Mapping of future technology themes in sustainable energy

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Abstract

Purpose – *To anticipate science and technology (S&T) changes and shifts in the competitive environment for the preparation of strategic development in an organization, this paper aims to address a structured analysis method for future technology trajectories and interactions by mapping and associating the future technology themes in foresight reports with a state-of-the art technology classification system. The objective of this paper is to develop an integrative method for systematically clustering, analyzing and visualizing the path for technology development and transformation.*

Design/methodology/approach – *Delphi topics related to sustainable energy were collected from strategic foresight reports of Japan, South Korea and China, and used as sources for future technology themes analysis. A standard mapping taxonomy based on international patent classification system was used to map out the technology concept described in these future technology themes. Technology interactions can be identified through a causal effect analysis during the mapping, and the results among selected countries are cross-compared and visualized in an aggregated view.*

Findings – *By this standard mapping taxonomy and structured analysis, future technology themes in strategic foresight reports from countries in focus are systematically mapped and integrated for viewing future technology options and interactions. Similarities and discrepancies for prospecting the future technology trajectory among these countries are also identified.*

Research limitations/implications – *It would be a significant contribution if this structured analysis could be applied more broadly across different geographic regions or across research areas in foresight reports. This research may help to solve the practical difficulties faced during the secondary analysis of foresight studies in foresight preparatory studies by providing a consistent classification framework to make comparison and aggregation of future technology options from different countries/regions. Also, this classification framework can provide a bridge for linking with current technology performance such as patent productivity or quality and help in identifying the gaps between the probable future changes in S&T and the current capability.*

Originality/value – *The integrative method in this research provides a way to combine both the advantage of strategic technology foresight and competitive technology intelligence by utilizing the results deriving from the former as targets for analysis and the analytic practice deriving from the latter to identify the possible competitive or cooperative landscapes in the future.*

Keywords *Strategic technology foresight, Competitive technology intelligence, Delphi topic analysis, International patent classification system, Sustainable energy, Innovation, Forward planning*

Paper type *Research paper*

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1. Introduction

Foresight and competitive intelligence (CI) are two fields that seek to address future-oriented environmental scanning (Calof and Smith, 2010). Foresight activities have become more and more popular all over the world and the proliferation of foresight activities among all sorts of economies can be observed. Also, the rule of foresight has changed from the previous explorative forecasting to more be come more oriented to strategic planning (Martin, 1995). Foresight is no longer undertaken with the claim to forecast or predict a certain future situation, but recognizes the possibility of alternative futures and also tries to shape or create certain paths of development (Gavigan and Cahill, 1997; Grupp and Linstone, 1999). Therefore, many countries not only use foresight as a tool to improve anticipatory intelligence but also use it as a priority-setting tool. In some Asian Countries such as Japan, South Korea and China, foresight has been taken as a tool for priority setting or R&D agenda setting. Japan has utilized the result of the 8th Foresight activity to form the Innovation 25 policy and the result of the 3rd Foresight activity of South Korea has resulted in 21 future technology areas. Also, China has used the result of foresight for selection of their critical technologies. Even in some small countries in Europe like Austria, foresight results have been used for the implementation of policy measures (Aichholzer, 2001).

Competitive intelligence is a systematic way to collect and analyze public information about competitors and use it to make decisions. The context and importance of competitive intelligence is based partly on the resource-based theory, which is one of the theories most integrated into current management thinking and emphasizes the importance of a resource-based view of an organization (Powell and Bradford, 2000; Barney, 1986; Grant, 1991; Markides and Williamson, 1994). According to the resource-based theory, competitive advantage occurs only when there is a situation of resource heterogeneity and resource immobility (Barney, 1991). With this perception, conventional strength, weaknesses, opportunities and threats (SWOT) analyses are informed by the need to maintain these core competences in the face of the development by competitors of their own core competences and key assets (Hax and Majluf, 1996). Therefore, the ability to access new markets can only be prepared if knowledge about competitor's intention and capabilities can be monitored. Without such knowledge the capacity to access existing and new markets and to identify and maintain the basis of competitive advantage will be limited (Powell and Bradford, 2000). In addition to the resource-based theory, the modern emphasis is on network approaches to industrial strategy and the need for partnering approaches to manage these networks of buyers, suppliers and peer companies, knowing the capabilities and intents of other organization for non-competitive purposes. Competitive intelligence is also important to retain a dynamic understanding of the technology trajectories of the surrounding industrial environment (Nelson, 1997). Therefore, it is not possible generate a viable and appropriate technology strategy without a perception of the changing technical capability of our own industry and that of related industries (Powell and Bradford, 2000).

Given the importance of investing in the right technology for companies and staying abreast of technological change, acquiring an advanced understanding of technology and its potential market shifting effects, competitive technology intelligence (CTI) has been generated and popularized (Calof and Smith, 2010). In general, CTI is competitive intelligence within the R&D arena (Herring, 1993; Ashton *et al.*, 1994). It has been defined as:

> . . . business sensitive information on external scientific or technological threats, opportunities, or developments that have the potential to affect a company's competitive situation.

Ashton and Klavans (1997) also defined three basic objectives for CTI activities:

1. to provide early warning of external technical developments or company moves that represent potential business, threats or opportunities;
2. to evaluate new products, processes or collaborative prospects created by external science and technology (S&T) activities in time to permit appropriate responses; and
3. to anticipate and understand S&T-related shifts or trends in the competitive environment as a preparation for organizational planning and strategic development.

To date, studies on CTI have used a full range of analytical techniques, including content analysis, patent analysis, bibliometrics, competitor profiling, early warning assessment, scientometrics, science mapping, scenarios, network analysis and so forth (Calof and Smith, 2010).

A new integrated domain – strategic intelligence and foresight on technology (SIFT), a combination of CTI and Strategic technology foresight (STF) – was recently proposed by Calof and Smith (2010). They indicated that STF can be both a source of CTI and a means for its application. STF is derived from technology foresight and foresight, where the emphasis is not only on the technologies of the future but also on their strategic importance in shaping the socio-economic horizons of organizations and national economics. CTI and STF are moving towards an integrated capability and their future applications seem to be quite similar, i.e. to guide R&D decisions. In looking at the timeframes associated with CTI, they are of a shorter duration to foresight and are more of a predictive nature than STF. Therefore, integrative SIFT can provide an advantage to existing CTI practice in that its principal analytical technique of Delphi, which involves integrating knowledge from broad and diverse groups, could be of benefit to CTI.

During the input phase or preparatory phase of many different foresight activities, technology or research topic mapping by reviewing existing foresight activity is becoming more and more popular. One such is a foresight activity called ''FISTERA'', which is a large-scale technological foresight study that was designed to benchmark current information society technologies (ISTs) and develop strategies for future ISTs in order to realize the goal stated in the Lisbon Objective (Fujii, 2006). In FISTERA, many national foresight exercise reports were scanned and important ISTs were listed and scouted. In Delphi Austria, an analysis of the Japanese, German, French, British Delphi studies was conducted to separate and evaluate worldwide technology trends during the preparatory studies (Aichholzer, 2001). In addition, after the Delphi Austria foresight process, the results of the Austria Technology Delphi were also re-classified according to the standard classifications of industry – i.e. the NACE classification – in order to facilitate their use by industrial economists and policy makers and to propose an explanation of the old structures/high performance paradox (Tichy, 1999; Orwat, 2003). Another famous example is the foresight activity mapping used by the European Foresight Monitoring Network (EFMN), a Europe-wide network inspired and financed by the European Commission within the framework of the Foresight Knowledge Sharing Platform implemented under the Research Framework Programme (FP7). A specially designed taxonomy is used for mapping (Popper, 2009). The mapping dimension of EFMN, especially for the science and technology field and socio-economic sectors which the collected foresight activity explicitly address, are fingerprinted based on the Frascati Manual classification and the NACE code classification, which is an EU-accepted industrial classification of industry. Therefore, the standard classification framework provides an easy way to take an aggregated and structured view to see the future science and industry development from foresight collected from all over the world.

In the foresight experience of small countries such as the foresight activity conducted in Austria named ''Delphi Austria'', foresight activity was regarded as a ''search tool'' to identify their strengths in R&D, and in particular to identify innovation potentials and niches within technology trends where Austria might find opportunities to achieve leadership within the next 15 years (Aichholzer, 2001). Therefore, monitoring among scanned future trends, selecting and making positioning, and then specializing in small segments of the world market become the main focus of a small country. Therefore, it is crucial to develop a systematical method in which future trends can be easily detected, analyzed and visualized.

It has been shown that fingerprinting of foresight activities by using a widely accepted or standard classification system will make it easier to take a cross-foresight comparison and for analysis. Therefore, a structured mapping method that uses a worldwide accepted international classification system – i.e. International Patent Classification (IPC) – is applied as a basis for the mapping of the contents of future technology themes, especially for Delphi topics, to systematically detect and analyze future technology development and interactions.

2. Methodological approach

2.1 Delphi method background

Delphi was developed in the 1950s by the US RAND Corporation and has become a widely accepted and frequently used research method, especially for foresight or for future oriented research. Delphi is a subjective-intuitive research method that aims at a consensus on a particular topic among a group of experts, while the procedure follows an anonymous, multi-stage communication process based on several survey rounds (Turoff, 1970). Previous publications have proved that the technique is an established method for foresight activities and that Delphi outperforms other group formats such as statistical groups or standard interacting groups in terms of effectiveness (Rowe and Wright, 1999). It is commonly assumed that the method makes better use of group interaction (Rowe *et al.*, 1991), whereby the questionnaire is the medium of interaction (Martino, 1983). The Delphi method is especially useful for long-range forecasting (20-30 years), as expert opinions are the only source of information available. Meanwhile, the communication effect of Delphi studies and the value of the process are also acknowledged.

2.2 Basic information for the scanned Delphi topics

The Delphi topics used for sustainable energy are chosen from foresight reports from Japan, South Korea and China. Table I summarizes the basic information for the scanned foresight reports and details for their foresight activities.

By proper selection of sustainable energy related topics, the Delphi topics were first extracted based upon their original category in the foresight reports. When the scope of the original category is broader than sustainable energy, topics were selected according to the knowledge of a domain expert. After selection, these Delphi topics are then mapped by the following taxonomy framework.

2.3 Mapping of Delphi topics

2.3.1 Taxonomy framework for mapping. Delphi topics collected from the scanned foresight reports are somehow diversified and have subtle differences in the scope of their descriptions. Therefore, the topics need to be restructured or mapped to a proper taxonomy framework, and then technology trends can be easily identified based on the mapped result. In this paper, the content of the Delphi topics was mapped according to a patent classification system, the eighth edition International Patent Classification (IPC) published by World Intellectual Property Organization (WIPO), which is recognized worldwide. The IPC, established by the Strasbourg Agreement of 1971, provides for a hierarchical system of language-independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. WIPO is a specialized agency of the United Nations. It is dedicated to developing a balanced and accessible international

Table I Basic information for scanned foresight reports from Japan, South Korea and China

	Japan	*South Korea*	*China*
Report Title	The 8th Science and Technology Foresight Survey Delphi Analysis	Prospect of future society & future technology of Korea-challenges and opportunities (Korea 2030)	China's Report of Technology Foresight 2004
Report year	2005	2005	2004
Project promoter/initiator	Ministry of Education, Culture, Sports, Science and Technology, Japan	The Ministry of Science and Technology of the Republic of Korea	Ministry of Science and Technology
Agency or organization responsible for the foresight activity	Science and Technology Foresight Center, National Institute of Science and Technology Policy (NISTEP)	Foresight and Strategy Planning Team, Korean Institute of S&T Evaluation and Planning (KISTEP), The Science and Technology Policy Research Institute (STEPI)	Technology Foresight Research Team, National Research Center for Science and Technology for Development
Time horizon	2035	2030	2020
Original category	Energy and resources	Energy and the environment	Energy
Participation (Delphi second round)	202 experts	390 experts	177 experts
Counts of Delphi topics related to sustainable energy	35	76	83

intellectual property (IP) system that rewards creativity, stimulates innovation and contributes to economic development while safeguarding the public interest. In order to keep the IPC codes up to date with the progress of technology development, IPC codes are continuously revised and a new version of the IPC is published regularly by the WIPO (World Intellectual Property Organization, 2011).

The taxonomy framework of IPC codes is used for the mapping of the content of Delphi topics mainly based on the following reasons. Patent documents have long been regarded as a useful source for technology management because they include technical and application/commercial information. Patents are oriented towards the legal protection of technologies and therefore the classification of patents is based on technologies or products that use specific technologies (Schmoch, 2008). There is long history in economics of the use of patent data to understand the process of invention and innovation (Griliches, 1990; Schmookler, 1966). Also, patent documents are widely used as a source for technology forecasting, CTI and for analysis of technology convergence (Kayal, 1999; Shih *et al.*, 2010; Curran and Leker, 2011). Based on the IPC code given to each patent document, statistics regarding the code or advanced analysis can be done easily to compare development or the trajectory among different technology domains. Therefore, the IPC code, as a classification system for the state-of-the-art technology, provides a route for linking mid- to long- term technology, as described in the technology vision of a Delphi topic, to the present or near-future technological trajectory.

The main difference between patent documents and Delphi topics lies in the fact that a patent describes in longer text an invention that has been proved of concept and for which the technology is ensured to be feasibility, while Delphi topics describe a technology that can be in any stage between research exploration to commercialization, with the description being relatively short. In addition, the content of Delphi topics depends on the time horizon of the foresight activities. For example, the foresight activity of Japan has up to a 30-year time horizon, and hence the technology trends provided by the scanned Delphi survey will provide a long-term view while the result from patent analysis for CTI or for forecasting provide a short-term view. Also, survey results of Delphi topics are collective intelligence from the expert interaction of scanned countries, while patent analysis provides a more evidence-based view (Popper, 2008).

2.3.2 Overall procedures of the mapping. Table II outlines the overall procedures of the mapping. Seven steps are needed to finish the mapping. The key steps are from Step 3 to Step 7. In Steps 3 and 4, the keywords of the Delphi topics, especially the technology/product term should be extracted, and the extracted or identified keywords are mapped for their corresponding IPC code. The IPC code is a five-level hierarchical classification system. There are eight sections, 120 classes, 628 subclasses and about 70,000 groups. The more specific the technology/product keyword described in the Delphi topic, the lower level of code (i.e. more digits of the code) can be given to these keywords.

Table II Overall procedures for mapping of Delphi topics

Procedure	*Description*
Step 1	Collect Delphi topics from foresight reports of Japan, South Korea and China
Step 2	Select topics related to sustainable energy based on the original category in the foresight reports and confirmed by domain experts
Step 3	Identify the technology/product keywords or terms in each Delphi topic through content analysis
Step 4	Assign the corresponding IPC codes (main-group level or above) for these technology/product related terms in each of the Delphi topics analyzed
Step 5	Distinguish with the identified IPC codes as a source or an application of technology
Step 6	Convert these IPC codes to the WIPO technology classification based on the WIPO IPC-Technology Concordance Table
Step 7	Map the technology distribution/interaction by WIPO technology classification and demonstrate by a matrix table or social network analysis

For converting and aggregating to the 35 WIPO technology classifications in Step 6, IPC subclass/main-group level mapping or above is preferred.

To get more information on technology interaction from the Delphi topic descriptions, especially for the identification of technology linkages or causal effects, the keywords and their corresponding IPC codes are distinguished between source/application technologies in Step 5.

In Step 6, we have used a higher-level classification, through which 628 subclasses are aggregated into 35 technological fields, as also proposed by WIPO. Descriptions of the 35 classification fields and their corresponding code numbers are listed in Table III. In addition, Table IV shows part of the WIPO IPC-Technology Concordance Table utilized during Step 6.

After each Delphi topic is mapped to the IPC code and aggregated to the WIPO technology field, the linkage or interaction between the technologies can be demonstrated by a matrix table, or can be visualized in advance by social network analysis.

2.3.3 Examples of Delphi topic mapping. Figure 1 shows an example of Delphi topic/theme mapping, especially from keyword extraction, IPC code mapping, source/application technology identification, and mapped result aggregation to WIPO technology classification. The Delphi topic in the example is from Japan, and involves ''Polymer electrolyte fuel cells for automobile use''. The keywords extracted by content analysis are ''polymer electrolyte'' and ''fuel cells''. By using the IPC subclass code for mapping, the IPC

Table III WIPO technology classification

No.	*Field*
1	Electrical machinery, apparatus, energy
2	Audio-visual technology
3	Telecommunications
4	Digital communication
5	Basic communication processes
6	Computer technology
7	IT methods for management
8	Semiconductors
9	Optics
10	Measurement
11	Analysis of biological materials
12	Control
13	Medical technology
14	Organic fine chemistry
15	Biotechnology
16	Pharmaceuticals
17	Macromolecular chemistry, polymers
18	Food chemistry
19	Basic materials chemistry
20	Materials, metallurgy
21	Surface technology, coating
22	Micro-structure and nanotechnology
23	Chemical engineering
24	Environmental technology
25	Handling
26	Machine tools
27	Engines, pumps, turbines
28	Textile and paper machines
29	Other special machines
30	Thermal processes and apparatus
31	Mechanical elements
32	Transport
33	Furniture, games
34	Other consumer goods
35	Civil engineering

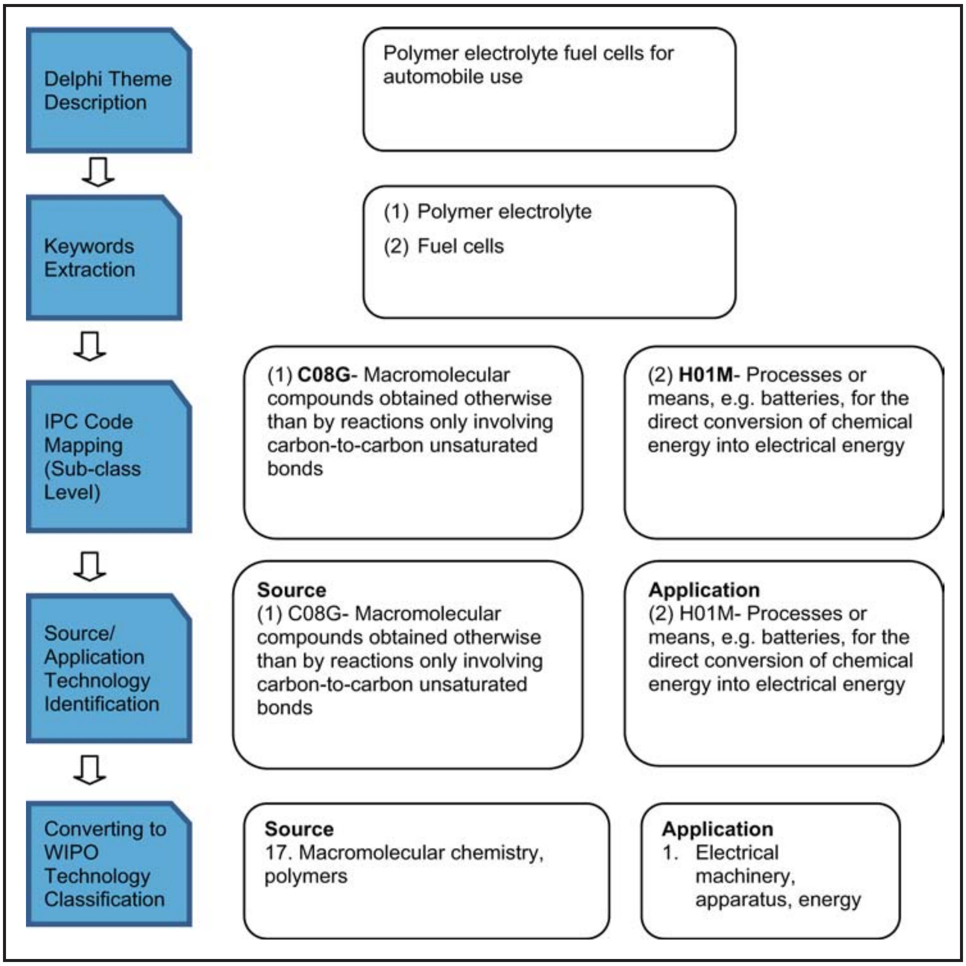
Source: Schmoch (2008)

Table IV Examples of WIPO IPC technology concordance table

Field	*IPC codes*
1. Electrical machinery, apparatus, energy	F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z
17. Macromolecular chemistry, polymers	C08B, C08C, C08F, C08G, C08H, C08K, C08L

Source: Schmoch (2008)

Figure 1 Example for Delphi topic mapping



code C08G covering ''polymer electrolyte'' is identified, which represents ''MACROMOLECULAR COMPOUNDS OBTAINED OTHERWISE THAN BY REACTIONS ONLY INVOLVING CARBON-TO-CARBON UNSATURATED BONDS'', and the IPC code H01M covering ''fuel cell'' is identified, which represents ''PROCESSES OR MEANS, e.g. BATTERIES, FOR THE DIRECT CONVERSION OF CHEMICAL ENERGY INTO ELECTRICAL ENERGY'', is also identified. After the IPC codes for the keywords are mapped, the source/application technology for the Delphi topics are identified through causal effect analysis, namely the source IPC code and the application IPC code are distinguished by the judgment of a domain expert. To aggregate the mapping and see the result from a bird's-eye view, the IPC codes identified are converted into the WIPO technology classification as part of the Concordance Table shown in above Table IV.

3. Results, impacts and policy options and implications

Since the time horizons surveyed in the three scanned foresight report are different, the Delphi topics need to be screened again based on their realization time for cross-country comparison. The time horizons surveyed for Delphi topics in Japan are ‘‘time of technological realization’’ and ‘‘time of social application’’. The time horizons surveyed for Delphi topics in South Korea are ‘‘time of international realization’’ and ‘‘time for domestic realization’’. The time horizon is not specific in the Chinese Delphi topics but the forecasting time horizon for the whole foresight activity was set at up to the year 2020, by which technology that can be realized before the year 2020 is pre-selected. Therefore, Delphi topics with a realization time before the year 2020, which is ‘‘time of technological realization before 2020’’ for Japan, ‘‘time of international realization before 2020’’ for South Korea and all Delphi topics from China, are used as the main target for analysis and for comparison. Twenty-six Delphi topics in Japan, which counts for 74.3 percent of the total Delphi topics, were regarded as having realization before the year 2020. The remaining six and three Delphi topics are regarded as having realization between the years 2021 and 2030 and after the year 2031, respectively. In South Korea’s case, most of the Delphi topics were regarded by experts as having realization before the year 2020; only one topic regarded as having realization between the years 2021 and 2030. In China, all the topics were regarded as having realization before the year 2020. Table V summarizes the realization time distribution of Delphi topics in Japan, South Korea and China.

3.1 Mapping technology interactions in Delphi topics

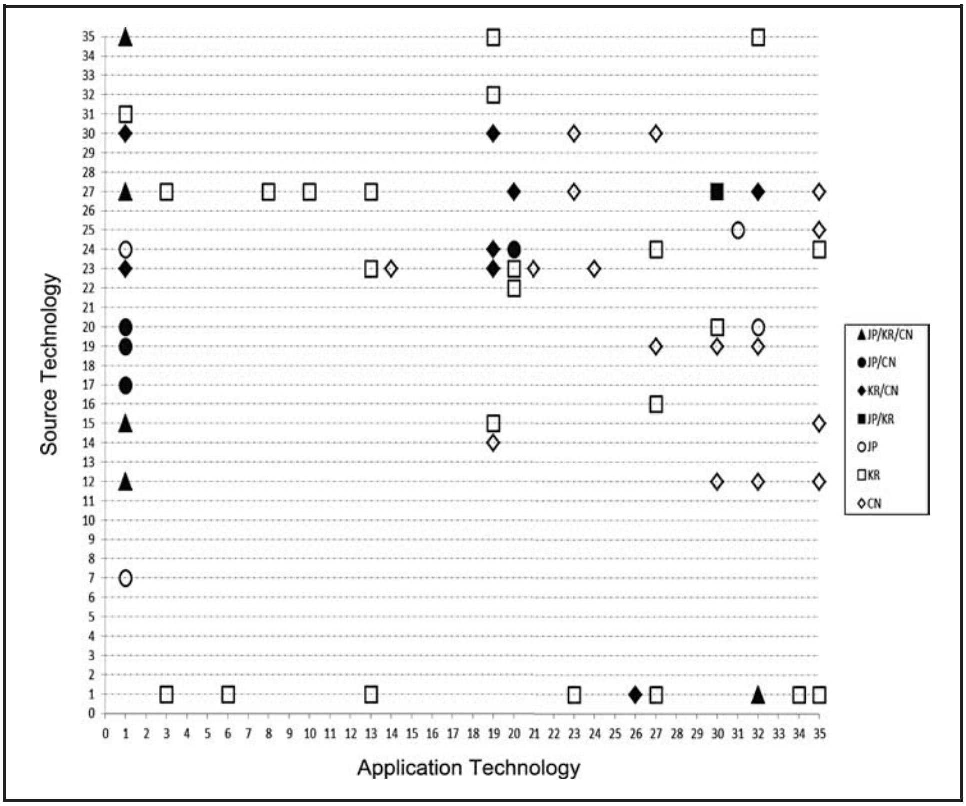
3.1.1 Summary result of the mapping in three countries. The mapping results are demonstrated using the 35 technology fields suggested by WIPO. The summary results of the mapping for technology interaction prospected by Japan, South Korea and China is shown in Figure 2. The *y* axis denotes the source technology and the *x* axis denotes the application technology. Interactions between source and application technology that can be identified in Delphi topics in either the Japan, South Korea or China reports are labeled with symbols. Different symbol represent different meanings. For example, ‘‘▲’’ means the technology interaction can be identified simultaneously in Japan (JP), South Korea (KR) and China (CN), ’’•’’means the technology interaction can be identified only in Japan (JP) and China (CN), and so on. Interactions within the technology field are not shown in Figure 2.

By viewing the union result of the mapping from the application technology side, conventional energy technology 1 (Electrical machinery, apparatus, energy) is a hot technology application before the year 2020, where the possible source technologies comprise technologies 7 (IT methods for management), 12 (Control), 15 (Biotechnology), 17 (Macromolecular chemistry, polymers), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 23 (Chemical engineering), 24 (Environmental technology), 27 (Engines, pumps, turbines), 30 (Thermal processes and apparatus), 31(Mechanical elements) and 35(Civil engineering). Technology 19 (Basic materials chemistry) is also prospected by these three countries as second hot application technology before the year 2020, where the possible source technologies comprise technologies 14 (Organic fine chemistry), 15 (Biotechnology), 23 (Chemical engineering), 24 (Environmental technology), 30 (Thermal processes and apparatus), 32 (Transport) and 35 (Civil engineering). The third hot application technology before the year 2020 is technology 32 (Transport), and the possible

Table V Realization time distribution of Delphi topic in Japan, South Korea and China

	Before 2020		*2021-2030*		*After 2031*	
Time horizon	*Topics*	*Ratio (percent)*	*Topics*	*Ratio (percent)*	*Topics*	*Ratio (percent)*
Japan	26	74.3	6	17.1	3	8.6
South Korea	75	98.7	1	1.3	0	0
China	83	100	0	0	0	0

Figure 2 Summary result of the mapping in three countries



source technologies are derived from technologies 1 (Electrical machinery, apparatus, energy), 12 (Control), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 27 (Engines, pumps, turbines) and 35 (Civil engineering).

From the source technology side, technology 27 (Engines, pumps, turbines) is the hottest source technology for application to other technologies before 2020, where the possible application technologies comprise of technologies 1 (Electrical machinery, apparatus, energy), 3 (Telecommunications), 8 (Semiconductors), 10 (Measurement), 13 (Medical technology), 20 (Materials, metallurgy), 23 (Chemical engineering), 30 (Thermal processes and apparatus), 32 (Transport) and 35 (Civil engineering). Technology 1 (Electrical machinery, apparatus, energy) is also prospected as a hot source technology, especially by South Korea, and the corresponding application technologies comprise technologies 3 (Telecommunications), 6 (Computer technology), 13 (Medical technology), 23 (Chemical engineering), 26 (Machine tools), 27 (Engines, pumps, turbines), 32 (Transport), 34 (Other consumer goods) and 35 (Civil engineering). Also, technology 23 (Chemical engineering) is prospected as a source technology for other seven technologies, comprising technology 1 (Electrical machinery, apparatus, energy), 13 (Medical technology), 14 (Organic fine chemistry), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 21 (Surface technology, coating) and 24 (Environmental technology). When technology 24 (Environmental technology) is as source technology, the prospected application technologies will be technologies 1 (Electrical machinery, apparatus, energy), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 27 (Engines, pumps, turbines) and 35 (Civil engineering).

The overlapping result for technology interaction mapped by the Delphi topics from the three countries can also be seen in Figure 2. The overlapped interactions identified among the three countries include source technology 12 (Control) to application technology 1 (Electrical machinery, apparatus, energy), technology 15 (Biotechnology) to technology 1

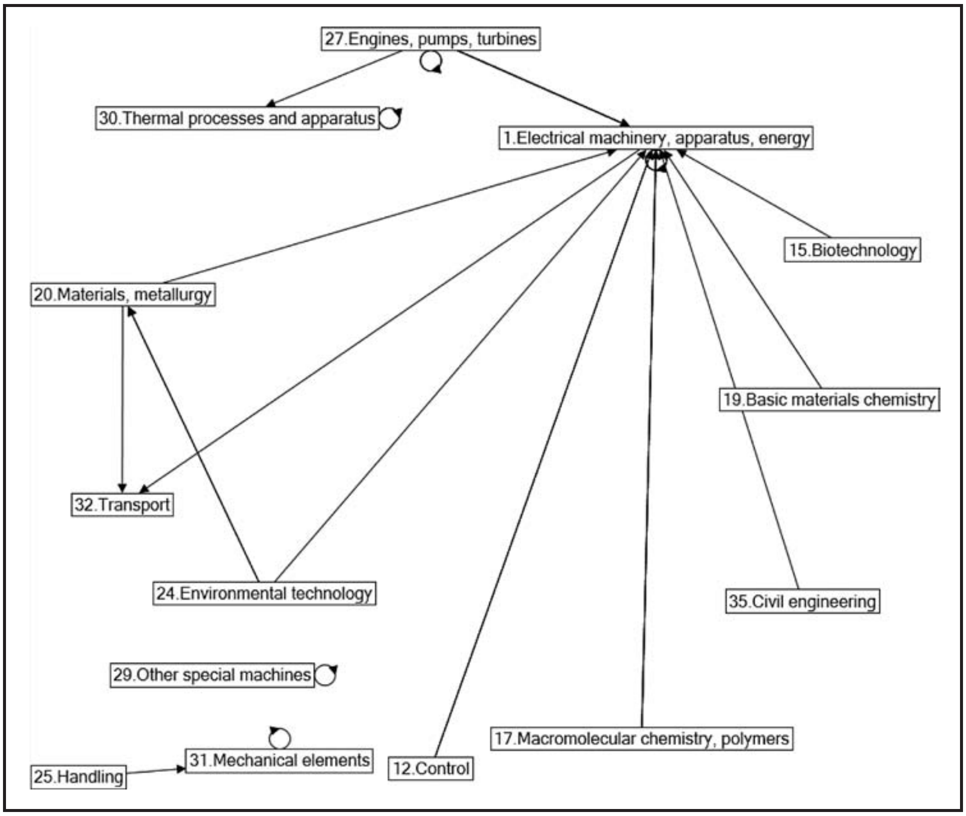
(Electrical machinery, apparatus, energy), technology 27 (Engines, pumps, turbines) to technology 1 (Electrical machinery, apparatus, energy), technology 35 (Civil engineering) to technology 1 (Electrical machinery, apparatus, energy), and technology 1 (Electrical machinery, apparatus, energy) to technology 32 (Transport). The keywords extracted from the content of the Delphi topics that link with the overlapping result of the mapping are summarized in Table VI.

3.1.2 Mapping result of Japan. From the mapping result of Japan, nine Delphi topics of the total 26 Delphi topics (34.6 percent), show interaction within single technology. Interaction across technologies can be deduced from the remaining 17 Delphi topics, and the interactions are demonstrated by a directional social network analysis (SNA) with a tool named NodeXL[1] in Figure 3. If more than one interaction can be deduced from a single Delphi topic content, more than one linkage will be given. A total of 20 interactions were identified from these 17 Delphi topics. The Delphi topics that show only interaction within a single technology are demonstrated by a loop symbol.

Table VI Keywords of Delphi topics that link with the overlapping result of the mapping in the technology interaction

Source technology	*Application technology*	*Country*	*Key words in Delphi topics*
12 (Control)	1 (Electrical machinery, apparatus, energy)	Japan	Energy management technology/electricity storage technology/efficiently use distributed generation; new grid technology/micro grids/stability of distributed generation
		South Korea	Distributed electric power/solar power
		China	Ultra-large scale/power system security and defense; advanced and reliable distribution network and system technology for electricity; distributed power generation systems; next-generation SCADA technology; heat, electricity, cooling cogeneration/building use
15 (Biotechnology)	1 (Electrical machinery, apparatus, energy)	Japan	Artificial photosynthesis technology/solar energy conversion efficiency; technology for electric power generation/synthetic fuels manufacturing/gasification of biomass
		South Korea	Verified *in vivo* photosynthetic/organisms convert energy; bio-energy/battery technology
		China	Biofuel; biomass gasification power generation
27 (Engines, pumps, turbines)	1 (Electrical machinery, apparatus, energy)	Japan	Large capacity combined cycle power generation/large scale gas turbines; micro cogeneration systems/residential use; ceramic micro gas turbines/thermal efficiency; ocean-thermal conversion/electric power generation
		South Korea	Cogeneration fuel cell/residential use; ocean energy; very large (5 MW) wind power generation equipment design; ocean energy/seawater desalination
		China	Integrated gasification combined cycle
35 (Civil engineering)	1 (Electrical machinery, apparatus, energy)	Japan	Large-area thin-film solar cells; conversion efficiency
		South Korea	Solar and fuel cell power system
		China	Hydropower river basin development with complex conditions; large and very large grid-connected/photovoltaic power plant development in desert
1 (Electrical machinery, apparatus, energy)	32 (Transport)	Japan	Polymer electrolyte fuel cells/vehicle use
		South Korea	Material for battery/electric vehicles or transportation; fuel cell/vehicle use; hybrid power system/vehicle use
		China	Hybrid power system

Figure 3 Technology interactions across WIPO technologies for Delphi topics from Japan



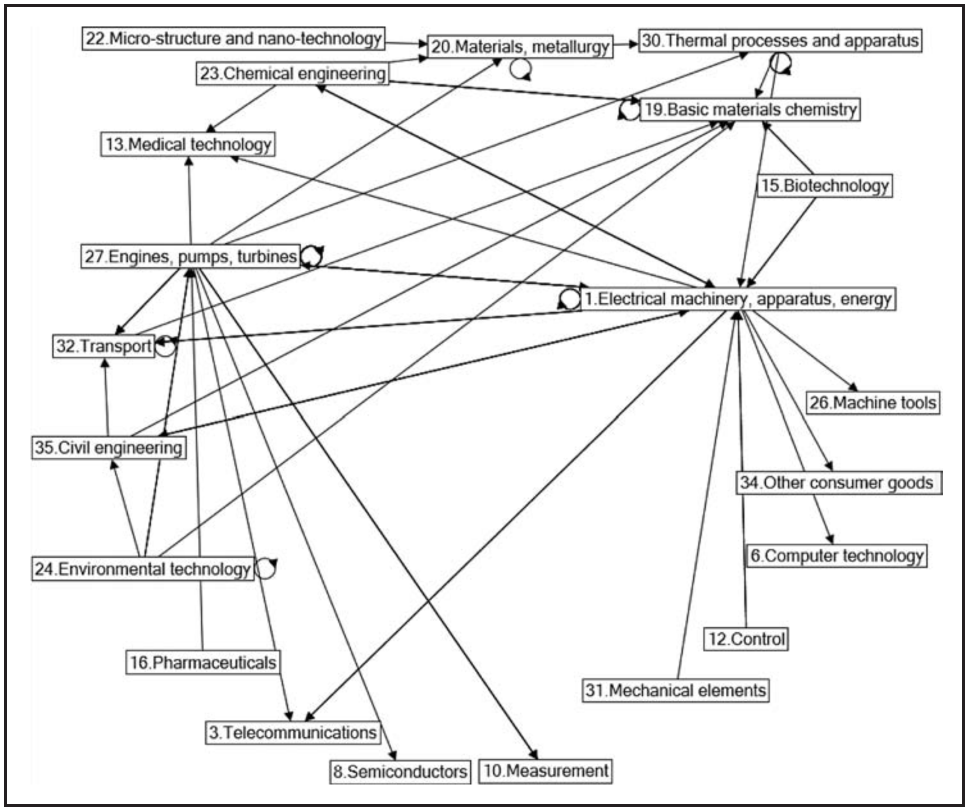
As shown in Figure 3, technology 1 (Electrical machinery, apparatus, energy) is the main targeted application technology by other technologies before the year 2020. The source technologies comprise technologies 12 (Control), 15 (Biotechnology), 17 (Macromolecular chemistry, polymers), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 24 (Environmental technology), 27 (Engines, pumps, turbines) and 35 (Civil engineering). The most intensive linkage of the interaction is source technology 27 (Engines, pumps, turbines) to application technology 1(Electrical machinery, apparatus, energy). The second most intensive linkage of the interaction is source technology 17(Macromolecular chemistry, polymers) to application technology 1(Electrical machinery, apparatus, energy).

3.1.3 Mapping result of South Korea. In South Korea, 25 of the total 75 mapped Delphi topics (33.3 percent) show only interaction within a single technology. Interaction across technologies can be deduced from the remaining 50 Delphi topics, and the deduced interactions are demonstrated by a directional social network analysis (SNA) in Figure 3. In total, 57 linkages are identified from these 50 Delphi topics.

A shown in Figure 4, the technology interactions of the Delphi topics before the year 2020 are much more divergent. From the application technology point of view, technology 1 (Electrical machinery, apparatus, energy) receives technologies from technologies 12 (Control), 15 (Biotechnology), 23 (Chemical engineering), 27 (Engines, pumps, turbines), 30 (Thermal processes and apparatus), 31 (Transport) and 35 (Civil engineering), especially technologies 23 (Chemical engineering) and 27 (Engines, pumps, turbines) show higher linkage with technology 1 (Electrical machinery, apparatus, energy).

Technology 19 (Basic materials chemistry) also shows as a hot application technology, the source technologies include technology 15 (Biotechnology), 23 (Chemical engineering), 24 (Environmental technology), 30 (Thermal processes and apparatus), 32 (Transport) and 35

Figure 4 Technology interactions across WIPO technologies for Delphi topics from South Korea



(Civil engineering). Technology 23 (Chemical engineering) shows higher linkages with technology 19 (Basic materials chemistry).

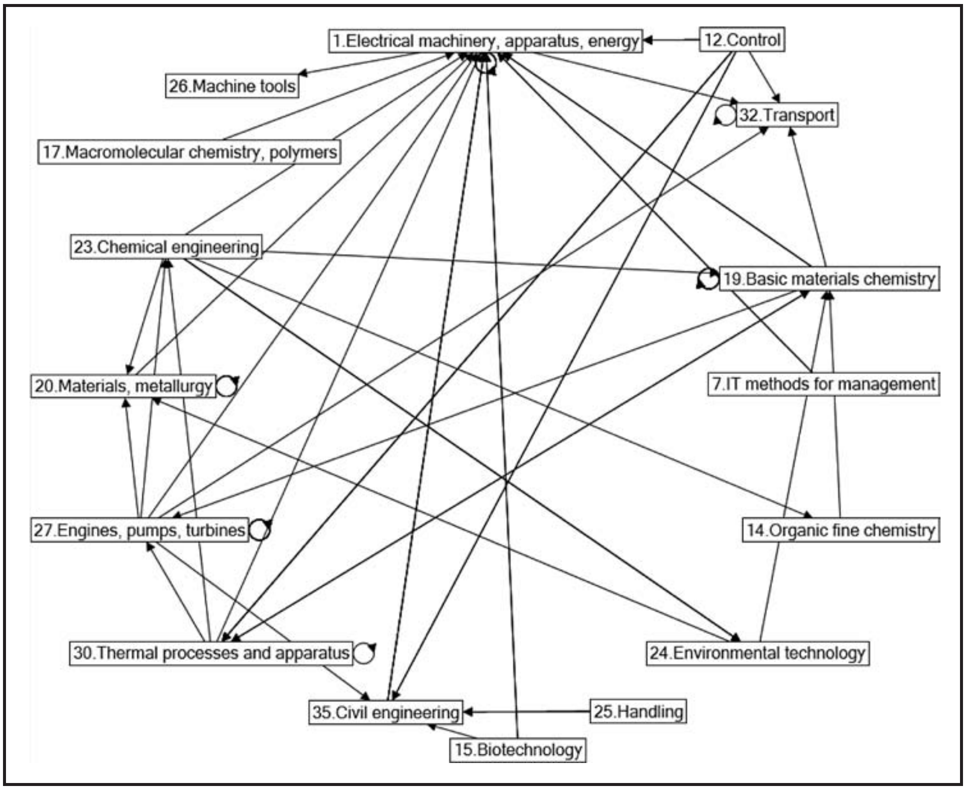
Technology 1 (Electrical machinery, apparatus, energy) can also be a source technology; the application technologies comprise technologies 3 (Telecommunications), 6 (Computer technology), 13 (Medical technology), 23 (Chemical engineering), 26 (Machine tools), 27 (Engines, pumps, turbines), 32 (Transport), 34 (Other consumer goods) and 35 (Civil engineering). Technologies 32 (Transport) and 35 (Civil engineering) especially show higher linkages with technology 1 (Electrical machinery, apparatus, energy).

Technology 27 (Engines, pumps, turbines) is also a hot source technology; the application technologies comprise of technologies 1 (Electrical machinery, apparatus, energy), 3 (Telecommunications), 8 (Semiconductors), 10 (Measurement), 13 (Medical technology), 20 (Materials, metallurgy), 30 (Thermal processes and apparatus) and 32 (Transport). The linkages are especially more intensive on technologies 1 (Electrical machinery, apparatus, energy), 10 (Measurement) and 32 (Transport).

3.1.4 Mapping result of China. In China, 37 of the total 83 mapped Delphi topics (44.6 percent) show only interaction within a single technology. Interaction across technologies can be deduced from the remaining 46 Delphi topics, and the deduced interactions are demonstrated by a directional social network analysis (SNA) in Figure 4. In total 50 linkages are identified from these 46 Delphi topics.

As shown in Figure 5, technology 1 (Electrical machinery, apparatus, energy) is a hot application technology. Source technologies comprise technologies 7 (IT methods for management), 12 (Control), 15 (Biotechnology), 17 (Macromolecular chemistry, polymers), 19 (Basic materials chemistry), 20 (Materials, metallurgy), 23 (Chemical engineering), 27 (Engines, pumps, turbines), 30 (Thermal processes and apparatus) and 35 (Civil

Figure 5 Technology interactions across WIPO technologies for Delphi topics from China



engineering); and 12 (Control) and 35 (Civil engineering) show especially higher linkages with technology 1 (Electrical machinery, apparatus, energy). Another hot application technology is technology 35 (Civil engineering). The possible source technologies comprise technologies 12 (Control), 15 (Biotechnology), 25 (Handling) and 27 (Engines, pumps, turbines); 12 (Control) and 25 (Handling) reveal especially higher linkages.

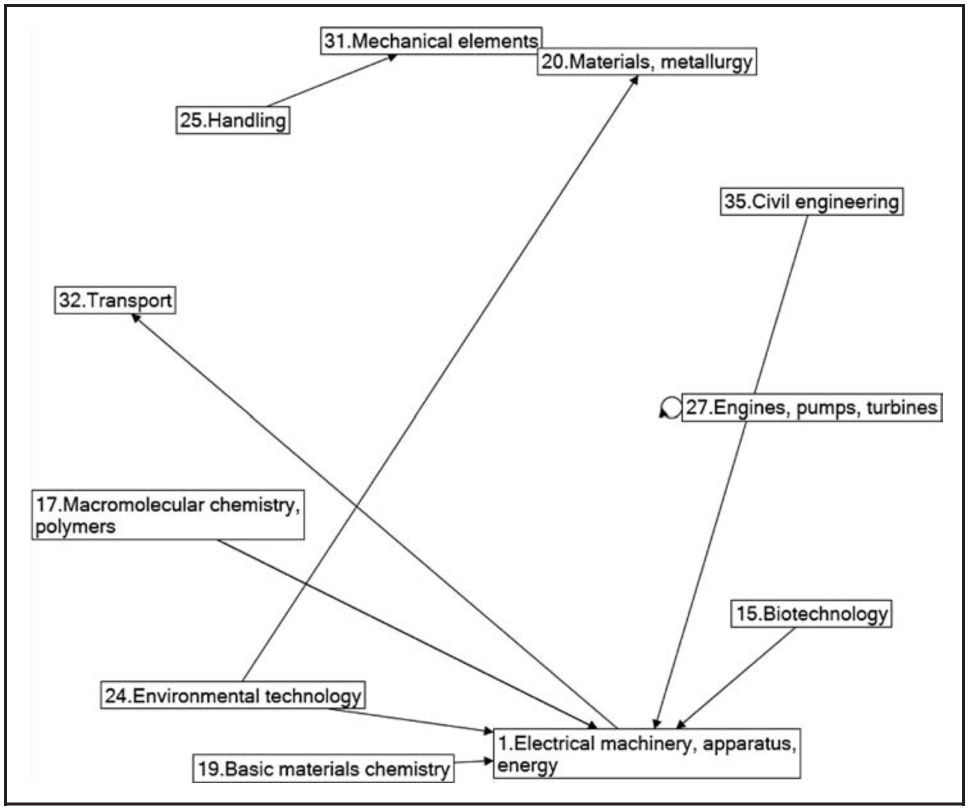
Technology 12 (Control) is a hot source technology in China. The possible application technologies comprise technologies 1 (Electrical machinery, apparatus, energy), 30 (Thermal processes and apparatus), 32 (Transport) and 35 (Civil engineering), but technologies 1 (Electrical machinery, apparatus, energy) and 30 (Thermal processes and apparatus) reveal higher linkages. Another hot source technology is technology 23 (Chemical engineering). The application technologies comprise of technologies 1 (Electrical machinery, apparatus, energy), 14 (Organic fine chemistry), 19 (Basic materials chemistry), 20 (Materials, metallurgy) and 24 (Environmental technology); technology 24 (Environmental technology) especially has more linkages with technology 23 (Chemical engineering).

3.2 Mapping interactions across technologies from the top 25 percent important Delphi topics in each country

Since the foresight results of these three countries were intended to be used for reference in priority setting or in the R&D agenda setting process, it may therefore be strategically important to identify what kind of technologies are rated as important for these three countries; this may provide a CTI value. Therefore, the top 25 percent important Delphi topics before 2020 are selected according to the foresight result in each country, and the deduced linkages for the selected topics are also demonstrated by a directional social network analysis (SNA). The analyzed results for Japan, South Korea and China are demonstrated in Figures 6-8.

In Figure 6 (Japan's result), seven Delphi topics and ten linkages are identified. Most of the interactions are related to application technology 1 (Electrical machinery, apparatus,

Figure 6 Technology interactions across WIPO technologies in top 25 percent important Delphi topics from Japan

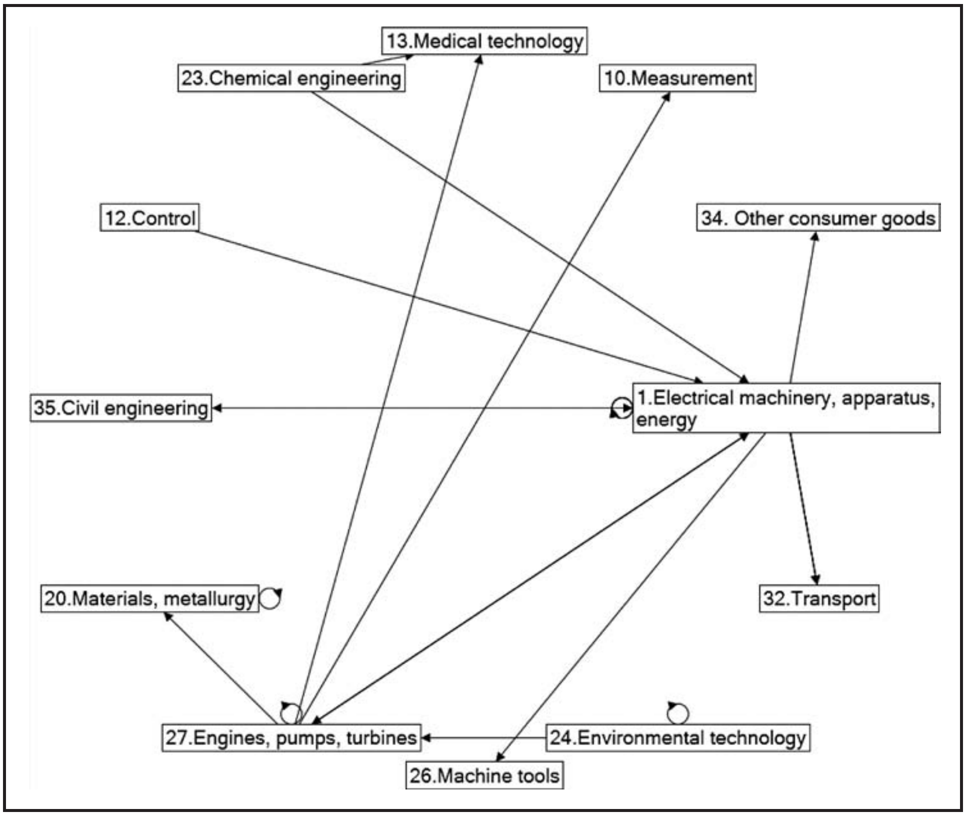


energy). The important source technologies comprise technologies 15 (Biotechnology), 17 (Macromolecular chemistry, polymers), 19 (Basic materials chemistry), 24 (Environmental technology) and 35 (Civil engineering). The content of the related Delphi topics contain ''Technology for electric power generation and synthetic fuels manufacturing using the gasification of coal, biomass, and waste'', ''Polymer electrolyte fuel cells for automobile use'', and ''Large-area thin-film solar cells with a conversion efficiency of at least 20 percent''.

Other linkages are source technology 24 (Environmental technology) to application technology 20 (Materials, metallurgy), or source technology 25 (Handling) to 31 (Mechanical elements). Technology 27 (Engines, pumps, turbines) is self-interacted. The content of the related Delphi topics contain ''CO_2 recover, sequestration and storage technology'', ''Hydrogen supply infrastructure networks for fuel cell automobiles'', ''Geologic disposal technology for high-level radioactive waste'', and ''Technology to drastically reduce waste through nuclear transformation of radionuclides in high-level nuclear waste''.

In Figure 7 (South Korea's result), 19 Delphi topics and 22 linkages are identified. One of the main focuses is technology 1 (Electrical machinery, apparatus, energy) since many other source technologies will contribute to technology 1 (Electrical machinery, apparatus, energy) and simultaneously technology 1 (Electrical machinery, apparatus, energy) is also a means for application to other technologies. The source technologies contributing to technology 1 (Electrical machinery, apparatus, energy) comprise source technologies 12 (Control), 23 (Chemical engineering), 27 (Engines, pumps, turbines) and 35 (Civil engineering), while the content of the Delphi topics contain ''Distributed power generation with energy conversion efficiency of more than 40 percent and large-scale solar power in practical use'', ''The commercialization of high efficiency and ultra-low price thin film solar

Figure 7 Technology interactions across WIPO technologies in top 25 percent important Delphi topics from South Korea



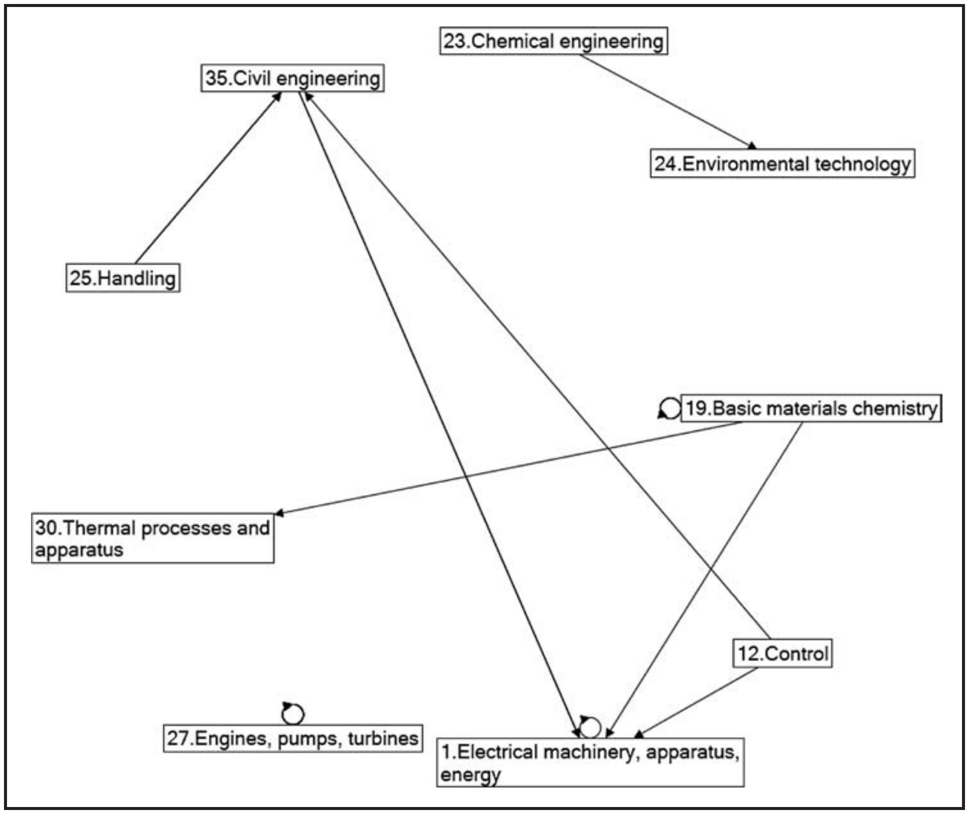
cells'', ''Solar and fuel cell power system in practical use'', and ''Residential cogeneration fuel cells in practical use''.

The application technologies for source technology 1(Electrical machinery, apparatus, energy) comprise technologies 26 (Machine tools), 27 (Engines, pumps, turbines), 32 (Transport), 34 (Other consumer goods) and 35 (Civil engineering). Higher linkages are demonstrated in technology 1 (Electrical machinery, apparatus, energy) to application technology 32 (Transport), and the related Delphi topics contain ''Development of high energy density of the large battery materials for electric vehicles and various transportation use'', ''Fuel cell vehicles for practical use'', and ''Hybrid power system with alternative energy in practical use''.

In the rest of the linkages, some technologies are self-interacted, examples being technologies 1 (Electrical machinery, apparatus, energy), 20 (Materials, metallurgy), 24 (Environmental technology) and 27 (Engines, pumps, turbines), and the related Delphi topics contain ''Verify the principle of super-conductivity at room temperature'', ''High-efficiency power generation equipment (efficiency 90 percent) commercialization'', ''Development of distributed power technology with large-scale use of alternative energy supply'', ''Development of low-cost and high-purity hydrogen mass production technology'', ''Development of zero emission power generation system combined energy plant'', and ''Development nuclear waste processing method that can reduce the size of nuclear fuel after use and effectively recycle and reuse''.

Other cross-interacted technologies include source technology 27 (Engines, pumps, turbines) to application technology 10 (Measurement); technologies 23 (Chemical engineering) and 27 (Engines, pumps, turbines) to technology 13 (Medical technology); technology 27 (Engines, pumps, turbines) to technology 20 (Materials, metallurgy); and

Figure 8 Technology interactions across WIPO technologies in top 25 percent important Delphi topics from China



technology 24 (Environmental technology) to technology 27 (Engines, pumps, turbines). The related topics contain ''Development of bio-information technology that can use Terahertz in biomedical operation'', ''Development of simulation technology than can simulate the interaction of living organism with micro-plasma for medical equipment'', ''The ultra-high-temperature air-cooled nuclear reactors in practical use which can be used to generate clean energy – the economic mass production of hydrogen'', and ''Maximization of nuclear reactor safety/economic in operation, optimization of the new nuclear reactor design and efficiency of monitoring/ lowering the risk by optimization and actively use of information technology''.

The mapping distribution of the Delphi topics of China shows that about half of the important topics are self-interacted (Figure 8); examples include technologies 1 (Electrical machinery, apparatus, energy), 19 (Basic materials chemistry) and 27 (Engines, pumps, turbines). The content of these topics comprises ''Large-capacity long-distance transmission of electricity'', ''Deep-sea oil and gas mining'', ''Coal (direct, indirect) liquefaction'', ''Coal gasification by pressurized fluidized bed'', ''deep coal mining technology'', ''advanced million-kilowatt pressurized water reactor technology'', ''Nuclear safety and radiation safety'', ''Chinese prototype of fast reactor nuclear power plant design and verification technology'', ''High level radioactive waste geologic disposal technologies'', and ''MW level wind turbine and the key technologies of main components and industrialization'', ''Advanced spent fuel reprocessing technology'', and ''Heavy-duty gas turbine technology''.

Meanwhile, technology 1 (Electrical machinery, apparatus, energy) is a hot application technology. The possible cross-interacted source technologies come from source technology 12 (Control), 19 (Basic materials chemistry), and 35 (Civil engineering). The content of these topics comprise ''Large scale network security and defense system for electricity'', ''Effective supercritical/ultra supercritical power generation technology'', ''Key technology of solar cells'', and ''Hydropower river basin development with complex conditions''.

In the rest of the linkages, technologies with cross interactions include source technology 23 (Chemical engineering) to application technology 24 (Environmental technology); technology 19 (Basic materials chemistry) to technology 30 (Thermal processes and apparatus); and technologies 12 (Control) and 25 (Handling) to technology 35 (Civil engineering). The content of these topics comprises ''Circulating fluidized bed flue gas desulfurization'', ''Coal gasification-based poly-generation technology'', ''Energy consumption analysis for construction and building environmental systems and energy saving optimization technology'', and ''Low permeability reservoir to improve oil recovery''.

In summary, by mapping the important topics from the Delphi survey results of Japan, South Korea and China, differences in technology development focus or portfolio strategy can be identified. From Japan's result, technology development is more focused on using different source technologies to conventional energy technology 1 (Electrical machinery, apparatus, energy), reflecting of the ''select'' and ''focus'' technology strategy used in the 3rd Basic Plan on S&T of Japan. South Korea seems to be employing a different strategy; it focuses not only on possible source technologies to conventional energy technology 1 (Electrical machinery, apparatus, energy), but also tries to explore the possibility for supplying technology 1 (Electrical machinery, apparatus, energy) as an important source technology, and it shows a convergent/divergent dual technology development strategy. In mapping of China's important topics, almost half show interactions within a single technology, and technology 19 (Basic materials chemistry) shows a key position. Also, technology 23 (Chemical engineering) is especially emphasized in China's important topics, and is to be used as a source technology to technology 24 (Environmental technology). This technology linkage reflects that the challenges faced by China, i.e. the environmental issues caused by the mass use of conventional energy such as coal, must be solved, and the corresponding technology development will be an important priority.

4. Conclusion

The main objective of this paper has been to address a structured analysis method. The proposed method can help to identify future technology trajectory and interaction by mapping and associating the future technology themes described in strategic foresight reports from selected countries with a state-of-the art technology classification system. The technology concept in future technology themes is mapped by the classification framework, and the interaction between technologies is identified through a causal effect analysis. Similarities and discrepancies in future technology options among countries are successfully analyzed, and important technology trajectories for each country are specifically highlighted and compared.

In summary, there are some operational and methodological benefits that can be provided by the integrative analytic method of this study. One is to help solving the practical difficulties faced during the secondary analysis of foresight studies in foresight preparatory studies, with the aim of anticipating future S&T changes and shifts in the competitive environment. By providing a consistent classification framework, the mapping and comparison of future technology options from different countries/regions become more effective. Also, the method combines both the advantage of strategic technology foresight and competitive technology intelligence, by utilizing the results derived from the former as a target for analysis but the analytic practice derived from the latter to identify the possible competitive or cooperative landscapes in the future. When entering into the foresight phase, such kinds of research output can be used as a knowledge base for brainstorming among participants, and help to building the desired vision and strategy for developing future technologies. Meanwhile, from a resource-based strategic concept, this classification framework can provide a bridge to link the future technology themes with current technology performance such as patent productivity or quality, or even with scientific performance, and can thus help in identifying the gaps between the probable future changes in S&T and current capabilities. While some scientific literature databases have been re-classified by using IPC code, this kind of capability gap identification becomes easier. For example, The Inspec Database, produced by the Institution of Engineering and Technology (IET), contains records from the world's technical and scientific literature and has been mapping its indexing schemes to the WIPO IPC scheme in order to assign IPC codes to relevant records since January 2010 (Vivavip, 2010). In addition, since the IPC code provides a hierarchical framework for mapping future technology themes, demonstration of the future technology trajectory and intelligence in different level of technology scope is possible. Therefore, not only policy makers at the national level but also researchers who are conducting a research agenda can use such a structured analysis result to see the future trends in their proper scope and to check how they can position or respond to the future competitive landscape.

However, there are some limitations for this study. The result of the analysis is based on the foresight activities of three large Northeast Asian countries and some of the technology interactions are prospected differently by these three countries. The difference in technology options or prospects may be derived from the different context of energy use and specific intentions that these countries want to achieve. Therefore, regional characteristics may bias the results of the research. This kind of bias may be compensated for by including opinions from other regions such as Europe or America. Also, the IPC code has some limitations in mapping the content of Delphi topics in describing a system innovation in which technology or product innovation are not the main focus, or in cases where the the Delphi topics describe a technology with vague scope. Third, since the mechanism of incorporating of foresight results into research or development priorities is different in each country, the technology intelligence demonstrated by this research still needs to be monitored and confirmed further by other complementary data or sources.

Note

1. NodeXL is an online free tool for social network analysis, which can be accessed at http://nodexl.codeplex.com/

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