RESEARCH MATERIAL No.290

The 11th S&T Foresight: S&T Foresight 2019

Close-up science and technology areas for the future in 2050

-Extraction and analysis through a combination of AI-related technologies and expert judges-

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Summary

1. Background and Objectives

1.1. Background and Objectives of the 11th Science and Technology Foresight

National Institute of Science and Technology Policy (NISTEP) has been conducting "Science and Technology Foresight" every five years since 1971. Since the Science and Technology Basic Law was established in 1995, the study has been conducted according to the formulation schedule of the Science, Technology, and Innovation Basic Plans. Since around the year 2000, back casting or seeking for solution to social challenges has become the mainstream attitude toward science and technology policymaking. To meet requirements from policymakers, there was a change in the study framework from technology or seeds driven approach, where they consider the future of society based on science and technology developments, to society or needs driven approach, where they discuss the better society before identifying relevant scientific and technological issues.

"The 11th Science and Technology Foresight: S&T Foresight 2019" (hereinafter referred to as the 11th Foresight) conducted an examination into science and technology development and the desired society in the future, aiming to provide fundamental information that contributes to the discussion of science, technology, and innovation policies including the 6th Science, Technology, and Innovation Basic Plan.

The structure of the 11th Foresight is outlined in Figure 1. In consideration of the increased complexity of the relationship between technology and society, the study is promoted from the dual viewpoints of science and technology, and society. It is configured to examine "future of society" and "future of science and technology" separately before integrated discussion of both futures for "future images of society brought about by the development of science and technology."

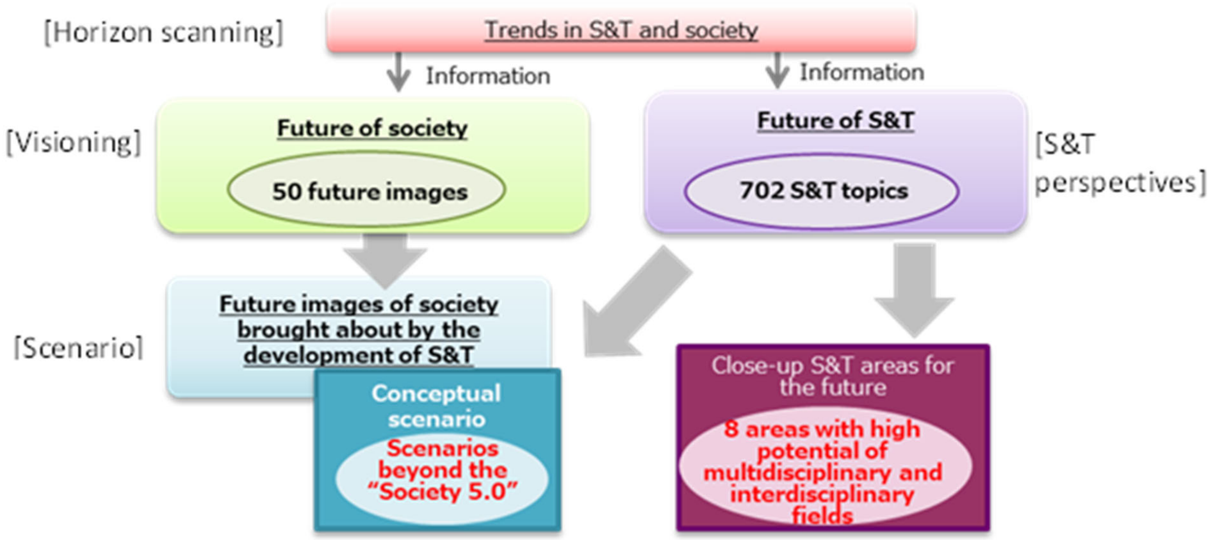


Figure 1. Structure of the 11th S&T Foresight

1.2. Objectives of the Study

Amid the global promotion of scientific and technological innovation to carve out a new future and solve various problems, renewed attention is being focused on the areas of science and technology that cross and integrate multiple academic disciplines. One of the reasons for this is the emergence of social issues that cannot be dealt with solely by academic disciplines that have become increasingly specialized and segmented, such as global environmental problems, responses to demographic changes, and the securing of energy, food, and resources, and the need for solutions to these issues. In addition, cross-disciplinary integration of these areas can lead to the solution of scientific problems. For example, clarifying physical and biological phenomena that have never been captured before is becoming possible through the integration of state-of-the-art measurement and advanced information processing technologies. Furthermore, it is expected that new knowledge will be created through intellectual inspiration and the integration of different fields.

Under these circumstances, this survey extracted "close-up science and technology areas" that should be addressed from the viewpoint of science and technology innovation policy and conducted an analysis of the characteristics of each area, based on the 702 science and technology topics selected in the Delphi survey (examination of the future of science and technology) conducted in 2018-2019 as part of the Science and Technology Foresight. These close-up areas mainly focus on the areas that have high potential for cross-disciplinary integration as described above[*1], but also target areas that focus on specific fields, in consideration of the possibility of creating a new technological field through refining and sharpening individual fields.

This study is characterized by the combination of expert judges and AI-related technologies*2 that have made remarkable progress in recent years. Prior to the extraction of the close-up science and technology areas by expert judges, topics were grouped by natural language processing (distributed representation) and hierarchical clustering analysis using AI-related technologies for 702 science and technology topics. The natural language processing performed here has a unique feature: it was based on a 300-dimensional, distributed representations of words (vectors) that had been calculated separately using a large data set.

To rephrase the above approach, topics in which similar words appear in 702 science and technology topics were considered to be semantically and scientifically related, and these topic groups were grouped together to generate science and technology clusters. After quantitative and qualitative analysis of these science and technology topic clusters, a total of 16 close-up science and technology areas were identified in a meeting of expert judges and consisted of eight areas with high potential for cross-disciplinary integration and eight areas with a focus on specific fields. It was thought to be difficult to extract the close-up science and technology areas by looking over all 702 science and technology topics, relying solely on the visual inspection of experts. Thus by combining AI-related technology and expert judges, it was possible to extract close-up science and technology areas efficiently and effectively.

Furthermore, for these close-up science and technology areas, the main science and technology topics belonging to each area were compared with the results of the Delphi survey to analyze the scientific and technological characteristics of each area. Consequently, in the eight areas with high potential for cross-disciplinary integration, those addressing a wide range of social issues related to humans, society, the earth, and the environment, and areas that consist of common core technologies and systems were identified. In addition, mathematical science, data science, and quantum science have attracted attention as the core science and technology aspects for these eight areas, with the ability to process enormous amounts of data obtained by a wide variety of measurements, observations, and surveys and connect these to evaluations and predictions. Conversely, the eight areas with a focus on specific fields were indicated as noteworthy areas in each of the seven fields established in the Delphi survey, and their relevance to the eight areas with a high potential for cross-disciplinary integration was also indicated. From the content of these close-up science and technology areas, it is considered that a broad analysis of science and technology is possible using a method that combines AI-related technologies and expert judges, as developed in this study.

*1. Areas are extracted based on science and technology topics, and since it does not directly indicate that these are areas that cross or integrate fields, they are positioned as areas with high potential.

*2. In this study, AI refers to artificial intelligence and related technologies, with a focus on machine learning and natural language processing, which are often referred to as AI in the media.

2. Method of Extraction and Analysis for Close-up Science and Technology Areas

The flow of the extraction and analysis of the close-up science and technology areas is shown in Figure 2.

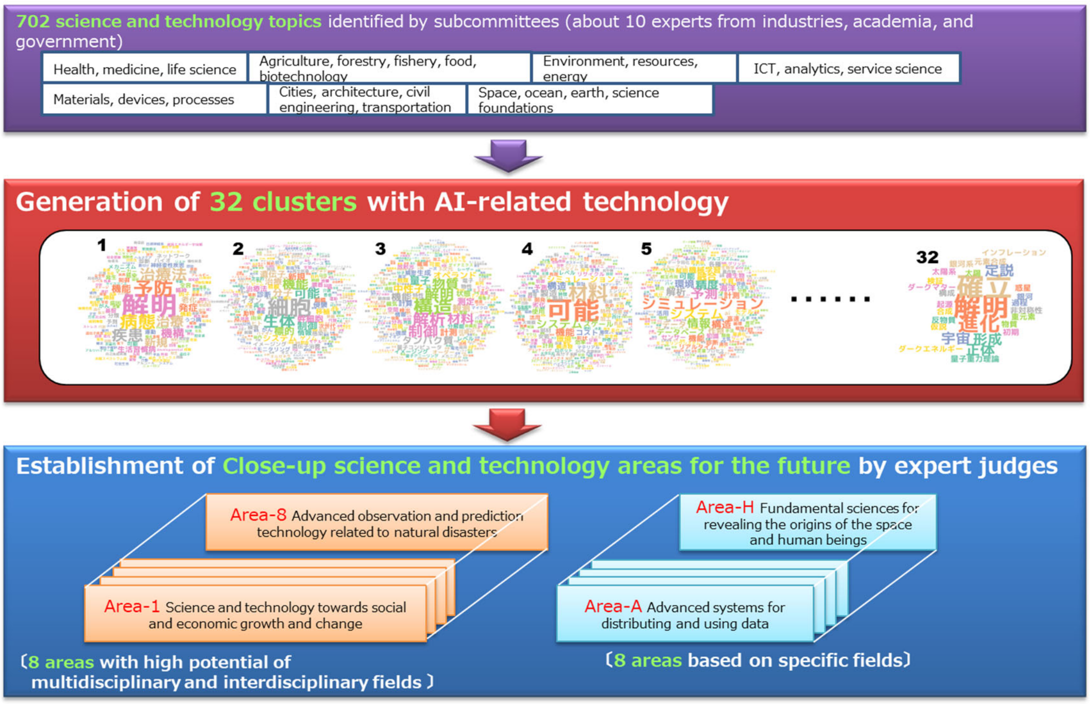


Figure 2. The flow of the extraction and analysis of the close-up science and technology areas

The close-up science and technology areas were based on the 702 science and technology topics selected in the Delphi survey conducted in 2018-2019 (see NISTEP Report No. 183 for details). In this Delphi survey, seven areas of science and technology were established (hereinafter referred to as the “seven areas of the Delphi survey”), and science and technology topics were selected as R&D issues to be addressed by 2050.

The seven fields in the Delphi survey are as follows (1) Health, Medical and Life Sciences; (2) Agriculture, Forestry, Fisheries, Food, and Biotechnology; (3) Environment, Resources, and Energy; (4) ICT, Analytics, and Service Science; (5) Materials, Devices, and Processes; (6) Cities, Architecture, Civil Engineering, and Transportation; (7) Space, Ocean, Earth, and Science foundation.

Among the 702 science and technology topics in the seven fields in the Delphi survey, groups of topics with similar expressions were considered to be semantically, scientifically, and technologically related, and were grouped across areas using AI-related technologies to generate science and technology topic clusters (see 2.1 below) and were analyzed quantitatively and qualitatively (see 2.2 below), and the expert judges extracted the close-up science and technology areas (see 2.3 below). For each of the extracted close-up science and technology areas, a comparative analysis among the areas and an analysis of the characteristics and contents of each area was conducted by comparing the main science and technology topics belonging to the areas with the results of the Delphi survey (see 2.4 below).

2.1. Grouping of Science and Technology Topics Using AI-related Technologies (generation of science and technology topic clusters)

The following illustrates the flow of the grouping of science and technology topics (Figure 3).

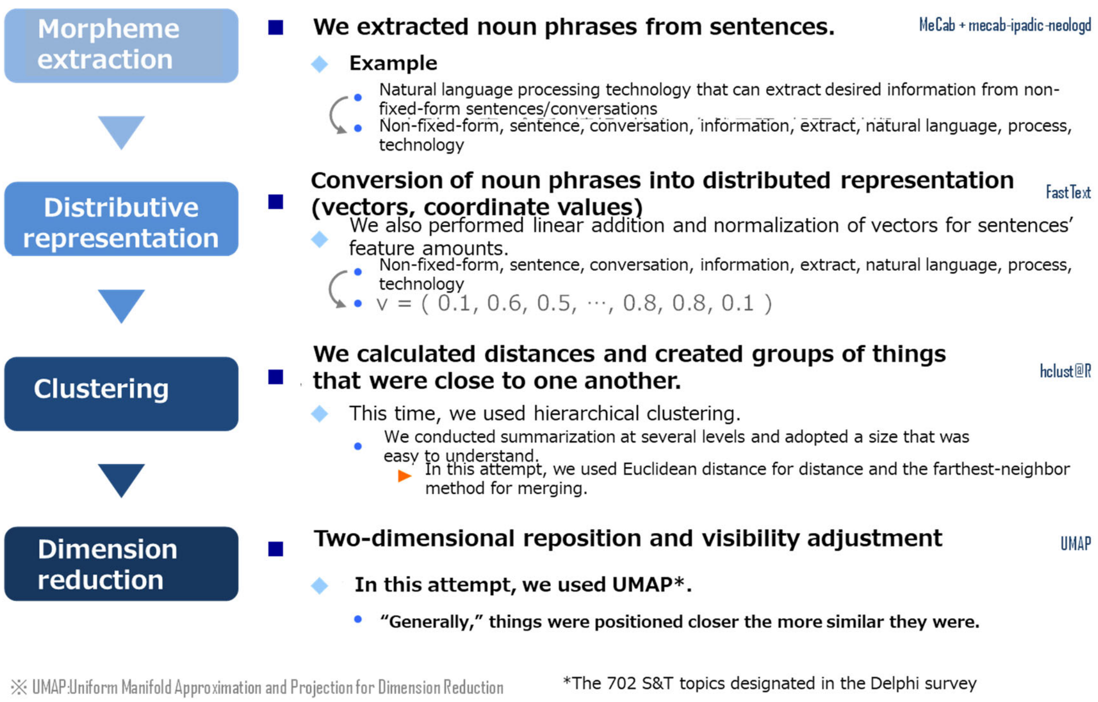


Figure 3. Flow of grouping of science and technology topics

First, noun phrases were extracted for science and technology topics through morphological analysis (decomposition of sentences into the smallest units of meaning) ("Morpheme extraction" in Figure 3).

Next, the science and technology topics were converted to vectors based on these noun phrases. Here, the feature value for each topic was calculated based on a 300-dimensional, distributed representations of words (vectors) that were calculated separately using a large data set (“Distributive representation” in Figure 3).

Using the above feature value of science and technology topics, similar topics were grouped by hierarchical cluster analysis. Regarding the number of clusters in this analysis, these were divided into multiple levels, such as 2, 4, 8, 16, 32, 64, and 128, and 32 classifications were used at each level based on ease of human interpretation and semantic validity, resulting in 32 science and technology topic clusters (see Figure 3, “Clustering”).

Finally, a visualization was created based on the above results. First, dimension reduction was used to map the 702 science and technology topics and 32 science and technology topic clusters. As mentioned previously, the feature values of the science and technology topics are 300-dimensional vectors, and were dimensionally reduced and converted to two dimensions (“Dimension reduction” in Figure 3). The results are shown in Figure 4.

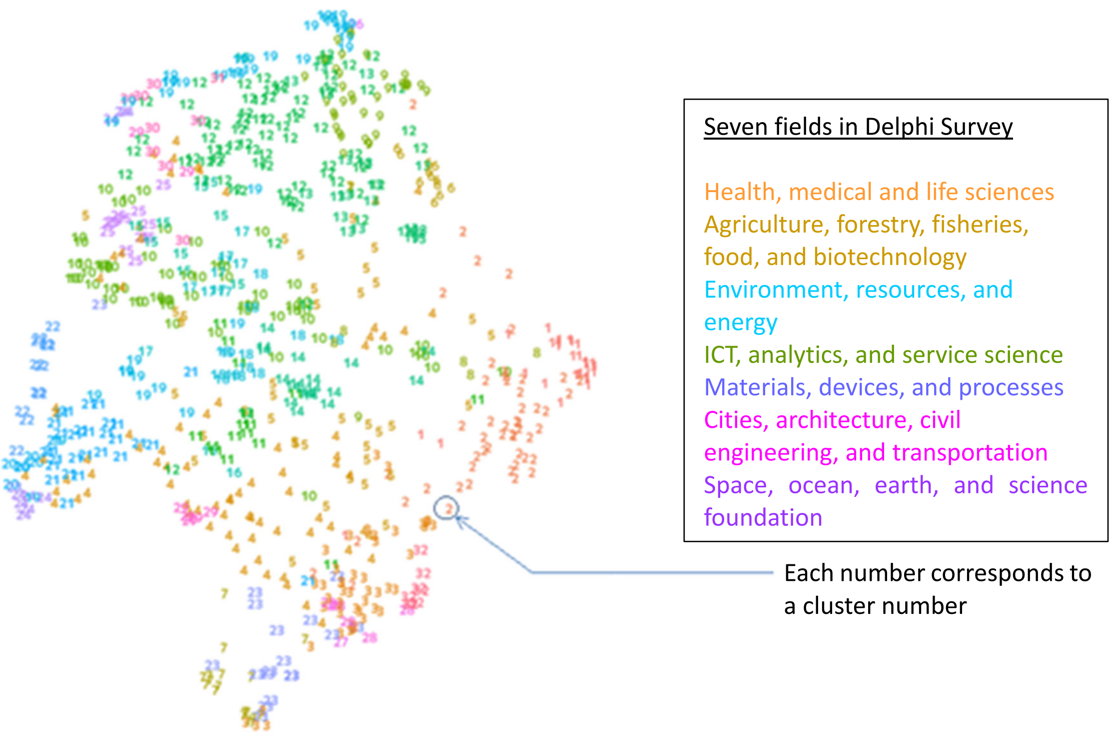


Figure 4. Mapping of 32 Science and Technology Topic Clusters to 702 Science and Technology Topics

*Software and algorithms used: FastText, umap
Please note that after clustering in 300 dimensions, the image was compressed to 2D for visualization, so some parts appear to be mixed.

Next, the data was visualized to illustrate the characteristics of each science and technology cluster. The number of occurrences of noun phrases for science and technology topics was counted for each cluster, and the results were output as a word cloud that mapped the number of occurrences to the size of the text.

2.2. Quantitative and Qualitative Analysis of Science and Technology Topic Clusters

A quantitative and qualitative analysis of the clusters was conducted visually to show the characteristics of the 32 science and technology topic clusters. Specifically, the number of science and technology topics and the number of areas to which the topics belong (any of the seven areas of the Delphi survey) were quantitatively analyzed.

Furthermore, as a qualitative analysis, the scientific and technological characteristics of the science and technology topic clusters were analyzed, and names were tentatively assigned to the clusters.

2.3. Extraction of Close-up Science and Technology Areas from Science and Technology Topic Clusters by Expert Judges

To extract the close-up science and technology areas, expert meetings were held (on February 28 and March 5, 2019) consisting of the chairpersons of the subcommittees established for each of the seven fields in the Delphi survey (subcommittees for each of the fields shown in Figure 4).

The expert group first formulated guidelines for extracting the close-up science and technology areas from the science and technology topic clusters. The guidelines are as follows.

- The main targets are science and technology areas that include at least 10 topics in two or more areas and are considered to have high potential for cross-disciplinary integration. Conversely, areas that contain more than 10 topics in one or two fields are considered to be science and technology areas with a focus on specific fields.
- Areas of science and technology that are important in resolving scientific and social issues are the target
- Consideration was given to a balance in terms across the entire science and technology domain

With this combination of the above guidelines, the results of 2.1 and 2.2, and the expert judges, the relevance of each science and technology topic cluster was assessed from a scientific and technological perspective. Based on the results, eight close-up science and technology areas with high potential for cross-disciplinary integration were extracted, after some restructuring, such as integrating clusters whose contents are similar in science and technology as appropriate. In addition, eight close-up science and technology areas with focus on specific fields were also extracted.

Each close-up science and technology area was given a name, and 10 science and technology topics were selected as representative topics per area (five topics were selected for some areas). (Below are the main science and technology topics for each area.) A total of 16 close-up science and technology areas were finalized at the 11th Science and Technology Foresight Review Committee meeting (held on June 4, 2019; the lead investigator was Dr. Michiharu Hamaguchi, President of the Japan Science and Technology Agency), which is an advisory board for the overall Science and Technology Foresight.

2.4. Analysis of the Characteristics of the Close-up Science and Technology Areas in Comparison with the Results of the Delphi Survey

By analyzing the responses to the questionnaire items of the Delphi survey (Table 1), it was possible to compare the areas of the main science and technology topics of each close-up science and technology area selected in 2.3, and analyze the characteristics and contents of each area. In proceeding with the analysis, relevant materials and advice were obtained from the chairpersons of the filed subcommittees of the Delphi survey, members, working group members, visiting researchers at NISTEP, and experts from external organizations.

Table 1. Questionnaire items and analysis methods for science and technology topics in the Delphi survey

Item	Content
Importance	Present level of the topic's importance for Japan, in order to realize a desirable society 30 years from now
International competitiveness	The level of Japan's current international competitiveness in terms of the topic
Prospect of scientific/techno-logical realization	The period in which the topic will be scientifically/technologically realized somewhere in the world
Policy-measures for scientific/ technological realization	Policy measures called for to scientifically/technologically realize the topic ・ human resources development [HRD] ・ enlarged R&D funding [Funding] ・ improvement of research platform [research platform] ・ domestic collaboration/cooperation [domestic collaboration] ・ international collaboration/standardization [Int’l collaboration] ・ improvement of legal regulations [Regulations] ・ addressing ethical/legal/social issues [EISI] ・ others
Prospect of social realization	The period in which the topic will be socially realized in Japan, following its scientific/technological realization somewhere in the world
Policy-measures for social realization	Policy measures called for to socially realize in Japan ・ human resources development [HRD] ・ project subsidies [Project subsidies] ・ improvement of business environment [Business environment] ・ domestic collaboration/cooperation [Domestic collaboration] ・ international collaboration/standardization [Int’l collaboration] ・ improvement of legal regulations [Regulations] ・ addressing ethical/legal/social issues [ELSI] ・ others

3. Overview of the Close-Up Science and Technology Areas

3.1. Eight Areas with High Potential for Cross-disciplinary Integration

The name and summary for each area, and a word cloud showing the characteristics of the science and technology topic clusters on which the areas are based, are shown in Table 2. Areas that address a wide range of social issues related to humanity, society, or the earth and environment were extracted (Areas 1, 2, or Areas 6, 7, and 8), and areas consisting of common core technologies and systems were extracted (Areas 3, 4, and 5). Mathematical science, data science, and quantum science have attracted attention as the core science and technology for these eight areas, with the ability to process enormous amounts of data obtained by a wide variety of measurements, observations, and surveys and connect these to evaluations and predictions.

Table 2. Names and summaries of the eight close-up science and technology areas with high potential for cross-disciplinary integration

<table>
<tr><td rowspan="2">No</td><td colspan="2">Name</td></tr>
<tr><td>Word Cloud (S&T Cluster)</td><td>Summary</td></tr>
<tr><td rowspan="2">1</td><td colspan="2">Science and technology towards social and economic growth and change</td></tr>
<tr><td></td><td>Science and technology areas that understand and control more diversified and complicated social phenomena (Large Social Complex Systems) by modeling and simulating them by making full use of information processing technology and mathematical science.</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Next-generation biomonitoring and bioengineering for precision medicine</td></tr>
<tr><td></td><td>A science and technology area consisting of biomonitoring that comprehensively understands various interactions in the human body, aiming at precision medicine that considers individual differences in genes, environment, and lifestyle, and also bioengineering that develops medical technology based on the results.</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Atomic and molecular level analysis technology using advanced measurement technology and information science tools</td></tr>
<tr><td></td><td>Science and technology that integrates advanced measurement that enables the observation and survey of previously unseen objects, and information science, such as simulation, informatics, and AI, to lead to scientific clarification and the development of technologies in a wide range of practical fields, including drug discovery, catalysts, materials, and crops.</td></tr>
</table>

4	Creation of novel materials and manufacturing systems	
		A scientific and technological area consisting of elemental technologies that form the basis of manufacturing that is expected to bring about new value creation through advanced manufacturing and distribution systems enabling mass customization and meeting the diverse needs of individuals and global society in the future, such as solving social issues related to the earth and the environment and improving humanities' QoL.
5	Advanced electronic and quantum devices that revolutionize ICT	
		A scientific and technological area consisting of the human-machine interface and sensing in the IoT, which are the basis of deepening and fusion of human-machine relationships. Electronic devices with new materials and functions such as high-efficiency and high-speed devices that support advanced ICT systems with less environmental impact. Furthermore, science and technology fields related to quantum devices that have enormous information processing capabilities and are expected to be able to non-invasively measure and sense living organisms with high accuracy.
6	Monitoring, evaluation and prediction technology of global environment and resources by space utilization	
		By observing the Earth extensively from space and on the ground, it is possible to deepen our understanding of the Earth's environment and resources, and improve our ability to predict changes that will lead to the exploration and management of energy and resources, and crisis management against natural disasters.
7	Science and technology for promoting circular economy	
		Science and technology areas related to diverse technologies and systems such as renewable energy, waste reduction and recycling, and sharing to promote the "Circular Economy", a new economic model achieving economic growth by recovering, regenerating, and reusing consumed resources continuously.
8	Advanced observation and prediction technology related to natural disasters	
		A science and technology area for avoiding disaster damage so that no one is left behind, involving basic research to investigate the causes of natural disasters such as earthquakes, volcanic eruptions, and heavy rains that have occurred frequently in Japan in recent years, including technology for predicting the occurrence of these disasters, and science and technology related to national land conservation and design.

3.2. Eight Areas with Focus on Specific Fields

The name and summary for each area, and a word cloud showing the characteristics of the science and technology topic clusters on which the areas are based, are shown in Table 3. These areas were identified as noteworthy science and technology in each of the seven areas of the Delphi survey described in Chapter 2.

Table 3. Names and summaries of the eight close-up science and technology areas with focus on specific fields

No	Name	
	Word Cloud (S&T Cluster)	Summary
A	Advanced systems for distributing and using data	
		Science and technology areas that collect, share, analyze, and utilize a wide variety of large amounts of data such as industrial, medical, and educational data, personal information, and research data, while maintaining the balance between protection and use.
B	Robotic technology that blends into human society to support and expand various human activities	
		Science and technology areas that support and expand areas including various social and industrial activities such as manufacturing/services, medical/nursing care, agriculture, forestry and fisheries, construction, disaster response, in addition to individual abilities (e.g., memory and exercise) by integrating and utilizing autonomous robots , information terminals, and networks into human society.
C	Next-generation communications and cryptography	
		A science and technology area consisting of advanced encrypted technologies that support security in data usage in a wide range of fields, such as next-generation communication technology for wireless/wired and mobile devices that can use high-speed, large-capacity data that will be indispensable as an infrastructure for life and industry in general in the future society where data usage will increase.

D	Technology for preventing human errors in transportation	
		A science and technology area related to unmanned driving, maneuvering, and the operation of moving objects such as vehicles, aircraft, and ships based an intelligent transportation system by ICT to reduce the burden on humans and to expand the traffic capacity safely and efficiently in land, air, and sea traffic.
E	Disease prevention and treatment methods for life-course healthcare	
		A science and technology area related to research on genetic, environmental, and social factors related to diseases, research on the mechanism of aging/functional decline, development of prevention/diagnosis/treatment methods for age-related diseases, based on the concept of a life course approach that continuously captures the human developmental and experiential periods (fetal, infant, school-going, working, and old age) and provides appropriate prevention and treatment of diseases at each age stage, for lifelong health support (life course/healthcare) aimed at extending healthy life expectancy.
F	Sustainable agriculture, forestry and fishery systems that harmonize with ecosystems	
		Science and technology for the development of agriculture, forestry and fisheries based on a data-driven approach and the relationship with local communities and resources through the sustainable and effective use of ecosystem services as a benefit that ecosystems provide to humankind.
G	Energy-related technology for a sustainable society	
		Science and technology related to energy elemental technologies that are indispensable for the conversion from fossil fuels that emit CO_2 to renewable energy as future energy technologies that will be the basis of daily life and industry to build a sustainable society.
H	Fundamental sciences for revealing the origins of the space and human beings	
		A science and technology area in astrophysics, which has developed rapidly in the 21st century, and aims to elucidate the basic science of various phenomena and existence related to the universe, which is still a mystery.

4. Characteristics of close-up science and technology areas as seen from the results of the Delphi survey – Cross-interdisciplinary connections

An analysis of the relationship between the eight areas with high potential for cross-disciplinary integration and the seven areas of the Delphi survey shows that each area is related to multiple areas of the Delphi survey, particularly for Area 1, “technology for solving social issues that adapts to social and economic growth and change,” there was widespread involvement across five areas of the Delphi survey (the orange areas in the figure 5).

Conversely, the relationship between the eight areas focusing on specific fields and the seven areas of the Delphi survey was limited to one or two areas of involvement (blue areas in Figure 5).

The eight areas with a high potential for cross-disciplinary integration and the eight areas with a focus on specific areas showed scientific and technological relevance through several areas of the Delphi survey. Area 1 “technology for solving social issues that adapts to social and economic growth and change”; Area A “new data distribution and utilization systems”; Area B “robotic technology that blends into human society and supports and expands all human activities”; and Area C “next-generation communication and encryption technology” were shown as areas related to the ICT, analytics, service area, which illustrated the connection between the areas. Area 2 “next-generation biomonitoring and bioengineering for precision medicine” and Area E “disease prevention and treatment for life course healthcare” are related to the health, medicine, and life sciences area, with the former at the micro-level (molecular level) and the latter at the macro-level (individual and population level). Area 4 “creation of materials and manufacturing systems with new structures and functions”, and Area 6 “monitoring, evaluation and prediction technologies for the global environment and resources through utilization of outer space,” Area 7 “science and technology for promoting the circular economy, and Area G “energy technologies to promote a sustainable society” were shown to be related to the environment, resources, and energy area.

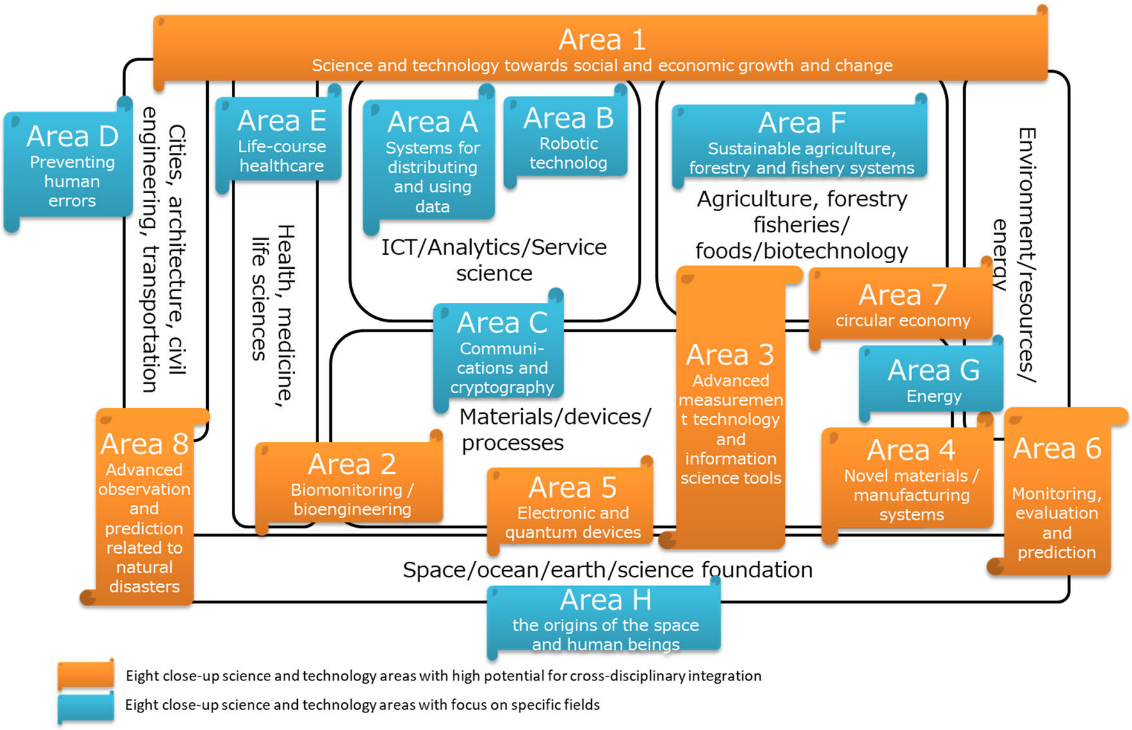
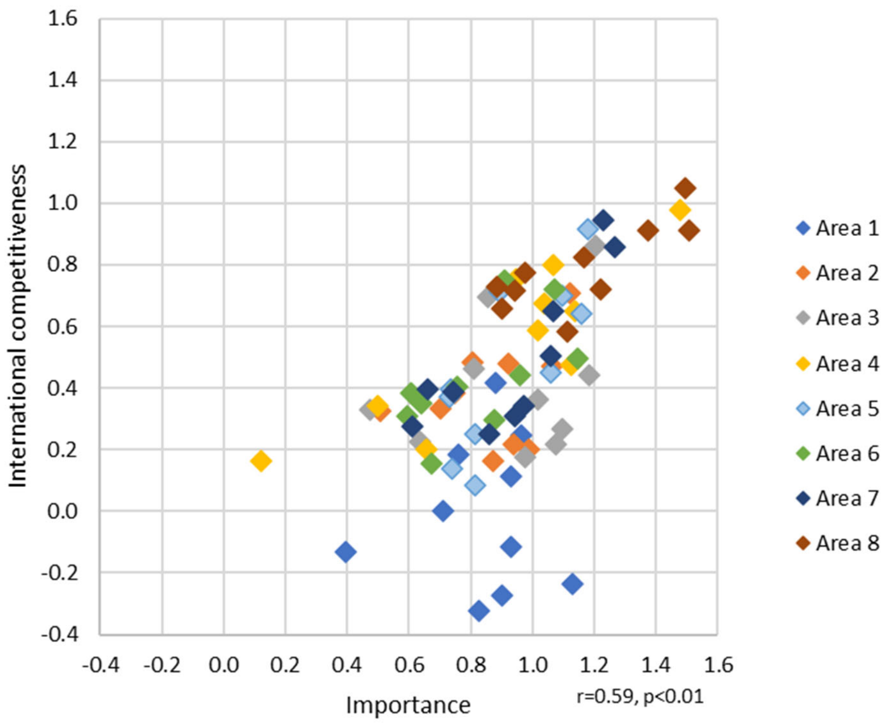


Figure 5. Relationship between the eight close-up science and technology areas with high potential for cross-disciplinary integration, the eight areas that are focused on specific fields, and the seven areas of the Delphi survey

5. Characteristics of Close-up Science and Technology Areas as Seen from the Delphi Survey Results – Eight Areas with a High Potential for Cross-disciplinary Integration

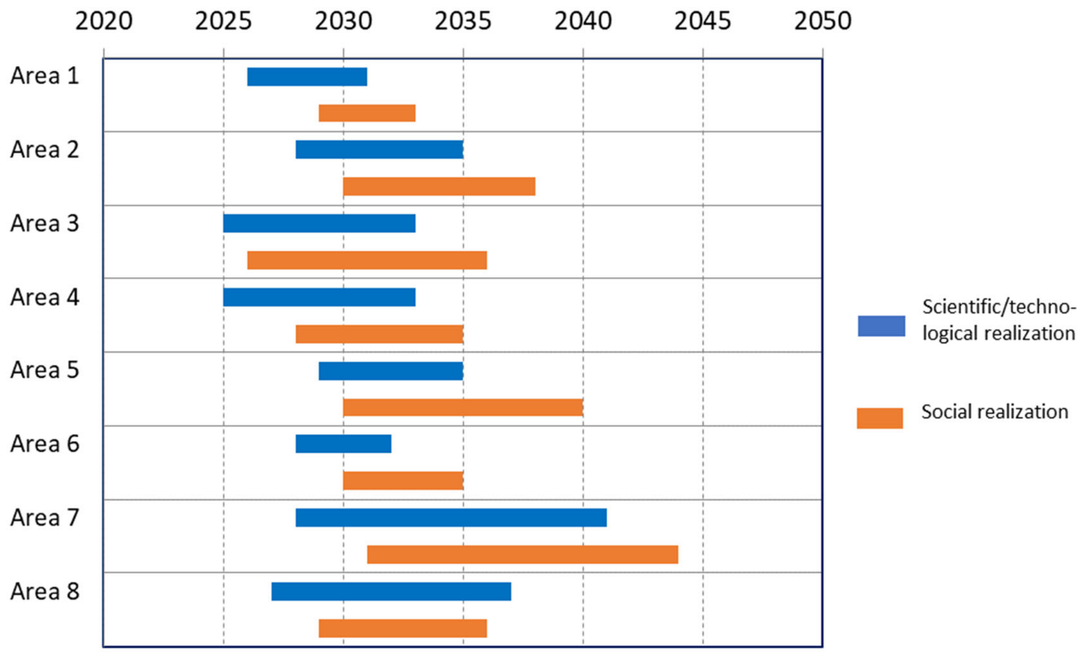
In the eight areas with a high potential for cross-disciplinary integration, a relatively strong positive correlation was found between the degree of importance and international competitiveness. The area with the highest level of importance and international competitiveness was Area 8, "advanced observation and prediction technologies for natural disasters" (Figure 6).



The areas contain ten topics each. The total of 80 topics are plotted according to their socores.

Figure 6. Importance and international competitiveness of major science and technology topics – Eight Areas with a high potential for cross-disciplinary integration

Among the 10 major science and technology topics in each area, the prospective time frame for realization of the topics was analyzed and compared among the areas, considering the range between the fastest and slowest prospects for scientific and technological realization (referred to as the realization period in this study). Areas with a short realization period are considered to require short-term intensive promotion measures, while areas with a long realization period are considered to require medium- to long-term promotion measures. As a result of the analysis, the shortest realization period regarding science and technology was four years for Area 6, "monitoring, evaluation and prediction technologies for the global environment and resources through utilization of outer space," and the shortest realization period regarding society was four years for Area 1, "technology for solving social issues that adapts to social and economic growth and change." Conversely, the longest period of realization both in terms of science/technology and society was thirteen years for Area 7, "science and technology for promoting the circular economy" (Figure 7).

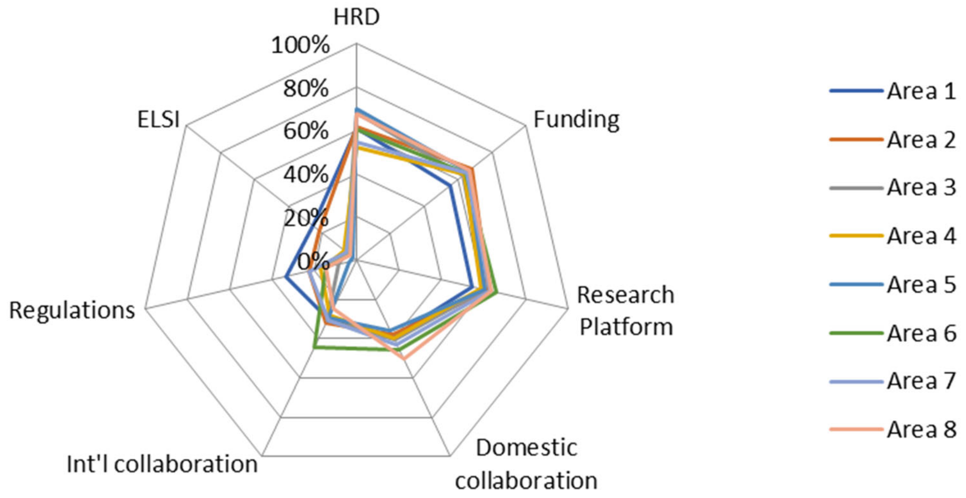


*Each bar shows the range between the fastest and slowest prospects for realization of topics included.

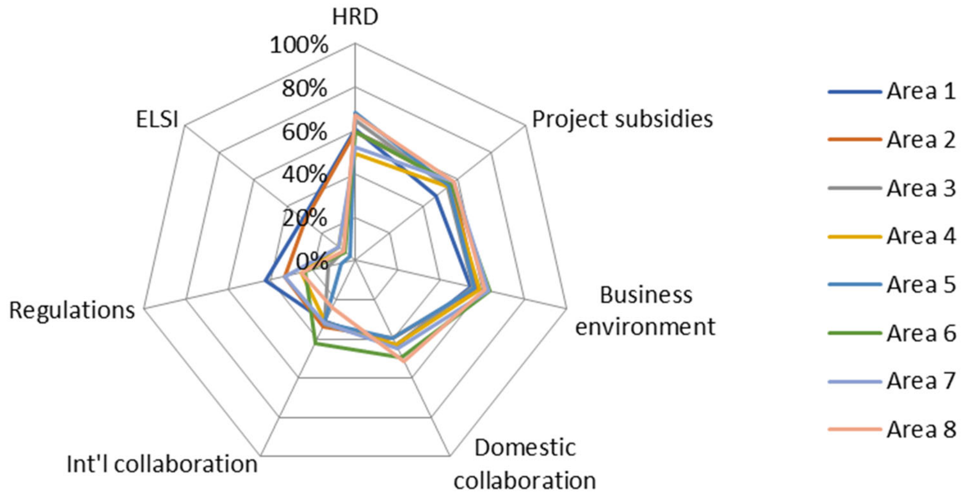
Figure 7. Outlook on scientific/technological and social realization – Eight areas with a high potential for cross-disciplinary integration

For common trends in policy measures for science and technology and social realization, the selection rate was the highest for "domestic collaboration/ cooperation" in Area 8 "advanced observation and prediction technologies for natural disasters," and "international collaboration/standardization" in Area 6 "monitoring, evaluation and prediction technologies for the global environment and resources through utilization of outer space," and "improvement of legal regulations" and "addressing ELSI" for Area 1 "technology for solving social issues that adapts to social and economic growth and change" (Figure 8).

Scientific/technological realization



Social realization

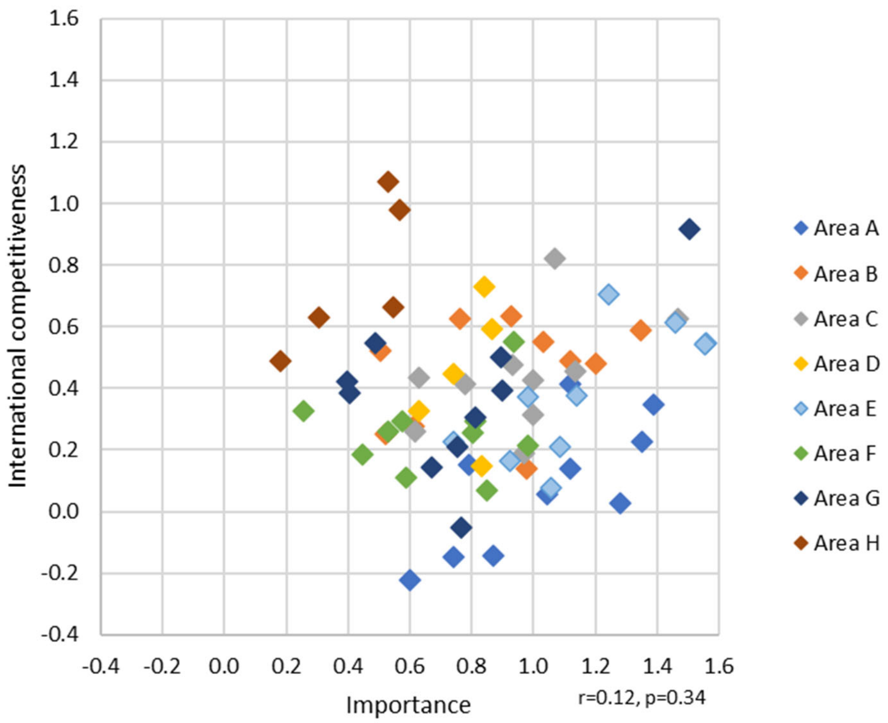


* Scores are the averaged ratio of respondents who select each policy means.

Figure 8. Policy measures for scientific/technological and social realization – Eight areas with a high potential for cross-disciplinary integration

6. Characteristics of Close-up Science and Technology Areas as Seen from the Results of the Delphi Survey – Eight Areas with a Focus on Specific Fields

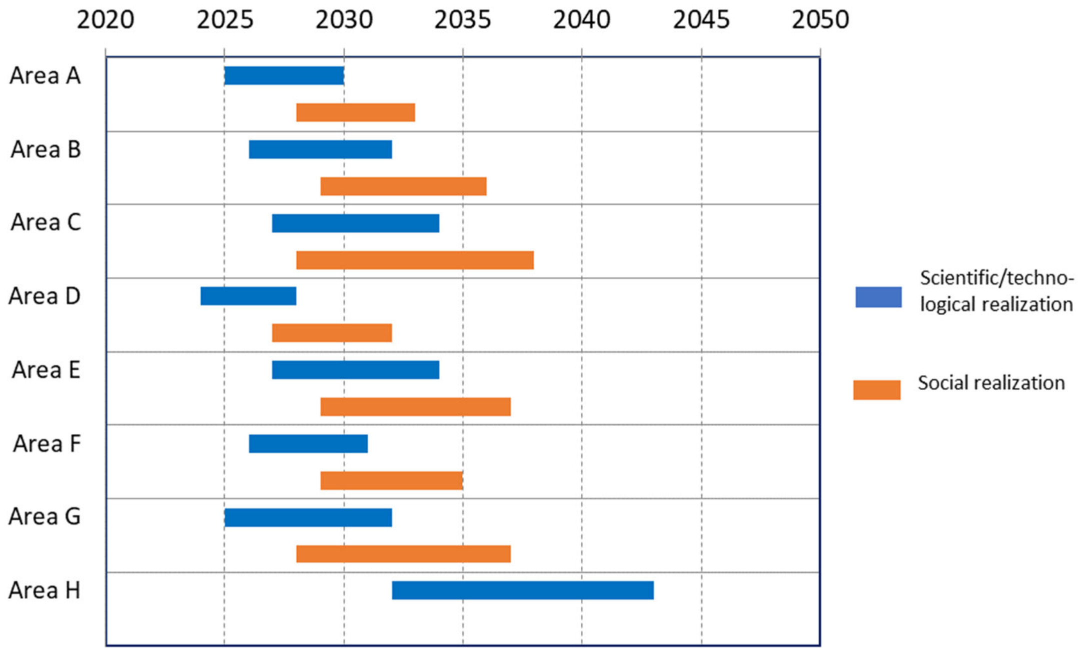
Unlike the eight areas with high potential for cross-disciplinary integration, the eight areas with a focus on specific fields did not show a significant correlation between the level of importance and international competitiveness.



The areas contain five/ten topics each. The total of 70 topics are plotted according to their socores.

Figure 9. Importance and international competitiveness of major science and technology topics – Eight areas focused on specific fields

Among the major science and technology topics in each area, the range between the longest and shortest prospective time frames for realization of the topics was analyzed regarding scientific and technological realization (realization period) and this was compared between the areas. Areas with a short realization period are considered to require short-term intensive promotion measures, while areas with a long realization period are considered to require medium- to long-term promotion measures. As a result of the analysis, the shortest realization period, both regarding science and technology and society, was for Area D, "technology to prevent traffic-related human error," which was estimated to be four and five years, respectively. Conversely, the longest realization period regarding science and technology was 11 years for Area H, “basic Science to solve the question on the origin of the universe and humanity," and the longest realization period regarding society was 10 years for Area C, "next-generation communication and encryption technology" (Figure 10).

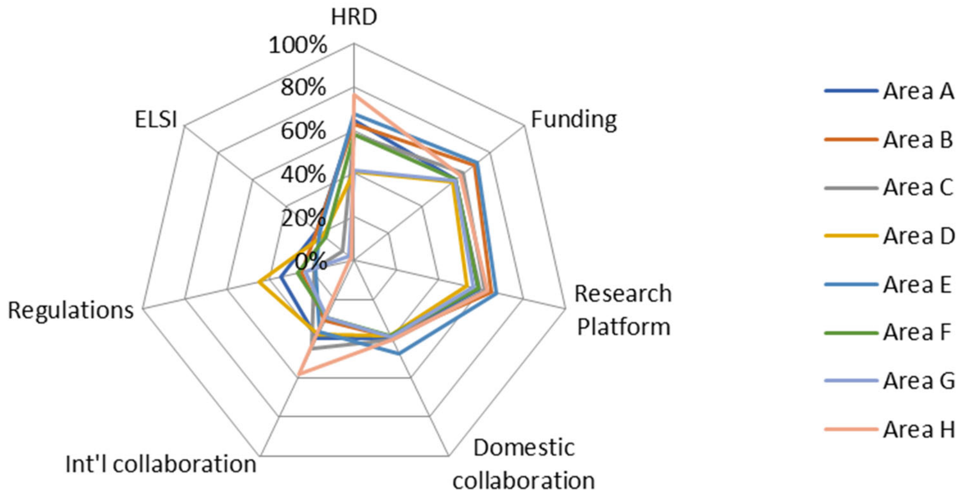


*Each bar shows the range between the fastest and slowest prospects for realization of topics included.

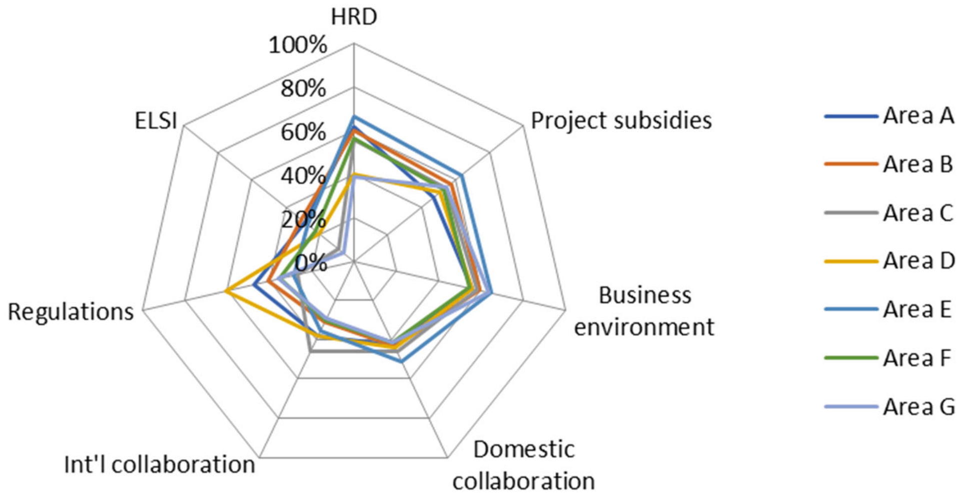
Figure 10. Outlook on scientific and technological and social realization – Eight areas with a focus on specific fields

Among common trends in policy measures for scientific and technological realization and social realization, "enlarged R&D funding," "project subsidies," "improvement of research platform," "improvement of business environment," and "domestic collaboration and cooperation" were selected most frequently for Area E "disease prevention and treatment for life course healthcare," and "improvement of legal regulations" was selected most frequently for Area D "technology to prevent traffic-related human error" (Figure 11).

Scientific/technological realization



Social realization



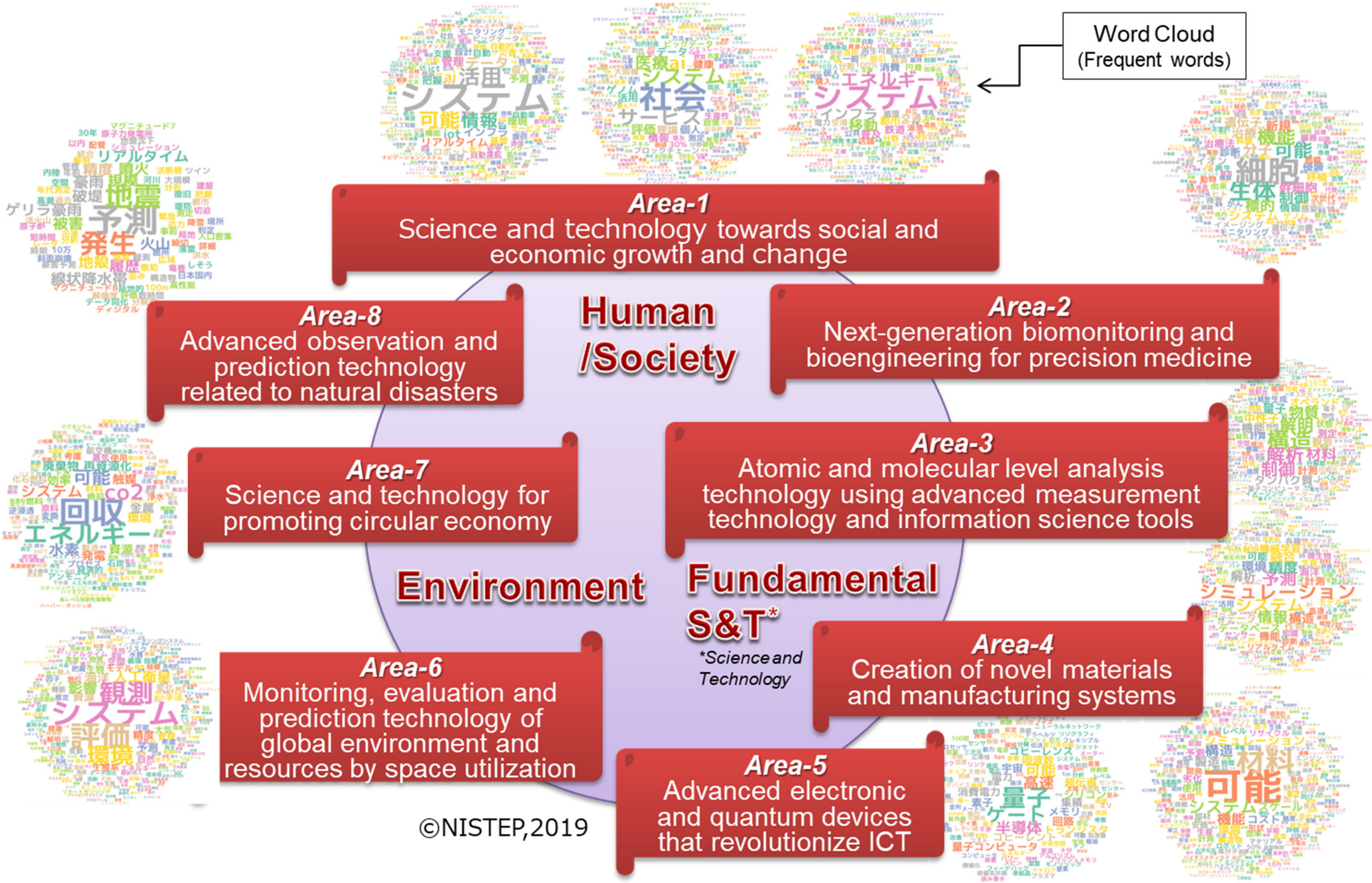
* Scores are the averaged ratio of respondents who select each policy means.

Figure 11. Policy measures for scientific and technological and social realization – Eight areas with a focus on specific fields

APPENDIX

8 areas with high potential of multidisciplinary and interdisciplinary fields

Note: The chronological tables indicate year of social realization. Years in paratheses at the end of each topic show scientific/technological realization. All the years are median of the survey result. The first number of each S&T topics is ID.


Word Cloud
(Frequent words)
Area-1
Science and technology towards social and economic growth and change
Area-2
Next-generation biomonitoring and bioengineering for precision medicine
Area-3
Atomic and molecular level analysis technology using advanced measurement technology and information science tools
Area-4
Creation of novel materials and manufacturing systems
Area-5
Advanced electronic and quantum devices that revolutionize ICT
Area-6
Monitoring, evaluation and prediction technology of global environment and resources by space utilization
Area-7
Science and technology for promoting circular economy
Area-8
Advanced observation and prediction technology related to natural disasters
Human /Society
Environment
Fundamental S&T*
*Science and Technology
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1. Science and technology towards social and economic growth and change

<Human/Society>

S&T area dealing with the challenges faced by large, social complex systems; using AI, IoT, quantum computing, solutions for ELSI, and cognitive science/behavioral economics for social infrastructure, urban architectural space, education, medicine, and financing and various other services/solutions based on socially shared capital.

Word cloud

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Basic information technology/ system

- 362:A new theory that further developed Service Dominant Logic, etc., whereby once the definition of a service based on dichotomy with things became completely a thing of the past, and after penetration of the perception that it is actions in general that brings value to individuals and society (2028)
- 397:Realization of an inclusive society where everyone can enjoy the benefits of digitization, by all citizens acquiring IT literacy and elimination of the shortage of IT talent (2028)
- 321:Optimal computer architecture when block chains are widely used as social infrastructure (2027)
- 383:Technology to qualitatively/ quantitatively simulate the service system before social implementation from economic, technical and social perspectives (2032)

Social realization: 2025, 2029, 2030, 2031, 2032, 2033, 2035

- 73:The management system for medical history, medication history, and personal genome information based on insurance cards, etc., incorporating IC chips, which will contribute to achieving precision medicine and improved medical quality (2026)
- 381:A system that makes it possible to estimate the social and economic impact of legal regulation, provides appropriate advice and risk presentation, including ascertaining situations where individuals and groups are located in real-time (2031)
- 293:Real-time monitoring and alarm system for heat risk using information technology (IoT, AI, big data, etc.) (2027)
- 393:AI/ block chain is introduced into education, establishing a learning style beyond the boundaries of schools, achieving a society with lifelong skill improvement (2028)
- 534:Technology to monitor, predict and control infrastructure with seamless coupling of physical and cyber space (2028)
- 112:Ultra-high-speed breeding (tailor-made) using AI and big data obtained from field-omics, phenomics, etc. (2029)

Service/solution of socially common capitals

2. Next-generation biomonitoring and bioengineering for precision medicine

<Human/Society> <Fundamental S&T>

S&T area concerning the use of completely non-invasive, high-sensitivity, high-precision, real-time monitoring to understand life phenomena at the levels of individual bodies, tissues/organs, cells, and molecules; in order to develop advanced medical technology; such as regenerative/cellular medicine using bioengineering and genetic treatment using next-generation, genome-editing technology.

Word cloud

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Biomonitoring

89:A minimally invasive real-time monitoring system for biopolymers and low-molecular weight molecules in circulating body fluids (2030)

458:Optical technology that enables the control of the position and measurement of the motion for micro/nano-machines and biomolecules (2030)

90:One cell omics analysis technique that retains cell position information (2028)

503:Monitoring technology capable of tracking the dynamics of cells and intracellular proteins, amino acids, ions, etc., with a time resolution of microseconds or less (2031)

470:Imaging technology using quantum entanglement: almost no light hits objects causing no damage to them (2035)

Social realization: 2030, 2032, 2033, 2034, 2035, 2038, 2040

Bioengineering

3:Drugs of novel type of functional molecules following on small molecules, peptides, antibodies and nucleic acids (2029)

10:Regenerative medicine technology to control the functions of intrinsic stem cells or transplanted stem cells (2030)

15:Gene therapy methods that widely realize gene repair therapy and single genetic disease treatment with next-generation genome editing technology (2029)

11:Allogeneic regenerative medicine technology/products that can completely avoid immune rejection (2031)

502:Production of regenerated tissues and organs using 3D printing technology (biofabrication) (2031)

*Precision medicine: Prevention and treatment of diseases that take into account individual differences in genes, environment and lifestyle

3. Atomic and molecular level analysis technology using advanced measurement technology and information science tools

<Fundamental S&T>

S&T are concerning the analysis, elucidation and prediction of structures and the states of structural/functional materials, macromolecules and biological molecules and the development/quality-management of agricultural and medical products. The technologies in scope for this include: advanced measurement technology using quantum beams, etc., and information science, such as simulation, informatics and AI.

Word cloud

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Advanced measurement technology

- 107:A portable high-throughput phenotype measurement system for agricultural crops using a broadband, ultra-compact optical device ranging from X-ray to terahertz, omics, chemical analysis and ICT (2028)
- 505:Elucidation of novel biological and biochemical phenomena using ultra-high precision measurements with quantum entangled light (2033)
- 680:In-situ observation technology that visualizes three-dimensional stress and strain, magnetic field distribution, etc., of functional materials and structural materials in the actual working process of using neutrons and X-rays (2026)
- 453:Ultra-high-resolution microscope capable of visualizing the interior of atoms and molecules on the picometer-scale measurement (2031)

Social realization: 2025, 2026, 2028, 2030, 2031, 2032, 2033, 2034, 2035, 2036

Advanced analysis through fusion of advanced measurement and data science

- 676:Advanced synchrotron-radiation measurement combined with information science (2025)
- 108:Growth prediction and diagnosis system for agricultural crops through integration of short to mid-term weather forecast and a high-precision crop model combining biological knowledge and AI (2028)

Technology applied computational science

- 469:Quantum simulator that enables drug design and catalyst design based on quantum chemical calculations (2031)
- 431:Technology for consistent simulations of synthesis process, machining process, and function prediction under actual use environments (2029)
- 649:A method for developing tailor-made medicines, cosmetics, etc., using pharmacokinetic simulation technology by supercomputer and a bioassay system using iPS cells, etc. (2031)
- 696:Hybrid system comprised of conventional computers, quantum annealing machines, and gate type quantum computers, which improves the efficiency of drug discovery and investment, and financial decision-making, etc., by 3 digits (2030)

4. Creation of novel materials and manufacturing systems

Word cloud

<Fundamental S&T>

S&T area concerning advanced production/distribution systems and cost-reduction for the purpose of putting materials and devices into practical use and using simulation and data to determine the structures and physical properties of materials; in order to contribute to the improvement of living environments in terms of underlying technologies for materials, structures, environments, and medicine

Advanced Manufacturing/Material development system

- 430:Multi-scale simulation technology to holistically analyze and predict time-dependent change from atomic-scale chemical reactions to macroscale characteristics and deterioration under external factors such as friction, stress, electromagnetic field, heat, photon, media, etc. (2029)
- 423:Technology for manufacturing functional structures composed of multiple materials (multi-material) and free forms (2028))
- 565:A system that automatically measures changes in factors such as temperature, impact and components in intermodal transport and can trace products from production, transportation and storage, through to use and disposal (2025)
- 419:Technology for autonomous transformation and conjunction of parts enabling expression of a new functionality and system integration (4D printing, 4D material) (2030)
- 483:Structural materials with self-repairing functions preventing deterioration and damage over time which can maintain the function of structures such as buildings (2033)

Social realization: 2025 — 2028 — 2030 — 2031 — 2032 — 2033 — 2035

Advanced material technology related to living and environment

- 493:3D food printing technology for manufacturing (forming) made-to-order food based on artificial foods such as artificial meat (2028)
- 495:Soft material with functions for robots to enable the same soft movements and feel as a person (2028)
- 499:Biocompatible material with biomimetic based surface and / or structure that dramatically improves durability and safety (2028)
- 241:Technology for economically separating and recovering useful metals from used products such as low-grade rare metal special steel (2030)
- 227:Long-life and low-cost secondary batteries that do not require replacement for electric cars (life: 15 years, cost: ≤JPY5000/kWh) (2029)

5. Advanced electronic and quantum devices that revolutionize ICT

<Fundamental S&T>

S&T area concerning high-speed, high-density, low-power-consumption electronic/information devices; high-efficiency power devices; and high-coherence quantum devices* (quantum computing/sensing) that will contribute to ICT innovation

Word cloud

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* This means duration (stability) of quanta.

High-performance/energy-saving electronic devices

- 460:Printable and stable flexible organic semiconductor transistors with mobility comparable to single crystal silicon, which can be mounted on curved surfaces and movable parts at low cost（2029）
- 465:Super parallel, low power consumption AI chip, achieved with monolithic three-dimensional integration of steep on/off transistors and analog memories（2030）
- 412:Highly efficient power semiconductors for electrical power and motive power further exceeding silicon carbide (SiC) and gallium nitride (GaN)（2029）

Social realization: 2030, 2032, 2033, 2035, 2036, 2037, 2038, 2040

Quantum device (Computing/Sensing)

- 694:Quantum sensors such as superconducting qubits, NV centers with coherent time exceeding 10 m (2028)
- 463:Single-spin information devices with a high speed and low power consumption beyond the limitation of CMOS devices (2033)
- 318:Gate type quantum computer (quantum circuit) which maintains several hundred bits of coherence by drastically improving the scalability of the currently considered methods (nuclear magnetic resonance and superconductivity) for achieving quantum gates（2033）
- 319:A quantum neural network including a quantum threshold gate and learning feedback achieved through realization of a quantum channel, quantum memory, etc. (2035)
- 413:New material that maintains quantum coherence at room temperature for a long period (2034)
- 471:Ultra-compact quantum sensor that exceeds the shot noise limit (2034)
- 648:Algorithms that fully utilize the characteristics of gate type quantum computers that can reduce the number of operations by 10 digits or more compared with classical gate type computers (2031)

6. Monitoring, evaluation and prediction technology of global environment and resources by space utilization

<Earth/Environment>

S&T area concerning monitoring/assessment and mathematical modeling to predict changes in the global environment and resources from the ground and from satellites for the purpose of coping with natural disasters and anthropogenic changes to the global environment and searching for energy; underground/oceanic; and agricultural, forestry, and fishery resources.

Word cloud

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Monitoring / evaluation / forecasting of the global environment

- 284:Monitoring system for vegetation distribution and ecosystem function using big data based on mobile data terminals, remote sensing, etc. (2028)
- 260:Simultaneously and continuously monitor technology for water areas with non-contact continuous sensing of water environment quality (2029)
- 640:Technology for constant observation of terrestrial and coastal areas at a spatial resolution of 30 m with geosynchronous satellites, for use in food, water and disaster risk management in East Asia, Southeast Asia and Australia (2029)
- 259:Generalization of a nationwide groundwater map through effective integration of satellite observation and ground observation (2029)
- 277:Long-term global environmental change forecast over 100 years based on high-resolution atmospheric circulation models, ocean general circulation models and global environment prediction models considering material and energy circulation associated with social activities through data assimilation (2032)

Social realization: 2030 | 2031 | 2032 | 2033 | 2035 | 2040

Global environment / resource monitoring / evaluation / prediction

- 623:Technology for marine environment monitoring and exploration in ice-bound seas (including under the ice) (2030)

Resource monitoring / evaluation / forecasting

- 231:Efficient mine exploration technology using ICT and satellites (2029)
- 628:Observation and data processing system for discovering underground resources, marine resources, etc., using satellites, marine and ocean sensors and autonomous unmanned vehicles(AUV), etc. (2028)
- 142:Wide area monitoring system of agriculture, forestry and fishery resources, including forestry, seaweed, and sea grass, by utilizing remote sensing and networks (2028)
- 262:Water resource and energy optimization technology based on climate/snowfall models and observations to effectively use snow as a resource (2029)

7. Science and technology for promoting circular economy*

<Earth/Environment>

S&T area concerning technologies for resource-circulation and sustainable production. The technologies in scope include: technology for turning CO2 and waste into resources; technology for the use of biomass; technology for disposing high-level radioactive waste; technology for the collection and use of rare metals; and technology for the management of harmful chemical substances within environmental circulation.

Word cloud

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Treatment and management of waste and harmful substances

- 253:Management of resources and hazardous substances through creation of a common database for material flow (2030)
- 181:Technology that uses plants and microorganisms to effectively remove and extract dioxins, heavy metals and rare metals from the soil (2031)
- 245:Technology to drastically reduce the amount of waste with nuclear transmutation of radionuclides in high-level radioactive waste using an accelerator (2041)

Recycling - Rare metals -

- 242:Technology to reasonably collect and use rare metals from small electronic devices, waste and sewage sludge from incineration fly ash (2028)
- 237:Economically recover technology for rare metals such as uranium from seawater (2039)

Social realization: 2030, 2031, 2032, 2033, 2034, 2035, 2039, 2040, 2044, 2045

Recycling - Energy, useful substances -

- 195:Co-production of energy and useful material using biomass (2029)
- 475:Aiming for a hydrogen society, a fuel cell where the amount of precious metal used is one tenth or less of that used in 2018, with consideration of catalyst deterioration (2032)
- 507:Biodegradable materials or materials with biochemical functions that achieve CO_2 fixation and waste recycling processes (2031)
- 216:Production of hydrocarbon fuels (such as aircraft fuel) by CO_2 recovered from the atmosphere and hydrogen sourced from non-fossil energy (2035)
- 479:Photoreduction catalyst or artificial photosynthesis with an energy efficiency of 20% or more in CO_2 recycling (synthesis of fuel or chemical raw materials) (2036)

* Circular economy: A new economic model that realizes economic growth by continuously collecting, reusing and reusing consumed resources, as opposed to the conventional one-way economy of consuming and disposing of resources.

8. Advanced observation and prediction technology related to natural disasters

<Earth/Environment> <Human/Society>

S&T area concerning technologies for the advanced observation and prediction of natural disasters; such as torrential rain, earthquakes, and volcanic eruptions; and the attendant damages thereof. The scope similarly includes: river-course design combining long-term environmental conservation with maintenance/management and land conservation through the prediction of geologic changes in places such as mountains and coastlines.

Word cloud

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Observation and prediction of earthquakes and volcanoes

- 631: Technology to improve the dating accuracy of 50 to 100 thousand years ago to elucidate the history of active faults and volcanic eruptions (2030)
- 585: Technology to determine earthquake damage in real-time using the digital twins of nuclear power station building, piping and nuclear reactors (2028)
- 634: Technology for measuring regional crustal stress fields in seism genic area (2030)
- 629: Evaluation of the urgency of identifying the next volcano likely to erupt or unlikely to erupt, from all active volcanoes in Japan (2031)
- 632: Technology to predict the location, scale, timing (within 30 years), and damage of inland earthquakes with magnitude 7 or higher (2037)

Social realization: 2025, 2029, 2030, 2032, 2033, 2035, 2036

Prediction of storm and flood damage, etc. and conservation and design of national land

- 644: Technology for predicting localized heavy rain, tornadoes, hail, lightning, snowfall, etc., several hours ahead with spatial resolution of 100 m or less, using high-resolution simulation and data assimilation (2027)
- 539: Real-time prediction of damage related to slope failure and earth structure based on highly accurate predictions of localized torrential rainfall over a short time (2027)
- 515: A sediment transport system for predicting geographical changes of land, including mountain and coastline regions, estimations and technology to appropriately conserve land (2032)
- 512: Technology to sense levee breaches in advance using a combination of prediction and observation (2028)
- 514: River channel design technology integrating long-term environmental conservation and maintenance (2029)

[The 11th S&T Foresight: S&T Foresight 2019 series]

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Close-up Science and Technology Areas for the Future in 2050 -Extraction and Analysis through a Combination of AI-related Technologies and Expert Judges-, Research Material No.290, June 2020, NISTEP
DOI: http://doi.org/10.15108/rm290

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