphasis is placed on how key technologies or emerging technologies should be integrated and adequately embedded in society to achieve social goals and tackle social issues. Foresight is expected to facilitate a framework for integrated knowledge.

2. The 9th Science and Technology Foresight in Japan

A variety of methods have been adopted in alignment with the objectives of a project, including extrapolative/normative methods or qualitative/quantitative methods. Literature review, expert panel, and scenario are three major methods that are commonly used around the world, and they are all qualitative (European Commission, 2009). In recent years, the development of the internet has broadened the potential of exercises: it has enabled the enhancement of foresight objectives (Cachia *et al.*, 2007) and reduced the burdens of cost and time (Gordon and Pease, 2006). Combining methods has been recognized as a precondition of successful foresight since a variety of combinations have been discussed and applied around the world. A tailor-made combination of different methods is widely employed to obtain implications for policy making (Cuhls *et al.*, 2008). Meta-analysis on foresight methods shows the trends of combination (Popper, 2008):

- scenario is often used with literature review, expert panel, and trend extrapolation/megatrends;
- the Delphi method is often used with literature review, expert panel, and brainstorming; and
- workshop is used with literature review, expert panel, and scenario.

Scenario requires extensive knowledge of the field under investigation, and information from other sources is expected to be interpreted (Mietzner and Reger, 2005). The Delphi method is regarded as one of the useful information sources for scenario (Loveridge, 1999). The Delphi method is also discussed from the viewpoint of a combination with road mapping (Kanama *et al*., 2008). According to the meta-analysis mentioned above, around 20-39 percent of Delphi exercises are combined with scenario.

The 9th Science and Technology Foresight in Japan (see Figure 1) focuses on science and technology, which are expected to be the main players for addressing global or national challenges through innovation in the future. Considering the relation between science and technology and society along the lines of science in and for society, it is necessary to have a broad view from both the technological and social aspects. The 9th Foresight exercise employed three different types of methods to meet this requirement:

1. Delphi that focuses on the technological aspect;
2. scenario that explores the interaction between the technological aspect and the social aspect; and
3. workshop that aims for the participation of citizens.

The exercise was conducted by the National Institute of Science and Technology Policy from 2008 to 2010. It started with a discussion on social goals and their relation to science and technology, considering changes on a global or national scale. Based on the discussion, four global or national challenges were set as the goals of science, technology and innovation. They act as an umbrella covering three investigative studies which were carried out independently by using the methods mentioned above. The three studies complement each other:

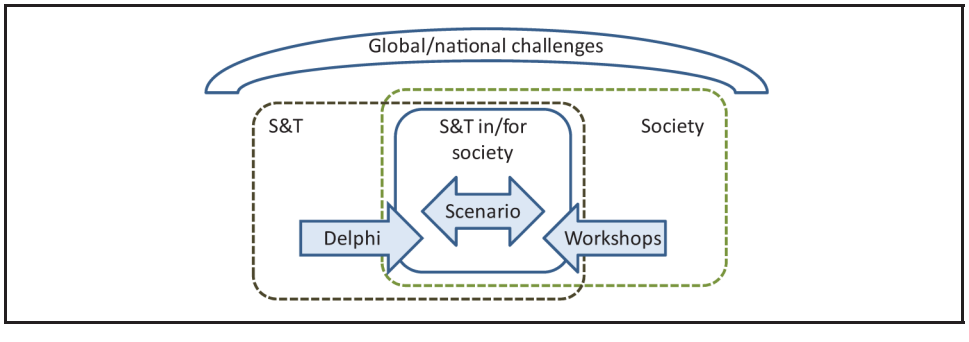
- Delphi provides technological perspectives for the challenges;
- scenario reveals the social impact of technological development and the required social conditions toward addressing the challenges; and
- workshop provides tangible examples of the challenges on a regional scale as well as the technological and social conditions involved.

The approach is characterized from two aspects:

1. interdisciplinary or diversified discussion; and
2. the mission-oriented or problem-solving approach.

The main points are expert panels by cross-disciplinary theme rather than by technological discipline, the active participation of specialists in social science and humanities, discussion by a variety of participants including the younger generation and local residents, and focused discussion rather than dealing with subjects exhaustively.

Figure 1 Overview of the 9th Foresight



2.1 Setting global or national challenges

The first step of the exercise is to identify the expectations for science and technology. The preliminary discussion was conducted to identify the missions of science and technology that would play an important role in drawing up a picture of future society. Four expert panels were organized for this discussion and designated as ''Security'', ''Safety (Reassurance on safety)'', ''International collaboration'', and ''International competitiveness''. They reviewed the mission of science and technology, and selected 24 priority issues (National Institute of Science and Technology Policy, 2009). The results of the preliminary discussion clearly indicated the importance of systematic integration – in other words, science and technology to be embedded in society as a socialized system.

With the discussion above and the dramatic changes occurring inside and outside Japan as a backdrop, the 9th Foresight exercise narrowed down the course of actions, in terms of scientific and technological challenges, into the following four global or national challenges:

1. central player in the scientific and technological arena;
2. sustainable growth through green innovation;
3. successful model for healthy-aging society; and
4. secure life.

2.2 Delphi

Delphi is characterized by repeated questions for the collective convergence of opinions, and it has been used in Japan as a technique for large-scale questionnaires targeted at experts in science and technology since 1971.

The Delphi survey in the 9th Foresight exercise aims to outline the future prospect of development in science and technology from the viewpoint of ''what should be done from now on'' to resolve global or national challenges, whereby the important areas were extracted through integrated discussions without being bound by existing disciplines. For this reason, panels consisted of experts in some related fields. The scopes and main focuses of the discussion were determined by panel members, and 12 panels accordingly discussed the topics and question items to be surveyed.

They set 94 areas (groups of inter-related topics) with 832 topics. Questionnaires from the viewpoint of a time span of 30 years until 2040 were carried out twice, and finally 2,900 responses were received in total.

2.3 Scenario

Three approaches were attempted for scenario building with a view to the desired future.

2.3.1 Scenarios by group work. Twelve groups of experts were set up under the challenges. They set the scenario themes, had extensive and interdisciplinary discussions, and created a positive scenario each about future changes that should be made; that is, a framework for reaching goals. Each scenario was supposed to be centered on drawing up the desired future and extensive coverage of key elements including priority research and development, human resource development, social conditions to be improved, and international expansion.

2.3.2 Scenes of life based on results of Delphi survey. Life scenes were developed based on the average future outlook of many experts. Delphi topics that were forecasted to be realized by 2025 were extracted and reframed as a form of scenes.

2.3.3 Future society as discussed by the younger generation. A group discussion by members of the younger generation was held to compensate for a possible age bias: By their nature, experts with a deep and broad knowledge who joined scenario groups or the Delphi survey come disproportionately from the middle-aged generation.

2.4 Workshop

Workshops were held in eight local regions in Japan, where the participants discussed desired regional lives in the future, and what kind of science and technology will be expected to contribute to realize them. Participants included citizens, researchers, business persons, and public officials from each region. This study aims to provide an initial platform on which the people in each region deepen their own independent discussions about their future vision. The discussions include a variety of aspects required, such as institutional renovation, inter-regional cooperation, and the region's place in the era of globalization.

3. Integrative study

3.1 Advantage of combination

A good public investment in research and development needs an overall picture of facets of science and technology that achieve innovation success to resolve challenges in the future. However, investigative studies that are implemented in parallel do not give a comprehensive and panoramic view. This integrative study attempts to derive an implication about what cooperation and convergence among scientific and technological areas will be required to address four challenges by combining information to draw up the whole picture of future science and technology.

Information for analysis is obtained from the Delphi survey and scenario building by group work in the 9th Foresight exercise. A combination of the outputs from the Delphi survey and scenario building has the possibility of providing a balanced whole picture of science and technology because they are considered complementary to each other also in regard to perspectives of development in science and technology. Implementation of the studies with loose linkage under common challenges enables combination with consistency.

Delphi deals with a variety of areas of science, technology and society, and therefore it contains events that are expected to make an implicit contribution or to become a common base in addition to events that have the potential for explicit contributions. It provides key areas of science and technology for addressing the challenges, looking at things holistically. However neither the relationship among events nor the necessary coordination or cooperation among them is mentioned. Events that are supposed to be affected largely by social factors like social acceptance or infrastructure building are not discussed in relation to them. Furthermore, Delphi rarely refers to the application of established technologies, tending instead to cover leading-edge technologies.

On the other hand, scenario gives sufficient discussion on scientific and technological events that make a direct contribution to the challenges, considering a variety of related factors. It also refers to the application of established technologies and collaboration possibilities among technologies. However, it cannot give a comprehensive view and define priorities for the whole country. All the information from scenario building is dependent on each theme. Events that may have implicit impact and base or general-purpose technologies tend to have little chance of being mentioned.

3.2 Procedure of combination

Text mining is employed to combine information from two sources, i.e. Delphi and the scenarios by group work. The keywords that frequently appear in and are characteristic to each scenario were extracted. A keyword is defined as consisting of more than two characters. Scores are assigned to all the keywords by the term frequency-inverted document frequency (TF-IDF) method shown below that is generally used in text mining; a high score is given to a keyword that appears in a specific scenario and a low score is given to a keyword that commonly appears in many scenarios.

The statements of Delphi topics are matched to the keywords in each scenario. If a topic statement has a keyword, that topic is given a score of that matched keyword. In this way, all

the Delphi topics are given scores by scenario according to their similarity, which are expressed as a score matrix.

Based on the matrix, Delphi areas (groups of relevant topics) and scenario themes are positioned on a two-dimensional map by correspondence analysis. Correspondence analysis is a widely used method to grasp the relations between two different categories of data. Items with many aspects in common with others are positioned near the center, while those with strong heterogeneity go to the periphery. Information on key areas from the Delphi survey is added to the map to discuss the overall view of science and technology for realizing innovation for solutions to the challenges. The procedure is shown in Figure 2.

4. Expected innovation

4.1 Relations between Delphi topics and scenarios

On average, one scenario has 4 percent of Delphi topics with scores greater than 100, and 75 percent of them with scores less than 30. In total, there are 329 Delphi topics with scores greater than 100 in at least one scenario, around 40 percent of all topics, because closely related topics vary from one scenario to another. They are regarded as topics that have a closer relationship with solving the challenges.

In Figure 3, the Delphi topics for each scenario are classified in decreasing order of score. The scenarios that contain many highly scored topics can be considered to offer a greater scope for contributions from science and technology. Five such scenario themes include:

1. ''Realization of a low-carbon society through the active use of the Smart-grid'';
2. ''World's highest level medical environment underlying a healthy society with longevity'';
3. ''Health information infrastructure for eliminating disparities'';
4. ''Stable supply of food''; and
5. ''Safely securing fossil and mineral resources''.

In terms of these themes, the importance of each scientific and technological event has already gained a common understanding among those concerned. It appears that the effort to grasp these future events systematically in a framework will gain importance.

On the other hand, the scenario themes with many low-scored topics are characterized by a low level of matching, which may indicate a lack of concrete measures and proposals in the scenarios or a shortage of relevant Delphi topics. The scenario theme of ''Integration of agriculture, forestry, and fishery industries into a unified entity'' is an example of this type, and may require a total review by experts. For such themes with less matching, an out-of-the-box discussion is needed on the contributions that science and technology can offer.

Figure 2 The procedure of analysis

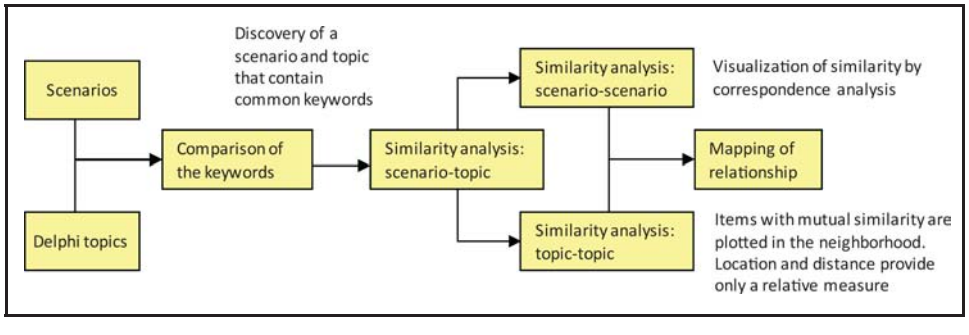
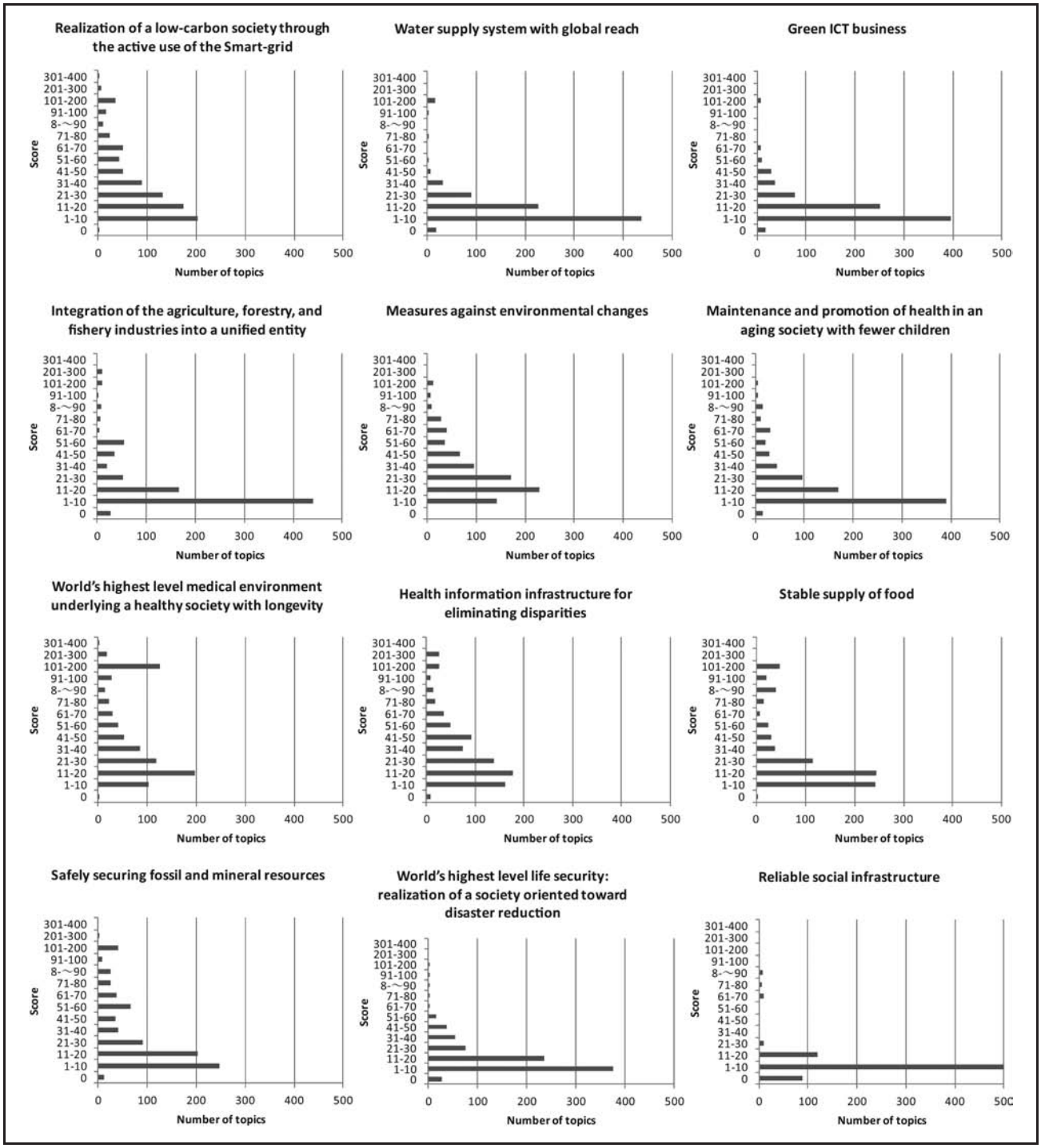


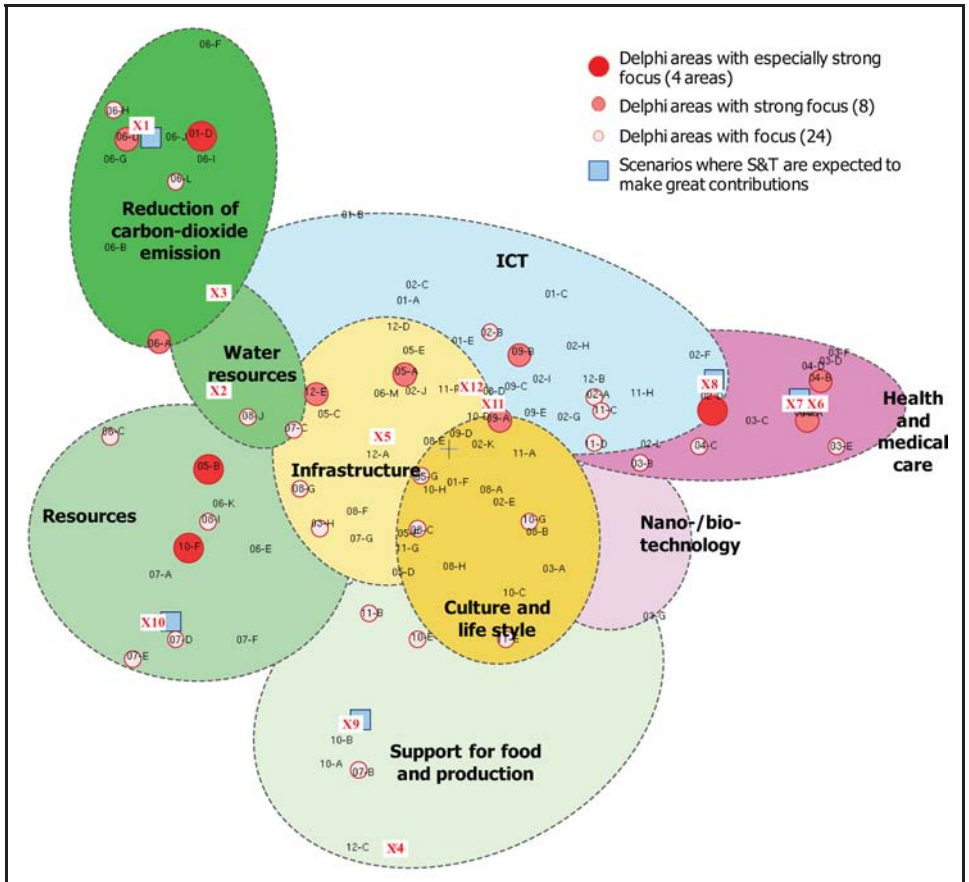
Figure 3 Distribution of relevant topics by scenario theme



4.2 Overall view

Relations between the scenarios and the Delphi areas (groups of inter-related topics) are summarized in a two-dimensional map (Figure 4). In the map, the items that have greater similarity and are more closely related are positioned near each other. Therefore, fundamental items in common generally come relatively near to the center of the map, while items with stronger heterogeneity go to the periphery. The scenarios and Delphi areas

Figure 4 Overall view of scientific and technological areas



Notes: X1-X12: ID of group scenarios. Other codes: ID of Delphi areas (the numbers indicate a panel)

closely related are grouped together in reference to the results of cluster analysis. As can be seen in the map, the scenarios and Delphi areas related to energy, resources, and environment gather on the left side, forming a broad and relatively loosely linked group. On the other hand, the scenarios and Delphi areas related to health and medical care gather on the right side, forming a group with different characteristics to the group on the left side. Groups related to ICT, infrastructure, and culture and lifestyle gather in the central part, indicating their status as common infrastructure.

4.3 Areas where innovation is expected in the future

The Delphi survey identified 36 key areas out of all 94 areas set by the panels, as shown in Table I. It is worth noting that 18 areas, half of the key areas above, are related to energy, resources, and environment. This implies that the areas that are conducive to the realization of energy-and-environment related future visions gathered much attention from experts in a variety of technological disciplines. In the map, circular dots indicate the 36 key areas above, which are graded according to the experts' expectation. Square dots indicate the five scenarios mentioned in section 4.1, where science and technology are expected to make great contribution because a lot of Delphi topics are closely related.

The group of clusters related to energy, resources, and environment on the left side can be regarded as indicating the first group of expected innovation toward resolving the challenges in the future society because it contains half of the 36 key areas and two out of the five scenarios that many Delphi topics are closely linked to. In addition, the group of clusters

Table I Areas of key importance for the resolution of four challenges

ID	*Key areas*
Energy, resources, and environment	
01-D	Energy-related[a]
03-H	Industrial bio-nanotechnology related to energy and environment
05-A	Geo-diagnosis technology[b]
05-B	Space and ocean management technology (including observations)[a]
06-A	Nuclear energy[b]
06-D	Renewable energy[b]
06-C	Fossil energy
06-H	Efficient power storage system
06-L	Energy saving
07-B	Agriculture, forestry, and fisheries resources
07-C	Water resources
07-D	Environment, recyclable resources, recycling, LCA
07-E	Hydrocarbon resources, mineral resources, and CCS
08-C	Lifestyle and environment
08-G	Evaluation of and countermeasures to global warming
08-I	Technology for urban waste minimization/material circulation for environmental conservation/resource- and energy-saving products
08-J	Pollution prevention for atmosphere, water and soil/circulative use technology for water resources
10-F	Energy, resources, and environment[a]
Health and medical care	
03-B	Applied bio-nanotechnology
03-E	Medical treatment (exogenous factor, metabolic disease, and psychiatric disease)
04-A	Medical treatment aiming at safety and security[b]
04-B	Creation of new medical technology[b]
04-C	Development of predictive and preventive medicine
Others	
02-D	Socialization of information[a]
02-A	Cloud computing
02-B	New principle for information and communication
05-G	Space technologies (including space medicine)
09-A	Base materials for nanotechnology[b]
09-B	Output (device, systemization and applied technology)[b]
10-E	Globalization, value-adding and market creation
10-G	Unpopularity of science and engineering, human resource problem, the declining birth rate and aging population
11-B	Management to prevent the decrease of competitiveness in the international market, development of internationally competent people, and cross-cultural cooperative management
11-C	Service management, management in the education and research field, environment business management, governmental institution management
11-D	Framework for facilitation of social innovation and network building
11-E	Management of humans, creation, management, and transfer of knowledge, education, and maintenance of education level by standardization
12-E	Strategy toward a sustainable infrastructure system[b]

Notes: [a]Delphi areas with especially strong focus; [b]Delphi areas with strong focus

related to health and medical care on the right side can be deemed to constitute the second group. It also contains two of the five scenarios above, although it has a small number of the key areas shown in Table I.

Other elements that possibly assume a high level of importance come from such areas as fundamental technology (e.g. ICT and infrastructure) and sociological science (e.g. lifestyle and management), and it is noteworthy that they are arranged in the central part of the map, overlapping the two groups described above. This indicates that it would be beneficial to develop an argument asserting such common factors when focusing on those groups. The ''Socialization of information'' area in the category of ''Others'' gained an especially high expectation, which indicates that the importance of ICT utilization is widely recognized, as are energy and environment related areas. The area addresses the issue of constructing a new information society system where ICT underpins the basic infrastructure of society, and

all the people living in the society benefit from it. The collaboration of these base technologies including ICT with mainstream innovation will be discussed further in the next section.

5. Common factors for future innovation

As stated in section 3, the approach employed here aims to take a comprehensive view of facets of science and technology that have the potential to make innovation happen and contribute to the solution of four challenges directly or indirectly. The result indicates two potentialities:

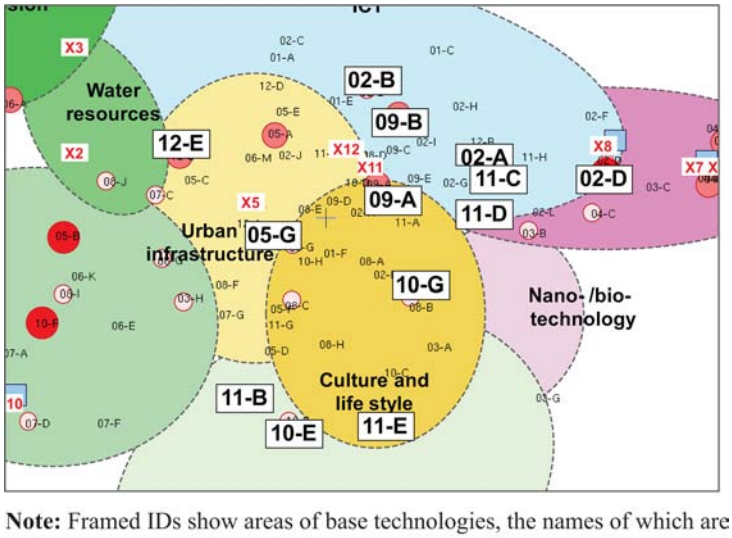
1. green-related innovation; and
2. life-related innovation.

This section discusses how base technologies in common are expected to become engaged in the two potentialities.

5.1 Examination from positions of key areas

As shown in Table I, 14 key areas are categorized as ''Others'', meaning areas that are not green-related or life-related areas. Figure 5 shows where these areas are positioned in the map of the overall view. Key areas related to ICT utilization and networking, service management and social innovation are positioned near life-related areas, which indicates that innovative progress will be made in health and medical care through collaboration with ICT and management technology. On the other hand, areas related to infrastructure management and globalization (international competition and cooperation) are positioned near green-related areas, which shows green innovation has a close relation to the international standpoint. Areas related to space and ocean sciences and materials science are positioned near the center and show no direct relation to the two potentialities of innovation: this indicates that these areas will play a role as a general-purpose technology or as a source of cutting-edge technology providing ground-level support to the concrete contributions of other technologies.

Figure 5 Relation between directions of future innovation and base technology areas



Note: Framed IDs show areas of base technologies, the names of which are shown in Table I

5.2 Examination of relationship between scenario descriptions and Delphi topics

Of the 12 Delphi panels, the number which each scenario has links to ranges from zero to nine. The five scenario themes mentioned in section 4.1 and shown as square dots in Figure 4 are linked to topics in at least half of all panels. This indicates that cross-cutting development efforts by experts from different disciplines, including base technologies, are expected to have a great effect in solving four challenges.

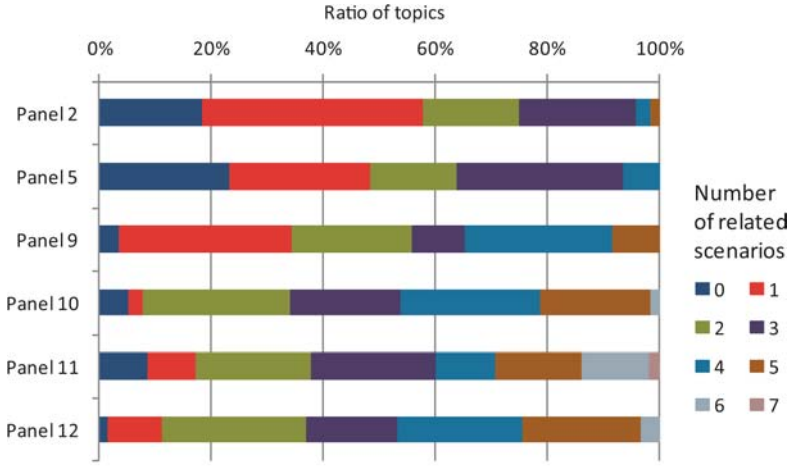
Another focus is Delphi topics in the key areas categorized as ''Others'' in Table I – that is, the topics in Panels 2, 5, 9, 10, 11, and 12. Figure 6 shows how many scenarios each topic has relations to. Here, topics that score 30 or more are regarded as being related to a scenario, and about 25 percent of all topics in each scenario meet this requirement. Panels 2 and 5 have around 20 percent of topics that have no relation to scenarios, and most of them are related to at most three scenarios. On the other hand, Panels 10, 11 and 12 have many topics that are common in several scenarios and around half of the topics are related to more than three scenarios. Panel 9 has both specific topics and common topics. Regarding base or common technologies related to ICT (Panel 2) and to earth/space (Panel 5), specific topics tend to contribute to specific issues, whereas when it comes to technologies related to hard and soft infrastructure (Panel 11 and 12), and to manufacturing (Panel 10), single topics tend to be related to solutions for several issues.

The extent of expected diversity in science and technology depends on scenario themes and the extent of relation to scenario themes depends on scientific or technological fields. This reflects complexity of the relationship between scientific or technological development and social benefit coming from it, which shows that the comprehensive view of science and technology is indispensable for discussing the desired future.

6. Conclusion

To bring about innovation in society through the effective use of the fruits of science and technology, foresight clearly should define an image of the future and show the framework

Figure 6 Ratio of topics that are related to several scenarios



Panel 2: Information technology including media and contents
Panel 5: Understanding of dynamics of space, earth, and life, and science and technology which expand the region of human activity
Panel 9: Fundamental technologies, including substances, materials, nanosystems, processing, measurement, etc.
Panel 11: Strengthening of management led/required by advancement of science and technology
Panel 12: Infrastructure technologies supporting daily life base and industrial base

toward its realization. Through this process, many findings come into view as to what should have priority for promoting innovation. Naturally, the approach to address global or national challenges goes far beyond the border of research and development in a single discipline, and necessarily involves collaboration across disciplines.

The 9th Foresight exercise was conducted under the concept of contributing to the future society. The points of the exercise were interdisciplinary or diversified discussion and a mission-oriented or problem-solving approach. Three investigative studies were carried out, employing methods of Delphi, scenario, and workshop in consideration of the four global or national challenges. They provided information about scientific and technological possibilities, and promoting factors toward specific social goals as well as the potential of each local region.

An integrative study then followed, using information from Delphi and scenario to get a whole picture of science and technology toward the desired future. Green-related areas and life-related areas define the major directions of our future efforts toward realization of the desired future. Common factors, including ICT, management and globalization, should be emphasized in connection with the promotion of innovation in these two areas.

This paper is a case study of combining foresight outputs at the last stage to identify the expected areas of future innovation and its promoting factors. Combination of information obtained from studies conducted independently under a common framework, could be regarded as an acceptable approach to take every advantage of method employed and position potential areas of future innovation with related areas to be promoted together in the whole picture. Further discussion should be focused on which research framework could lead to the better understanding of the overall picture and the direction toward the future.

References

Cachia, R., Compano, R. and Da Costa, O. (2007), ''Grasping the potential of online social networks for foresight'', *Technological Forecasting and Social Change*, Vol. 74 No. 8, pp. 1179-203.

Cuhls, K., Bode, O., Ganz, W. and Wanke, P. (2008), ''The BMBF Foresight Process'', paper presented at the 3rd International Seville Seminar on Future-oriented Technology Analysis, October 16-17, Seville.

European Commission (2004), *Converging Technologies – Shaping the Future of European Societies*, European Commission, Brussels.

European Commission (2009), *Mapping Foresight: Revealing how Europe and Other World Regions Navigate into the Future*, European Commission, Brussels.

European Commission (2010), *Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth*, European Commission, Brussels.

Executive Office of the President (2009), *A Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs*, Executive Office of the President, National Economic Council, Office of Science and Technology Policy, Washington, DC.

Gordon, T. and Pease, A.R.T. (2006), ''Delphi: an efficient, 'round-less', almost real time Delphi method'', *Technological Forecasting and Social Change*, Vol. 73, pp. 321-33.

Government of Japan (2001), *The 2nd Science and Technology Basic Plan*, Government of Japan, Tokyo.

Government of Japan (2006), *The 3rd Science and Technology Basic Plan*, Government of Japan, Tokyo.

Government of Japan (2011), *The 4th Science and Technology Basic Plan*, Government of Japan, Tokyo.

Kanama, D., Kondo, A. and Yokoo, Y. (2008), ''Development of technology foresight: integration of technology roadmapping and the Delphi method'', *International Journal of Technology Intelligence and Planning*, Vol. 4 No. 2, pp. 184-200.

Loveridge, D. (1999), ''Foresight and Delphi processes as information sources for scenario planning'', Ideas in Progress Paper No. 11, Policy Research in Engineering, Science & Technology, University of Manchester, Manchester.

Mietzner, D. and Reger, G. (2005), ''Advantages and disadvantages of scenario approaches for strategic foresight'', *International Journal of Technology Intelligence and Planning*, Vol. 1 No. 2, pp. 220-39.

National Economic Council (2011), *Strategy for American Innovation: Securing our Economic Growth and Prosperity*, National Economic Council, Council of Economic Advisors, Office of Science and Technology Policy, Washington, DC.

National Institute of Science and Technology Policy (2009), ''Emerging fields in science and technology for the 4th Science and Technology Basic Plan'', Research Material No. 168, National Institute of Science and Technology Policy, Tokyo.

National Institute of Science and Technology Policy (2010), ''The 9th Science and Technology Foresight'', NISTEP Report No. 140-142, National Institute of Science and Technology Policy, Tokyo.

National Science Foundation (2002), ''Converging technologies for improving human performance'', National Science Foundation, Arlington, VA.

National Science Foundation (2005), ''Managing nano-bio-info-cogno innovations: converging technology society'', National Science Foundation, Arlington, VA.

Popper, R. (2008), ''How are foresight methods selected?'', *Foresight*, Vol. 10 No. 6, pp. 62-89.

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