資料２
（別冊）

RECOMMENDATION
Transforming Society to Become Resilient and Sustainable beyond Catastrophic Disasters

August, 2023

Science Council of Japan

This recommendation was deliberated mainly by
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Executive Summary

1　Background

To overcome the catastrophic disasters such as enormous earthquake and tsunami disasters that are almost certain to occur in the first half of the 21st century, we have integrated the knowledge of various related academic fields and recommended an overarching strategy and feasible concrete measures to overcome catastrophic disasters from an academic perspective regarding what should be done in the remaining time and after the disasters occur.

2　Current Status and Challenges

There is a high probability that a Nankai Trough earthquake will occur in the first half of the 21st century, which has occurred almost every century since the 7th century. The Tokyo Inland Earthquake, which has an adjacent epicenter, might occur in close temporal proximity. According to the damage estimates by the government of Japan, the maximum estimated damage is 220 trillion yen for the Nankai Trough Earthquake and 95 trillion yen for the Tokyo Inland Earthquake. Summing up, the estimated damage by these two earthquakes amounts to more than 300 trillion yen. Disasters with damage exceeding 100 trillion yen are called "Trillion-Dollar Disasters." In the United States, which experiences many disasters yearly, large-scale disasters are called "Billion-Dollar Disasters." Although there has never been a "Trillion-Dollar Disaster" individually or in the annual total, the coming Nankai Trough Earthquake and the Tokyo Inland Earthquake could be the first "Trillion-Dollar Disasters" that humanity has experienced since the Industrial Revolution. Such "catastrophic disasters" of unprecedented scale are definitely an apparent threat to Japan's sustainable development and a significant threat to the sustainable development of the international community.

It is impossible to completely prevent the estimated damage in the time remaining before a disaster strikes. That is why this recommendation focuses on "resilience," which is the ability to overcome a disaster comprehensively, including streamlining and improving the efficiency of post-disaster emergency response and recovery/reconstruction processes, in addition to further improvement of damage deterrence. To improve resilience, it is essential to promote science and technology that aims for "consilience" of knowledge in the fields related to disasters as natural phenomena and knowledge in the fields related to disasters as social phenomena.

３　Recommendations - What Should We Do with the Remaining Time? -

In order to acquire resilience to overcome catastrophic disasters of the scale estimated by the government of Japan, all stakeholders should continue their efforts not only to prevent damage but also to focus on scientific studies and practices promoting disaster response and recovery. In what follows, we propose measures to be taken in line with the four priorities for actions in the Sendai Framework for Disaster Risk Reduction 2015-2030.

（１）Deepening and elaborating understanding of disaster risk

・To establish science and technology for improving disaster resilience and sustainability of societies with the ultimate three goals: 1) maintaining and improving the physical, mental, and social well-being of individuals, 2) strengthening the capacity for mutual support in communities, and 3) the coherent realization of disaster risk reduction, climate change adaptation, and sustainable development in society.
・To develop a disaster management system with an all-hazards approach, conversing multi-disciplinary knowledge covering all phases of disaster management, including forecasting, prevention/mitigation, early warning, emergency response, and recovery/restoration.
・To realize the consilience of knowledge for disaster resilience using information infrastructure to disseminate to society according to the Recommendation titled "Developing an Online Synthesis System (OSS) and fostering Facilitators to realize consilience" from Science Council of Japan in 2020.

（２）Establishing new governance to cope with disasters

・To establish the governance contributing to the transition to an autonomous, decentralized, and cooperative society as suggested by the irreversible changes caused by the COVID-19 pandemic.
・To ensure transnational resilience where multiple countries cooperate with each other in addition to improving the national resilience of land and sea, sovereignty, and people in each country.

・To stimulate risk communication on catastrophic disasters nationally and globally, starting with discussions at Science Council of Japan.

（３）Ensuring investment in financial expenditure, capacity development, and technological development against disasters

・To establish the role of investment in reducing human activities and asset accumulation at risk exposed to disasters such as medium to long-term spatial reorganization plans and maintenance of critical social infrastructure.
・To promote the concentrated investment in (1) improvement of qualitative and quantitative enhancement of market services to improve self-help capacity and (2) enhancement and diversification of insurance and mutual aid programs to provide mutual assistance aid based on the system.
・To enhance individual and grassroots community resilience capabilities to deploy strategic capacity development programs to respond to disasters more efficiently and effectively utilizing digital transformation (DX).

（４）Establishing proactive measures to enable Build Back Better

・To strengthen the transformative capacity to build a new society after a disaster with the awareness that "in an emergency, we can only do what we normally do," as well as a system that promotes proactive measures using DX.
・To present a vision of society after a catastrophic disaster (sustainability, green energy/zero carbon, national spatial planning, transition to an autonomous decentralized and cooperative community in terms of finance, economy, industry, international cooperation, etc.)

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To overcome the catastrophic disasters such as enormous earthquake and tsunami disasters that are almost certain to occur in the first half of the 21st century, we have integrated the knowledge of various related academic fields and recommended an overarching strategy and feasible concrete measures to overcome catastrophic disasters from an academic perspective regarding what should be done in the remaining time and after the disaster occurs. It is impossible to completely prevent the estimated damage in the time remaining before a disaster strikes. That is why this recommendation focuses on "resilience," which is the ability to overcome a disaster comprehensively, including streamlining and improving the efficiency of post-disaster emergency response and recovery/reconstruction processes, in addition to further improvement of damage deterrence. To improve resilience, it is essential to promote science and technology that aims for 'consilience [1]' of knowledge in the fields related to disasters as natural phenomena and knowledge in the fields related to disasters as social phenomena.

1 Background and Purpose of this Recommendation

Catastrophic disasters may impede sustainable development worldwide. In 2015, the Sustainable Development Goals (SDGs) [2] were set as a common goal for humanity to achieve. In the same year, it was also established the Sendai Framework for Disaster Reduction [3] and the Paris Agreement to mitigate and adapt to climate change [4]. Although these three global agendas appear to be independent, they should be viewed as systemic risks that are closely interrelated [5].

Systemic risk is a well-known economic and financial term that describes how the impact of insolvency in one place quickly spread through payment systems and markets to the entire world financial system during the 2008 Lehman Shock. In this recommendation, systemic risk refers to the risk that a problem in disaster risk reduction, climate change adaptation, or sustainable development that occurs in one place will spread to other problems and other regions because of their close interdependency so that it will become global challenges.

This interdependency resulted from the continuation of population growth and urbanization that started with the Industrial Revolution, which was accelerated after World War II.

In Japan, there is a high probability that a Nankai Trough earthquake will occur in the first half of the 21st century, which has occurred almost every century since the 7th century [6]. The Tokyo Inland Earthquake, which has an adjacent epicenter, might occur in close temporal proximity. According to damage estimates by the Government of Japan, the maximum estimated damage is 220 trillion yen for a Nankai Trough earthquake and 95 trillion yen for the Tokyo Inland Earthquake. Summing up, the estimated damage by these two earthquakes amounts to more than 300 trillion yen. Disasters with damage exceeding 100 trillion yen are called "Trillion-Dollar Disasters. In the United States, which experiences many disasters yearly, large-scale disasters are called "Billion-Dollar Disasters [7]." Although there has never been a "Trillion-Dollar Disaster" individually or in the annual total, the coming Nankai Trough earthquake and the Tokyo Inland Earthquake could be the first "Trillion-Dollar Disasters" that humanity has experienced since the Industrial Revolution. Such "catastrophic disasters" of unprecedented scale are definitely an apparent threat to Japan's sustainable development and a significant threat to the sustainable development of the international community. This recommendation provides an overarching strategy and feasible concrete measures to overcome "Trillion-Dollar Disaster" level catastrophic disasters that are expected to occur in the future.

２ What kind of catastrophic disasters are predicted to occur in the first half of the 21st century?

Catastrophic disasters can be predicted by science alone, but science alone cannot answer how to overcome them. That is why this recommendation adopts the worst-case scenario approach used in the policy assumptions based on scientific predictions of what kind of disaster risks can be scientifically predicted. We start with the scenarios for the Nankai Trough earthquake proposed by the Government of Japan. Then, we move on to the Tokyo Inland Earthquake scenario and further complications.

(1) Basic hazard scenario "Nankai Trough Earthquake

A Nankai Trough earthquake is an earthquake that occurs at the plate boundary located in the Pacific Ocean from Shizuoka Prefecture to Miyazaki Prefecture, where the Philippine Sea Plate is subducting at a rate of 5 centimeters per year beneath the Eurasian Plate on which western Japan rests. The strain accumulated at the plate boundary is released approximately every 100 years. Since the plate boundary is located at the bottom of the sea, tsunamis have caused significant damage in addition to the damage caused by seismic tremors. Historically, the subsequent earthquakes have been recorded:

The 684 Hakuho earthquake
The 887 Ninna earthquake
The 1096 Eicho earthquake
The 1099 Kowa earthquake
The 1361 Shohei earthquake
The 1498 Meio earthquake
The 1605 Keicho earthquake
The 1707 Hoei earthquake
The 1854 Ansei earthquake
The 1944 Showa Tonankai earthquake
The 1946 Showa Nankai earthquake.

Based on a time prediction model based on the history, the Headquarters of Earthquake Research Promotion (HERP) estimates that the expected time interval would be 88.2 years between the Showa Nankai earthquake and the next Nankai Trough earthquake with the magnitude 8-9 earthquake. HERP also estimates the probability of the next earthquake to occur within ten years from 2022 to be about 30%, 70-80% within 30 years, and 90% within 50 years. According to this prediction, the next Nankai Trough earthquake is to occur in the first half of the 21st century with a high probability.

(2) Possibility of Nankai Trough Earthquakes and the Tokyo Inland Earthquake being linked

The Tokyo Inland Earthquake, which has an adjacent epicenter to the Nankai Trough earthquake, might occur in close temporal proximity. While the predictions for the occurrence of the Nankai Trough earthquake are based on a time prediction model, the probability of an M7-class Tokyo Inland Earthquake is estimated to be 70% in 30 years based on the Poisson process for the southern Kanto area.

Because of the different estimation methods, no attempt has been made to directly estimate the linkage between the Nankai Trough earthquake and the Tokyo Inland Earthquake. However, both earthquakes occur in adjacent areas caused by the subduction of the Philippine Sea Plate. In 1855, the Ansei Edo earthquake occurred, causing extensive damage to Edo (present-day Tokyo) after the 1854 Ansei Nankai earthquake. Even though it is difficult scientifically to predict how a Nankai Trough earthquake and a Tokyo Inland Earthquake would occur in this century, we should take into account the worst-case scenario that both earthquakes would occur in the first half of the 21st century in close temporal proximity as a premise for disaster risk reduction policies.

(3) Potential Loss and damage from a Nankai Trough earthquake and the Tokyo Inland Earthquake

The Government of Japan has released two damage estimates for both the Nankai Trough earthquake and the Tokyo metropolitan area. For the Nankai Trough earthquake, a magnitude 9.0 earthquake is assumed as the most significant earthquake scenario after the 2011 Great East Japan Earthquake, with the following worst-case loss and damage: 323,000 fatalities, 623,000 injured, 1,346,000 buildings destroyed, 750,000 buildings burnt down, and economic loss of 214.2 trillion yen [8].

The worst-case scenario for the Tokyo Inland Earthquake in 2013 assumes a magnitude 7.3 earthquake similar to the 1995 Great Hanshin-Awaji Earthquake, with the epicenter in the southern part of central Tokyo, with the following worst-case loss and damage: 23,000 fatalities, 123,000 injured, 175,000 buildings destroyed, 412,000 buildings burnt down, and economic loss of 95.3 trillion yen. The evacuees are estimated to be up to 7.2 million people [9].

Given these two cases, the simple total of the damage would result in close to 350,000 fatalities and more than 300 trillion-yen economic loss. The largest disaster in Japan due to natural hazards since World War II was the 2011 Great East Japan Earthquake, which was a landscape-scale disaster where the Disaster Relief Law [10] was applied to 241 municipalities, resulting in 19,294 fatalities or missing, 126,500 buildings destroyed, 400,000 people evacuated, and 17 trillion yen in direct loss. The upcoming catastrophic disasters described above would have damage far greater than that of the 2011 Great East Japan Earthquake.

The 1923 Great Kanto Earthquake, the largest disaster in Japan's history, caused 5.5 billion yen in damage, more than three times the general budget of 1.47 billion yen at the time, according to "Tokyo Daishinsairoku Zensho" (1926), edited by the Tokyo City Office. The upcoming catastrophic disasters would be comparable in scale to the 1923 Great Kanto Earthquake, where their expected damage of over 300 trillion yen is more than three times larger than the general budget for FY2022, which is 107.6 trillion yen.

(4) Effects of extreme weather due to climate change

Due to extreme weather, weather-related disasters have become more frequent, widespread, and severe in Japan as much as the rest of the world since 1980. In Japan, we started to have such widespread disasters that the Disaster Relief Law was applied to more than 100 municipalities simultaneously since the 2011 Great East Japan earthquake, such as the torrential rains in July 2018 (West Japan), Typhoon Hagibis (No.19) in 2019, and the torrential rains in July 2020 [11].

Since unprecedented rainfall and giant typhoons due to extreme weather may occur every year and will continue on a global scale over a long period, it may compound and exacerbate catastrophic disasters due to the Nankai Trough and the Tokyo Inland Earthquakes.

In response to increasingly frequent, widespread, and severe weather-related disasters, it was promoted a new line of measures, in addition to improving local flood reservoir capacity, by the Ministry of Land, Infrastructure, and Transport, to reduce exposure to disasters and increase the capacity for advanced evacuation and disaster recovery by devising land use and the way of living [12]. Especially in three metropolitan areas (Kanto, Chubu, and Kansai) located in zero-meter areas, it is essential to strengthen these measures further to create a society that can mitigate widespread flood damage and support recovery from catastrophic disasters compounded by significant weather-related disasters. Since recovery and reconstruction following a catastrophic disaster is a lengthy, time-consuming undertaking, there is a risk that weather-related disasters may render the recovery efforts futile. We should anticipate that extreme weather for the next 30 years or so will have significant impacts on upcoming catastrophic disasters.

(5) Issues related to Long-term recovery and reconstruction

The results of the upcoming Nankai Trough earthquake and the Tokyo Inland Earthquake are expected to cause huge loss and damage due to shaking and tsunami, with up to 300,000 fatalities or missing and more than 300 trillion yen in direct loss, mainly on the Pacific Ocean side from Kanto to Kyushu. However, we need to take into account at least the following issues that are expected to intervene in the recovery process from this disaster. (1) Paralysis of various functions of Tokyo as the capital of Japan, (2) Disruption in east-west transportation capacity due to the unavailability of the Tokaido Shinkansen and Tomei/Shin-Tomei Expressways, (3) Decline in productivity due to the destruction of industrial infrastructure spreading across the Tokai region, including areas around Lake Hamana, (4) Increase in sovereign risk, which is credit risk to the government, resulting in higher long-term interest rates on government bonds and the depreciation of the yen, (5) the shortage of workers to meet reconstruction demand, and so on.

In addition, the occurrence of an event with a low probability but serious consequences cannot be ignored: (1) an eruption of Mt Fuji, as it erupted 49 days after the 1707 Hoei Nankai Trough Earthquake, or (2) an accident at the Hamaoka Nuclear Power Plant in Shizuoka Prefecture or the Ikata Nuclear Power Plant in Ehime Prefecture, as occurred at TEPCO's Fukushima Daiichi Nuclear Power Plant in the wake of the 2011 Great East Japan Earthquake.

(6) Population decline that would worsen the impact of catastrophic disasters

The world population has surpassed 8 billion. In general, the population continues to grow, mainly in developing countries, while the number of people in developed countries, in particular, has declined [13]. Japan is also entering a phase of population decline for the first time in its history, with the peak population in 2008. While population pressure has been a fundamentally positive factor for national development in the past in Japan, long-term population decline is expected to lead to a decrease in national strength, exacerbating and prolonging the effects of catastrophic disasters in the future.

A decreased working-age population due to population decline will make it difficult to secure human resources to engage in disaster response and reconstruction projects. It will also lead to a reduction in public assistance capacity due to lower tax revenues. The aging of the population, which will continue for some time to come, will lead to a decline in self-help capacity due to an increase in the number of people unable to act on their initiative. There are also concerns about reducing mutual help capacity through private networks due to a decrease in the number of people who can help each other. In addition, Japan has a high risk of low self-sufficiency for food and energy, making it even more challenging to recover from a catastrophic disaster.

3　What Past Catastrophic Disasters Teach Us about the Possible Impacts

In 2018, the Japan Society of Civil Engineers (JSCE) published a "Technical Study Report on Countermeasures for Mega Disasters Causing "National Disasters" [14]," and assessed the amount of possible damage and evaluated the impact of measures on damage reduction quantitatively by deploying social infrastructure development. At the same time, it listed the 1755 Lisbon earthquake [15], the 1854 Ansei Tokai and Nankai earthquakes followed by the 1855 Ansei Edo earthquake, and the 1970 Bora Cyclone as examples of catastrophic disasters in the past that could be described as "national disasters." In all of these cases, this report claimed that the occurrence of a catastrophic disaster resulted in significant changes in the countries that followed. Therefore, we need to clarify what would happen in the "National Disasters" case to learn lessons for overcoming catastrophic disasters.

(1) Possible changes in the state of the nation

History tells us that there are several scenarios for the changes in the state of a nation that can be expected as a result of a catastrophic disaster. (1) The most serious scenario would be the "diaspora," or ethnic disintegration. The country will cease to exist, and its people will be scattered worldwide. (2) The second scenario would be "vassalization" or "colonization" by a significant foreign power where the nation loses the right to govern. (3) The third scenario would be "regime change," which may result in a change in the domestic power structure where the opponent party comes to power. (4) The fourth scenario would be "no significant change" in the nation's state, where there could be a slow and steady "decline in national power."

The 1854 Ansei Tokai/Nankai Earthquake and the 1855 Ansei Edo Earthquake were followed by a change of government from the Edo shogunate to the new Meiji government. As indicated in this example, it should be studied further on the impact of the catastrophe disasters as a background factor facilitating the political power shift process.

(2) Decline in the relative status of the nation in the world

The 1755 Lisbon earthquake is said to be a trigger of the decline of Portugal. When disaster struck, Portugal was the world champion along with Spain, even though it had begun to show a declining trend due to economic competition with the Netherlands and the United Kingdom. As far as per capita GDP data from 1655 to 1855 is concerned, personal income was still at its economic peak even after the Lisbon earthquake (Maddison Project Database 2020) because of the reconstruction efforts of the Marquis of Pombal, who served as the premier after the earthquake. Per capita GDP declined rapidly and by less than half after he lost his position. There are various theories about Portugal's decline, and we await further empirical research on the impact of the Lisbon earthquake.

４ What is disaster resilience

Disaster resilience is defined twice by the United Nations (UN) as the ability to overcome adversities. In 2009, UNISDR (now UNDRR) defined "disaster resilience" in a glossary [16], and it was expanded at the UN General Assembly in 2017 [17]. By comparing these two definitions, it reveals three basic points on disaster resilience. Namely, (1) What are the entities that possess disaster resilience? (2) What kind of capabilities do these entities have? (3) How do these entities behave in the face of adversity? We will examine each of these in turn.

(1) Three kinds of entities which possess resilience

The two definitions assume three entities that possess disaster resilience, namely systems, communities, and societies. Systems in this recommendation refer to human beings as indivisible entities. Communities refer to all kinds of organizations based on human interactions. Society includes impersonal entities such as cities, buildings, and infrastructure so that we talk about city resilience, building resilience, and infrastructure resilience. These three entities are not independent of each other but interrelated.

(2) Disaster resilience is the sum of self-help, mutual help, mutual assistance, and public help

Since disaster resilience is the ability of an entity to cope with adversities, it consists of the capabilities of individuals, communities, and societies, which are interrelated with each other.

In other words, disaster resilience can be operationally defined as the sum of self-help by individuals, mutual help by communities, and public help by society. The "Report of the Study Group on Community-based Comprehensive Care [18]", which was made public in March 2013, points out that "self-help, mutual help, and public help" have five elements. This report points out two types of mutual help: help provided through private human networks (family, relatives, friends, volunteers, etc.), and help provided through systems (insurance, mutual aid), The repost also points out two types of self-help: help based on spontaneous activities of individuals, and purchasing market services. Public help is defined as help by tax money based on laws. This five-element model used in the welfare sector is quite unique in the sense that the purchase of market services is included as a type of self-help to serve as the support to enable people to be independent as much as possible. This model may be applicable in case of recovery from disasters.

(3) Three types of behavior exhibited by the entity

The UN 2017 definition lists six types of responses to a hazard: "resist, absorb, accommodate, adapt to, transform and recover from." These six responses can be broadly classified into the three types shown in the figure below: (1) no change (resist, absorb), (2) temporary change (accommodate, recover), and (3) permanent change (adapt, transform).

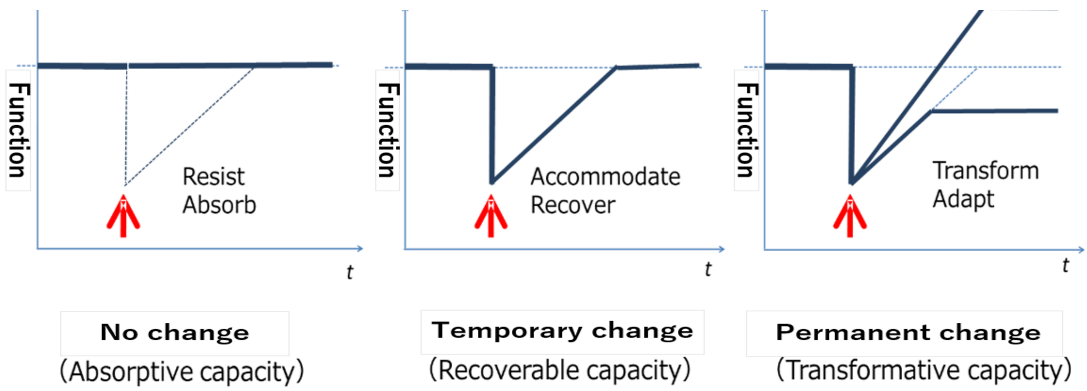

Figure Three types of resilience behavior

as defined by the UN 2017 definition
(Prepared by Subcommittee based on Bruneau et al. [19])

① No change (resist, absorb) happens when the entity can absorb the effects of the hazard, and no outward change appears in contact with the hazard. This is the case when disaster resilience is very high, or the hazard is not so strong. This ability is called "absorptive capacity.

② A temporary change (accommodate, recover) happens when a temporary loss of functionality occurs in the face of adversities. This triggers activities to restore functionality as soon as possible. Such a temporary change and subsequent recovery in response to a hazard appears as a model case of disaster resilience. This ability is called ″recoverable capacity.

③ Permanent change (transform, adapt) is a newly added behavior in the 2017 definition. An entity moves to a new state after a temporary loss of function in the face of adversities. If the hazard is too severe, the entity may not be recovered fully. On the other hand, it may move to a new state with improved functionality than before, triggered by distress, called ″transformative capacity ″ [20]. One example of transformative capacity is ″Build Back Better [21]″, one of the priority actions of the 2015 Sendai Framework for Disaster Reduction adopted after the 2011 Great East Japan Earthquake. Another example is ″Creative Reconstruction [22]" after the 1995 Great Hanshin-Awaji Earthquake.

Which of these three types of behavior is manifested depending on both the hazard intensity and resilience level of the entity? The identity of the entity is assumed to be maintained regardless of which type of response is manifested.

５　What Should We Do to Overcome a Catastrophic Disaster

It is impossible to completely prevent the expected damage in the time remaining before a disaster strikes. All stakeholders must focus on "resilience," which includes streamlining and improving the efficiency of emergency response, recovery, and reconstruction processes after a disaster strikes, in addition to prevention and mitigation. By taking advantage of scientific and technological expertise accumulated to date, it is necessary to improve preparedness proactively to minimize suffering and enable rapid recovery after a disaster strikes. Achieving these goals requires 'consilience' that enables the improvement of disaster resilience by integrating the knowledge of disasters as natural phenomena and that of disasters as social phenomena.

(1)　Japan has a high level of prevention capability against disasters.

Many countries around the world have low priorities for disaster risk reduction to believe that all they need to do is dispatch the military forces to clean up the mess and secure international assistance if a disaster strikes. Thus, the majority of disaster-related investment is spent on post-disaster response, recovery, and reconstruction, with only a small amount spent on proactive preparedness for disaster risk reduction (DRR). As an advanced country in DRR, Japan endorsed the UN's goal of improving preparedness in advance. As a result, the 2015 Sendai Framework for Disaster Risk Reduction emphasizes the state's importance of a systematic, peacetime approach to DRR.

(2)　Improve disaster resilience

However, he devastating damage caused by the 1995 Great Hanshin-Awaji and the 2011 Great East Japan Earthquake proved that the damage deterrence capacity in Japan needed to be improved. Even though seismic strengthening effectively deters structural damage, it requires an enormous amount of time to complete. Therefore, there is a practical need to improve the "ability to overcome disasters," which includes disaster response, recovery, and restoration from disasters, namely disaster resilience, given the currently anticipated damage due to upcoming catastrophic damage.

How to make a society recover from a disaster is a matter of social phenomena that has not been sufficiently examined scientifically so far. Therefore, there is an urgent need to develop empirical research program on "disasters as social phenomena" vigorously.

(3) Adopt an all-hazards approach

Even though research on forecasting and prevention for disasters has been conducted on a hazard-specific approach taking disasters as natural phenomena, an all-hazards approach can be applied to the process of recovering from disasters as social phenomena. This is because the process of disaster recovery has the following common objectives:

(1) Protecting the lives and livelihoods of those affected.
(2) Maintaining important social and economic functions.
(3) Early recovery and reconstruction from physical damage.

In recovery from disaster, there exists the case where no physical damage in some hazards, as in the case of the COVID-19 pandemic.

In the all-hazards approach, disaster response is basically generic in terms of the abovementioned three common objectives that can be applied to any hazard. Specific responses would be articulated depending on the result events created by the nature of the hazard at stake. Based on the all-hazards approach, it is suggested to be useful to systematize possible result events based on all kinds of past catastrophic disasters.

The first set of results events to be reviewed would be past examples of catastrophic earthquake disasters. In Japan, these include the 1703 Genroku Earthquake, the 1707 Hoei Nankai Trough Earthquake, accompanied by the Mt. Fuji eruption, the 1854 Nankai Trough Earthquake followed by the 1855 Ansei Edo Earthquake. The 1923 Great Kanto Earthquake is well documented so that we can comprehensively examine the entire events from the occurrence of the disaster to its completion of long-term recovery. There are also numerous examples worldwide, including the 1755 Lisbon earthquake, the 1906 San Francisco earthquake, the 1948 Turkmenistan-Ashgabat earthquake, the 1985 Mexico earthquake, and the 2010 Haiti earthquake.

The next set of results events would be lessons from catastrophic disasters caused by hazards other than earthquakes. For example, studies on weather-related disasters, such as the 1970 Bhola Cyclone that led to Bangladesh's independence, can provide valuable empirical knowledge. The global pandemic of COVID-19 beginning in 2020 also offers much knowledge regarding international-scale disasters.

In the analysis focusing on the resulting events, it is essential to examine those measures both for preventing damage and for recovering from the disaster comprehensively. It is also important to look at them as a package of measures aiming for total optimization rather than partial optimization. It is then necessary to realize multiple lines of defense, in which various measures are combined to work redundantly by combining so-called "hard" measures, such as facility and equipment maintenance and stockpiling of materials and equipment, with a wide range of "soft" measures including planning, training, and human resource development.

(4) How to prepare for a catastrophic disaster that has never been experienced

A "Trillion-Dollar Disaster" is a devastating disaster on a scale never before experienced by humanity. In other words, the question is how to prepare for a disaster never experienced.

In past earthquake disasters, enormous damage has occurred when struck by unexpected or greater-than-expected hazards. An example of an unexpected hazard leading to a major disaster is the 1995 Great Hanshin-Awaji Earthquake, an inland earthquake near a large urban area. An example of a larger-than-expected earthquake is the 2011 Great East Japan Earthquake, which caused a massive tsunami with Mw=9.0. We need to ensure the capacity to cope with the unexpected or greater-than-expected.

In addition to hazard prediction, societal change due to various scientific and technological innovations may result in unforeseen and devastating damage because catastrophic disasters are low-frequency, high-impact events with long intervals between events. Much of the science and technology that supports society needs to be tested with the impacts of catastrophic disasters. For example, the 1923 Great Kanto Earthquake proved the vulnerability of Western-style brick buildings, believed to be the most advanced at the time, in contrast to the superior disaster resistance of reinforced concrete (RC) construction [23]. The 1995 Great Hanshin-Awaji Earthquake also demonstrated the excellent earthquake resistance of prefabricated houses [24], and the 2011 Great East Japan Earthquake proved the effectiveness of information dissemination via the Internet in the recovery process [25]. Much of the science and technologies in use currently await to be verified by catastrophic disasters with rapidly changing economic conditions, demographic trends, and international relations. It is needed to evaluate scientific and technological innovation critically with the possibility of catastrophic disasters in mind.

(5) New self-help, mutual help, and public help

It has been believed that "public help" plays a major role in disaster response currently. There are concerns about the downward trend of future "public help," because of both the huge Japanese budget deficit and decreased tax revenues due to the decline in the working-age population. It is suggested that more active participation of all stakeholders is necessary to overcome upcoming catastrophic disasters. To do so, we need to reconstruct the relationship among self-help, mutual help, and public help to foster the active participation of all stakeholders.

The active participation of all stakeholders must be premised on the dignity of risk, where those who participate make their decisions based on risk-informed self-determination [26]. It is important to create a society that respects this value in the sense that everyone should make decisions based on the premise that their choices may be detrimental to themselves. That makes people's choices serious and prudent. Developing disaster risk reduction measures based on the dignity of risk is necessary to achieve resilience to overcome catastrophic disasters.

6 Measures to prevent catastrophic disasters from becoming national

disasters

At the 3rd UN World Conference on Disaster Risk Reduction in 2015, the Sendai Framework for Disaster Risk Reduction was adopted as the primary document for global disaster risk reduction until 2030, where four priority actions were elaborated as the basic framework for DRR measures. In this recommendation, we propose recommendations for resilience and sustainability beyond catastrophic disasters based on four priority actions: (1) Deepening and elaborating understanding of disaster risk, (2) Establishing new governance to cope with disasters, (3) Ensuring investment in financial expenditure, capacity development, and technological development in response to disasters, and (4) Establishing proactive measures to enable Build Back Better. The following are the main issues to be addressed.

(1) Deepening and elaborating understanding of disaster risk

Science aimed at disaster risk reduction has been making steady progress. One of the most prominent examples is the establishment of the Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis (commonly known as N-net). Japan deploys an observation network called MOWLAS for earthquakes, tsunamis, and volcanic activity, which consists of a total of over 2,100 observation points in both land and seafloor [27], for real-time hazard information dissemination. The land observation network was established based on the severe lesson learned from the 1995 Great Hanshin-Awaji Earthquake, and the seafloor observation network was established after the 2011 Great East Japan Earthquake. The N-net, which will be in operation from 2019 on the seafloor of the Pacific Ocean from Kochi Prefecture to Miyazaki Prefecture, is expected to shorten earthquake predictions by 20 seconds and tsunami predictions by 20 minutes, respectively. This is the first time in history that an observation network will be established in the ocean before a large-scale earthquake expected to occur in the future to contribute to a dramatic reduction in tsunami damage from a Nankai Trough earthquake. This may be one of the significant achievements of current science and technology.

Even if a dramatic reduction in mortality can be achieved, it is still necessary to reduce the direct damage of over 300 trillion yen. In addition to understanding hazards and exposures, disaster risk reduction requires those measures based on understanding the vulnerability and response capacity of individuals, communities, and society in the impacted region. The scientific community needs to identify what kind of goals each entity has and what kind of possible ways to ensure resilience to overcome the expected damage for each entity.

① Maintaining and improving individual well-being

Improving resilience at the individual level will lead to the maintenance and improvement of individuals' physical, mental, and social well-being, which is the goal of the Sixth Science, Technology, and Innovation Basic Plan. To achieve this goal, we need to improve our disaster preparedness skills individually by improving our ability to understand the risks accurately posed by upcoming catastrophic disasters to deal with them appropriately, based on the dignity of risk in mind.

Ikeda et al. [28] listed eight basic disaster preparedness skills, which can be developed through disaster education. These eight skills can be classified into three categories: (i) knowing disasters, (ii) preparing for disasters, and (iii) acting in response to disasters.

Knowing disasters consists of understanding disasters as both natural phenomena and social phenomena. There are two different approaches to learning about disasters as natural phenomena. As for geological disasters such as earthquakes and volcanoes, it is important to have a theoretical understanding because they occur only rarely. As for meteorological disasters, it is important to understand them through what happened in the past disasters because they occur almost every year. Preparing for disasters consists of two types of understanding disasters as social phenomena, which can be broadly classified into problems and issues that can be observed during a disaster and the lessons learned in response to those problems and issues.

There are four kinds of actions to be taken in preparation for and in response to disasters: (1) identification of local damage characteristics and response resources using a map, (2) damage prevention and mitigation actions before a disaster strikes, (3) how to protect oneself in the event of a disaster, and (4) mutual help during recovery from disasters. Systematization of empirical evidence relating to the abovementioned eight aspects is an indispensable step for improving the basic disaster preparedness of individuals.

In the recommendation titled "Toward the Contribution of Psychology to Civil Society for the Future: Enhancement of Psychology Education in High Schools and Training of Licensed Psychologists [29]" by the Science Council of Japan (September 2020), the expectations of civil society towards psychology pointed out the need for scientific and empirical recognition of the human mind and behavior, the usefulness of psychological literacy for promoting well-being, and the importance of psychological assistance in mental health. Seligman (2001) listed disasters as a life-turning setback element in addition to childhood experiences and everyday messiness [30]. WHO states that the well-being of a society can be judged by the extent to which it is resilient, able to act, and prepared to overcome hardship. [31] In order to promote understanding, preparedness, and action against disasters, the resilience of individuals within a society needs to be measured, and disaster education and basic disaster preparedness should be tailored to each individual.

② Strengthening Mutual Aid Capabilities through Mutual help

To improve resilience at the community level, it is important to examine the nature of mutual support among people. Before the Industrial Revolution, resilience functioned only based on private mutual aid among people living in a community of about 250 people. The Industrial Revolution led to urbanization, which gave rise to a new type of mutual help among city dwellers. Ishii [32] reports that even in today's urban slums, mutual help remains at the center of resilience to support people's livelihoods.

As Japan enters a population decline and aging phase, it is expected to become increasingly challenging to maintain the existing systems of self-help, mutual help, and public help. The aging population will make it difficult for individuals to engage in spontaneous activities. Mutual help through private networks may be directly affected by the population decline. Public help also will be more difficult because of working-age population decline. Accordingly, it is necessary to have a reformation of self-help, mutual help, and public help. Based on the five-element model of self-help, mutual heal, and public help, there will be two promising options. One is to improve self-help capabilities by enhancing the quality and quantity of market services. Another is to enrich system-based mutual aid mechanisms, such as insurance and mutual assistance program. No matter how large the upcoming catastrophic disaster would be, we have no other way except to rely on people's self-help, mutual help, and public help to overcome the disaster. It is urgent to expand academic concern for how to enhance new types of help in line with societal changes.

③ Coherent solutions for disaster risk reduction, climate change adaptation, and sustainable development

The second phase of the Integrated Research on Disaster Risk (IRDR) Program [33], sponsored by the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR), which began in 2021, recommends the promotion of integrative science to achieve "risk-informed sustainable development and planetary health." It clearly links disaster risk reduction with sustainable development. It also expresses a sense of crisis that population growth and urbanization will exceed and are exceeding the limits of the Earth's capacity to absorb their impacts and ultimately undermine human health. This view reflects the basic recognition that disaster risk reduction, climate change adaptation, and sustainable development are closely interrelated with each other at their core to form a systemic risk, even though they appear to be seemingly independent social issues.

The increase in population and urbanization continued since the Industrial Revolution made disaster risk reduction, climate change adaptation, and sustainable development become closely interrelated social issues over time. The increase in artificial materials and the massive burning of fossil fuels have caused global warming [34], biodiversity loss [35], and an increase in the number of disasters, such as floods and extreme weather events since 1980 worldwide [36]. Due to economic globalization, the impact of disasters may not be confined to a single country, and it spreads instantly around the world, posing a significant threat to sustainable development on a global scale. Therefore, there is a need for academic research that challenge the future of cities, infrastructure, and social systems, viewing disaster risk reduction, climate change adaptation, and sustainable development as interrelated social issues for a coherent solution.

To overcome the upcoming catastrophic disasters is not a problem limited to only Japanese disaster risk reduction. It is necessary to face with this problem on a global scale in collaboration with researchers in the fields of climate change and sustainable development. In addition to academic collaboration among related disciplines, it is essential to work with UN agencies and funding agencies as an international program that explores coherent solutions among the three social challenges. As an example, the recommendation titled "Toward the Realization of a Sustainable Global Society: Promoting Future Earth [37]" by the Science Council of Japan (April 2016) stated that Japan took an active leadership role in promoting this program, with a focus on environmental issues and a system to encourage interdisciplinary and trans-disciplinary research, including collaboration among researchers, practitioners, and policymakers in the international community and a report was presented on integrated global environmental change in 2023 [38]. It must be further promoted these efforts to resolve three social issues coherently and simultaneously.

④ Realizing consilience through Online Synthesis System (OSS)

To promote science that views the upcoming catastrophic disasters as systemic risks, it is essential to integrate such existing academic fields which were developed separately as disaster risk reduction, environment, and development. Thus, we must establish methodologies and mechanisms to enable interdisciplinary exchange and fusion of ideas.

As for forecasting and prevention for disaster risk reduction, academic disciplines have been established for each hazard, such as natural hazards, infectious diseases, accidents, terrorism, etc. In contrast, an all-hazard approach is adopted for emergency response after a disaster, which is generic for all hazards. Recovery and reconstruction may differ depending on whether the damage results from physical destruction or reduced human activity. Although the COVID-19 pandemic is an international-scale disaster with severe impacts, recovery efforts will focus only on rebuilding social and economic activities because there is no physical damage. On the other hand, disasters with physical damage due to natural hazards, accidents, or terrorist attacks require physical reconstruction.

For catastrophic disasters as systemic risks, in addition to integrating knowledge on predictive and preventive capabilities, it is also indispensable to work for a consilience with the knowledge on post-disaster risk reduction based on an all-hazard approach. It is necessary for establishing consilience to use web-based tools that play a role as a platform for all related fields to integrate knowledge from various fields. As a first step, the recommendation titled "Building a sustainable global society by strengthening disaster resilience: Developing an "Online Synthesis System (OSS) and fostering Facilitators to realize consilience" [39] by the Science Council of Japan introduced the OSS in September 2020.

The notion of OSS was first introduced in the recommendation titled "Disaster Risk Reduction and Promotion of International Research on Disaster Prevention and Mitigation - Recommendations for Implementation of the Sendai Framework for Disaster Reduction and Tokyo Statement- " [40] by the Science Council of Japan (February 2016). This recommendation proposed that it is essential for researchers, practitioners, and policymakers to deepen collaboration in their native languages in monitoring, impact assessment, and literacy activities for disaster risk reduction and to develop domestic and international partnerships to support such activities. OSS is a system that integrates various knowledge and procedures on the cloud (a system of systems) that helps all stakeholders to have an accurate and comprehensive understanding on both disaster resilience and sustainable development with a deep appreciation of the causal relationship, and an effective implementation of planning, execution, and evaluation to realize the coherent solutions. A prototype of web-based OSS was already proposed. The use of OSS, which has started mainly in the field of disasters due to natural hazards, should expand into total preparedness for catastrophic disasters by disseminating comprehensive knowledge to society. Consilience in disaster risk reduction should further diffuse into society to accelerate coherent solutions for three societal challenges: disaster risk reduction, climate change adaptation, and sustainable development.

(2) Establishing new governance to cope with disasters

Governance is primarily the notion of organizing, controlling, and managing a government or corporation, as well as the mechanisms and methods for doing so. Bevir [41] points out that the concept of governance has changed over time, from an idea initially founded on "authority" as its core, adding a "market" element, then to that now emphasizes "network" due to the expansion of geographic areas, and the diversification of issues to be addressed. In governance for disaster resilience, it is essential to review how disaster-related laws, systems, and activities are regulated and functioned to reduce disaster risk. In addition, the recommendation "Social Monitoring and Archiving: Verification of the Recovery Process and Recursive Governance" [42] (September 2020) by the Subcommittee on Issues of Social Monitoring and Recovery after the Great East Japan Earthquake for the Committee on Sociology, the Science Council of Japan, points to the importance of "recursive governance," in which policies have an inherent mechanism for making minor adjustments in response to unexpected circumstances deviating from assumptions over time.

① The New Normal Implies a Transition to an Autonomous, Decentralized, and Cooperative Society

When considering disaster risk governance, we can obtain great lessons from a global pandemic due to the COVID-19 started in early December 2019. In the discussion on the world after this pandemic [43], the notion of a "New Normal" was introduced as a new and irreversible trend toward realizing a society consisted of autonomous communities, which could be a turning point from the trend for urbanization and centralization since Industrial revolution. We name such a new society an autonomous decentralized cooperative society [44]. How irreversible these social changes should be examined in the future.

The introduction of the New Normal has dramatically progressed the adoption of telecommuting routines, the use of online conferencing, and the expansion of e-commerce (electronic commerce). It is a big question to what extent these ICT-based innovations will change the nature of society. For example, population growth in Tokyo prefecture, which had been continuous before COVID-19, experienced a decline from 2020 to 2022. How far will these trends continue? It should be clarified the irreversibility of the trend toward an autonomous, decentralized, and cooperative society.

In an autonomous, decentralized, and cooperative society, it should be considered first how to secure water, food, energy, and shelter, which are essential elements for our survival. These elements are needed to be produced locally for local consumption. We need to come up with the measures to promote a shift for local production for local consumption, from the current social structure that relies on imported food and energy.

In contrast, COVID-19 has dramatically accelerated the shift to everyday life relying on ICT, such life domains as work, education, medical care, and entertainment. Using high-speed, low-latency networks opens up the possibility of developing services on a global scale. This suggests that we may not be necessarily constrained by the notion of "national boundary" not so much as in the past. This is another point that needs further research.

The transition to an autonomous, decentralized, and cooperative society could be one of the future basic frameworks in Japan, where the population is declining. This future vision is also consistent with the Cabinet Secretariat's "Digital Garden City" Initiative [45] and the new National Land Formation Plan (National Plan) and National Land Use Plan (National Plan) approved by the Cabinet in July 2023 [46]. In the transition to an autonomous, decentralized, and cooperative society, it is required to realize the following points as indicated in section 6 of this recommendation: (i) maintaining and improving individual well-being, (ii) strengthening mutual aid capacities through mutual aid and mutual assistance, (iii) integrated solutions for disaster risk reduction, climate change adaptation, and sustainable development, and (iv) knowledge integration through OSS.

② Appropriate urban size and functions in an autonomous decentralized cooperative society

The transition to an autonomous, decentralized, and coordinated society will come to reconsider the urbanization that has continued since the Industrial Revolution. However, it is meaningless to return to the old days before the Industrial Revolution, where people lived in settlements with a population of around 250, lacking the basic services necessary we enjoy now for our daily life. In an autonomous, decentralized and cooperative society, what would be the appropriate urban size, and what kind of functions do cities have? The "Grand Design of National Land 2050, Reference Material (July 2014) [47]" compiled by the National Land Policy Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism indicates the desirable size of cities as "the population size of municipalities where there is a 50% and 80% probability that a service facility will be located." Based on this, a population of 50,000 to 200,000 is recommended as appropriate size for a city with the various urban functions necessary for the area. This recommendation suggests different challenges for metropolitan areas, regional core cities, and depopulated areas in current Japan, even though solutions should be applied for these three challenges must be coherent and simultaneous.

Metropolitan areas need to be transformed into urban areas that do not require long daily commuting. The current urban structure connects big central business districts with vast surrounding suburban areas by highly developed public transportation networks. This structure should be transformed to enable work and residence to be closer together which enables lifestyles with more free time. It is proposed that the reconfiguration of urban structure from the current unipolar structure to a combination of basic units with a high degree of autonomy, named "Cell City" with 6 km square as the basic unit (Iwasaki, 2000) [48].

Local core cities have an urban structure that most closely resembles the image of autonomous decentralized cities in terms of population size. Further commitment may be needed to expand local production for local consumption concerning basic survival needs. It is also required to improve transportation and communication networks to enhance services in the domains of work, healthcare, education, and entertainment to provide a higher quality of life.

Depopulation areas would increase in number further due to ongoing population decline. As a result, it would increase the cost of maintaining social infrastructure per capita in those regions, and it might be needed to make strategic contraction as an option for the near future. In contrast, it is desirable to improve the self-sufficiency for food and energy by transforming current agriculture, forestry, and fishery businesses into a "sixth industry" that uses the rich nature of these regions as joint social capital [48]. A similar argument was made in the recommendation titled "Creating an 'Inochi-machi' (town of life) " through national land formation utilizing green infrastructure against increasingly severe disasters caused by climate change [50] by the Science Council of Japan (August 2020).

③ Transnational resilience

To improve resilience to overcome the upcoming catastrophic disasters, we need to improve the resilience of our land and sea, nation, and people. However, it is not necessarily a good idea for us to take all of the predicament resulted from a catastrophic disaster by ourselves. Instead, we should consider transnational resilience, in which multiple countries cooperate with each other as partners. As an example, the Science Council of Japan's "International Commission on Science and Technology for a Sustainable Society, Subcommittee 2022" discussed transnational resilience, focusing on public health and social welfare during disasters under the theme of "disaster and health" [51].

Helping each other across national borders does not be limited only to the enhancement of international humanitarian aid in the emergency period immediately after a disaster strikes. The question is, "Can we create a forum where many countries can work together to consider ways to reduce future disaster risks, adapt to climate change, and ensure global sustainability as we recover from this catastrophic disaster in Japan. In other words, it should be an international challenge for every country that could hinder the sustainable development of the world? To have a positive answer to this challenge, Japan must become a so-called "country worth being helped." It also needs to increase the number of countries that can help Japan.

In order to realize coherently disaster risk reduction, climate change adaptation, and sustainable development, Japan must clarify its position in the world to enhance the value of coherence and to induce international governance where the international community can cooperate in times of crisis. Accordingly, Japan, both public and private sectors together, must keep its actions and contribution to the international community.

④ Activate risk communication

Upcoming catastrophic disasters would cause extensive physical damage in addition to emotional and socioeconomic hardship over a wide area, and it may prompt many people to seriously reconsider society's nature as it has existed. The transition to a new society may be prescribed by the speed of renewal of the society itself, which may take a long time. Opportunities for social change may emerge abruptly, such as the emergence of the new normal after COVID-19. There would be a strong possibility that the upcoming catastrophic disaster will trigger the transition to a new society.

What matters is how much discussion would have about what kind of society people would like to have before the catastrophic disasters strike. Thus, it is necessary to vitalize risk communication. Active and transdisciplinary discussion should be facilitated domestically and internationally through an inclusive process, allowing people of various backgrounds and positions to participate. Let us say to start this discussion with the Science Council of Japan. it should be elevated to a national debate. In this discussion, we must foster facilitators and continuously consider how we can contribute from an academic standpoint, including establishing a disaster risk communication science using OSS. Proactive measures must be taken for better preparedness before a disaster strikes and appropriate responses afterward.

(2) Ensuring investment in financial expenditure, capacity development, and technological development against disasters

The third priority action of the Sendai Framework for Disaster Reduction is an investment in disaster reduction. The Framework states, "Addressing underlying disaster risk factors through disaster risk-informed public and private investments are more cost-effective than reliance on post-disaster response and recovery primary, and it also contributes to sustainable development." [52] As Japan enters a phase of population decline for the first time in its modern history, we should reconsider our past approach to investment based on population growth. In light of the decline in the productive population, we need to enhance the resilience of each individual to engage in disaster response efficiently and effectively with a smaller number of people by utilizing digital transformation (DX). It should be found the ingenious ways to overcome problems caused by population decline by considering the new areas of investment and the new way of investment.

① Decrease in human activity and asset accumulation at risk of exposure to disasters

The first question to be considered is how to reduce hazard exposures actively. It is urgently needed to reduce and relocate human activities and asset accumulations at high risk of exposure to catastrophic disasters to safer locations as much and soon as possible. During the period of rapid population growth that has continued in Japan since the Meiji era (1868-1912), human activities and asset accumulation in high-risk areas have continued due to the scarcity of suitable residential areas. We should take the remaining time before catastrophic disasters as the opportunity to reduce exposure in high-risk using population decline.

According to various available data, Nankai Trough earthquakes have occurred almost every century since the 684 Hakuho earthquake. It suggests that it is necessary not only to consider overcoming the disasters caused by Nankai Trough earthquakes in this century but also to take into account the 22nd century and beyond. It should be formulated a medium- to long-term spatial reorganization plan which ensures the maintenance of basic functions as well as business continuity of critical social infrastructure.

The risk is defined by three factors: hazard, exposure, and vulnerability. In the current disaster risk reduction due to natural hazards, hazard prediction has become a reality to some extent. We need to explore the possibility of Reexamining the urban structure to reduce exposure as such countermeasures which would have a wide range of long-term lasting effects, in addition to continuing efforts to reduce vulnerability for each hazard. It is important for future research not to focus only on seismic risk but also on the effects of climate change by adopting an all-hazards approach.

② Greater investment by the private sector for improving resilience

The next consideration is the enhancement of investments that directly lead to improved resilience. Resilience can be operationally defined as the sum of self-help, mutual help, and public help. This definition indicates a future direction to improve resilience in Japan in population decline. First, since the aging of the Japanese population still continues, it will become more difficult for the elderly population to engage in spontaneous activities for disaster risk reduction. The continuous population decrease makes it challenging to maintain mutual help through private networks, a form of benevolent assistance. Reducing tax revenues due to the decline in the working-age population [53] will also make it difficult to maintain public help. To sum up, there remain two measures that are essential to improve resilience under population decline: (1) expansion of the quality and quantity of market services that contribute to self-help and their support, and (2) enhancement, diversification, upgrading, and dissemination of insurance and mutual aid programs, which are mutual assistance through systems. Since both measures are regarded as activities mainly taken by private-sector, it suggests an increase in investment in these areas will be the deciding factor for future improvement of resilience. Therefore, realizing "market" type governance is important, encompassing more active involvement of private businesses to help solve social issues.

A barrier to this is the idea of separating emergency situation from non-emergency situations or regular times. In this way, products for disaster risk reduction are to be used only in case of disasters. Since the opportunities and scope of such products have a limited use case potentially, it may be difficult for the private sector make investment in something that cannot be used regularly. Resilience, however, is the ability both to prevent hazard impacts as much as possible and recover from them as quickly as possible. Resilience does not distinguish between emergency situation and non-emergency situations by reducing negative impacts caused by adversities in a continuous manner, as in the case of insurance. The rapid acceleration of digitalization of society is promising in the sense that it links emergency situation with non-emergency situations smoothly, which may provide for the private sector to promote the notion of a "resilient lifestyle [54]" as a new comprehensive and sustainable business opportunity to help to solve social issues and bringing profits.

(4) Establish proactive measures to enable Build Back Better

The final priority action of the Sendai Framework for Disaster Reduction is to achieve emergency preparedness and "Build Back Better."

The question is, what can be done to rebuild Japan into a more resilient and sustainable country in preparation for the upcoming catastrophic disasters, i.e., what can be done to enhance the transformative capacity of a society faced with hardship to use it as an opportunity to build a better society?

① Disasters as an opportunity to build a new society

The lesson of the 1995 Great Hanshin-Awaji Earthquake and the 2011 Great East Japan Earthquake is that ″in times of emergency, we can only do what we usually do.” This bitter lesson means that transformative capacity is the ability to solve problems with a clear and drastic plan prepared before the event strikes to create a better society that is different from the existing one, within a short period after the onset of the event. Without such a plan, disaster victims would adhere to realizing their desire to “return to the way things were before the event.”

When the leaders of a society have prepared such a plan in advance, disasters may provide an opportunity to realize a transformation into a new society. The most famous example is the proposal of the Imperial Capital Renewal Plan [55] called “Tokyo Municipal Government Outline” by the then Minister of Home Affairs Shinpei Goto at the time of the 1923 Great Kanto Earthquake. Based on the plan he had formulated when he was the mayor of Tokyo, which had no chance of being realized yet, he submitted his reconstruction plan to the Diet within the first week of the earthquake. Then, his reconstruction plan was put into action with some reduction in scope. As a result, the basic structure of the current central Tokyo area was born at this time, and the idea is still alive today, 100 years later.

Similar examples of prior preparation reflected in recovery plans include Kobe City during the 1995 Great Hanshin-Awaji Earthquake [56] and Ojiya City at the time of the 2004 Niigata Chuetsu Earthquake [57]. In both cases, the cities were hit by an earthquake when the comprehensive plans were under preparation. Both plans were almost near the completion with active citizen participation in the years when the earthquakes struck. Although officials in both cities felt that all the preparation for their comprehensive plans would be wasted due to the disasters, the completed reconstruction plans showed that much of the content from the previous comprehensive plan was reflected in the recovery plan, with some addition of lessons from the disasters.

In all three cases, the earthquake was used as the trigger to put the preparations into action. In addition, all three cases have in common that the time available to freely decide the direction of recovery after a disaster was very short, only about the first two weeks after the occurrence of a disaster. Since the time to implement preparations is limited to a very short time and in the early stages of disaster recovery, it is critical how quickly the leadership team makes decisions for transformative recovery from the catastrophe.

In the 2022 "White Paper on Disaster Prevention," the Working Group on Pre-Disaster Prevention and Complex Disasters, consisting of experts established in the Cabinet Secretariat, made recommendations regarding future policy directions in anticipation of the coming Nankai Trough earthquake and the Tokyo Inland Earthquake [58]. To improve transformative capacity, it might be a very good starting point to evaluate critically the effectiveness of those recommendations with the broad participation of all stakeholders as the basis for transformative plan.

② Promote new proactive measures using DX

If we can only do what we usually do in disaster, we should actively consider improving our resilience through what we typically do. The upcoming catastrophic disaster will be on a scale never before experienced by humankind, and it will be tough to predict what may happen accurately. The use of digital twins [59], such as collecting information and data from the real world through IoT and reproducing the same conditions and situations as in the real world in digital space, and the quality of disaster response in unprecedented situations would be expected to improve by the use of ensemble simulation [60] [61] as well as an advanced and comprehensive computational method.

In disaster response simulations, given the assumption of a generic framework for disaster response, it might be useful to construct simulation based on frequently experienced disaster responses to weather-related disasters. It will provide basic experiences for trainees to learn possible result events through cases of high-frequency disasters. It is also important to simultaneously learn about the unique consequences of earthquake and tsunami disasters.

Due to the effects of extreme weather caused by climate change, weather-related disasters have intensified and become more widespread since the beginning of the 2010s. Wide-area weather-related disasters that simultaneously affect multiple prefectures have been occurring every year: 110 municipalities were affected by the torrential rains in western Japan in 2018, and 390 municipalities by the typhoon1919 in eastern Japan in 2019 in terms of the number of municipalities to which Disaster Relief Act was applied. It is estimated that the Disaster Relief Law will be applied to 707 municipalities in the coming Nankai Trough earthquake, and we should actively apply the experiences gained through weather-related disasters to upcoming wide-area earthquake disasters.

It is required to standardize disaster response to make nationwide mutual support possible for realizing effective disaster response in a wide-area disaster where multiple prefectures are affected simultaneously. This suggests that the national government of Japan should build on the progress of ICT to establish a nationwide standardized disaster response system to implement an emergency response DX on the cloud, in which over 1,700 municipalities can use this system for real disaster responses as well as drills and exercises. Using this cloud system, all municipalities would be able to conduct coordinated, effective, and efficient disaster response and exercises. By utilizing this system for such frequent weather-related disasters that have occurred in recent years, disaster response can be continuously upgraded by common visualization of the damage, common disaster response, and real compilation of actions, questions, and answers in the database as the source for further decision making. Promoting the creation of such a nationwide ICT environment is indispensable as an effective proactive measure for responding to upcoming catastrophic disasters.

③ Advance Presentation of Recovery Vision

Citing the examples of Tokyo City after the Great Kanto Earthquake, Kobe City after the Great Hanshin-Awaji Earthquake, and Ojiya City after the Chuetsu Earthquake in Niigata Prefecture, we introduced the importance of preparation for the physical reconstruction of impacted areas. We showed that the large-scale destruction caused by catastrophic disasters creates new social structural realizations. In each case, however, the time available to step into this transformation was limited to a short time immediately after the disaster. Preparation before the event strikes is essential to make use of this limited opportunity, and it must establish a system to ensure and improve transformative capacity that can use disasters as an opportunity to build a new society.

To this end, it is essential to present a vision of the society that should be realized after a catastrophic disaster (sustainability, green energy/zero carbon, national land planning, transition to an autonomous decentralized and cooperative society that leads to the realization of fiscal, economic, industrial, and international cooperation, etc.). It is necessary to construct and clarify in advance a vision for reconstruction that is in line with the social vision presented above, and all relevant organizations need to start preparations for its realization now.

7 Recommendations - What Should We Do with the Remaining Time? -

In order to acquire resilience to overcome catastrophic disasters of the scale estimated by the government of Japan, all stakeholders should continue their efforts not only to prevent damage but also to focus on scientific studies and practices promoting disaster response and recovery. In what follows, we propose measures to be taken in line with the four priorities for actions in the Sendai Framework for Disaster Risk Reduction 2015-2030.

（１）Deepening and elaborating understanding of disaster risk

・To establish science and technology for improving disaster resilience and sustainability of societies with the ultimate three goals: 1) maintaining and improving the physical, mental, and social well-being of individuals, 2) strengthening the capacity for mutual support in communities, and 3) the coherent realization of disaster risk reduction, climate change adaptation, and sustainable development in society.
・To develop a disaster management system with an all-hazards approach, conversing multi-disciplinary knowledge covering all phases of disaster management, including forecasting, prevention/mitigation, early warning, emergency response, and recovery/restoration.
・To realize the consilience of knowledge for disaster resilience using information infrastructure to disseminate to society according to the Recommendation titled "Developing an Online Synthesis System (OSS) and fostering Facilitators to realize consilience" from Science Council of Japan in 2020.

（２）Establishing new governance to cope with disasters

・To establish the governance contributing to the transition to an autonomous, decentralized, and cooperative society as suggested by the irreversible changes caused by the COVID-19 pandemic.
・To ensure transnational resilience where multiple countries cooperate with each other in addition to improving the national resilience of land and sea, sovereignty, and people in each country.
・To stimulate risk communication on catastrophic disasters nationally and globally, starting with discussions at Science Council of Japan.

（３）Ensuring investment in financial expenditure, capacity development, and technological development against disasters

・To establish the role of investment in reducing human activities and asset accumulation at risk exposed to disasters such as medium to long-term spatial reorganization plans and maintenance of critical social infrastructure.

・To promote the concentrated investment in (1) improvement of qualitative and quantitative enhancement of market services to improve self-help capacity and (2) enhancement and diversification of insurance and mutual aid programs to provide mutual assistance aid based on the system.

・To enhance individual and grassroots community resilience capabilities to deploy strategic capacity development programs to respond to disasters more efficiently and effectively utilizing digital transformation (DX).

（４）Establishing proactive measures to enable Build Back Better

・To strengthen the transformative capacity to build a new society after a disaster with the awareness that "in an emergency, we can only do what we normally do," as well as a system that promotes proactive measures using DX.

・To present a vision of society after a catastrophic disaster (sustainability, green energy/zero carbon, national spatial planning, transition to an autonomous decentralized and cooperative community in terms of finance, economy, industry, international cooperation, etc.)

Glossary

(1) Ensemble simulation

Ensemble modeling is a process where multiple diverse models are created to predict an outcome, either by using many different modeling algorithms or using different training data sets. The ensemble model then aggregates the prediction of each base model and results in once final prediction for the unseen data. The motivation for using ensemble models is to reduce the generalization error of the prediction. As long as the base models are diverse and independent, the prediction error of the model decreases when the ensemble approach is used. The approach seeks the wisdom of crowds in making a prediction. Even though the ensemble model has multiple base models within the model, it acts and performs as a single model. Most of the practical data mining solutions utilize ensemble modeling techniques.

Reference: Vijay Kotu: Bala Deshpande PhD, in Predictive Analytics and Data Mining, 2015

(2) Well-being

Well-being is a positive state experienced by individuals and societies. Similar to health, it is a resource for daily life and is determined by social, economic and environmental conditions. Well-being encompasses quality of life and the ability of people and societies to contribute to the world with a sense of meaning and purpose. Focusing on well-being supports the tracking of the equitable distribution of resources, overall thriving and sustainability. A society's well-being can be determined by the extent to which they are resilient, build capacity for action, and are prepared to transcend challenges.

Reference: WHO: Glossary of Terms, 2021.

(3) All-Hazards Approach

An all-hazards approach addresses capabilities-based preparedness to prevent, protect against, respond to, and recover from terrorist attacks, major disasters, and other emergencies.

Reference: FEMA, National Preparedness Guidelines, September 2007

(4) Disaster risk governance

・The system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy

・Annotation1: Good governance needs to be transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones. The system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy.

・Annotation2: Good governance needs to be transparent, inclusive, collective and efficient to reduce existing disaster risks and avoid creating new ones.

Reference: UNDRR Terminology,
https://www.undrr.org/terminology/disaster-risk-governance

(5) Green Energy
Green power shall be generated from renewable energy sources that meet all of the following conditions,
The details shall be by the methodology (Methodology for Green Power Type) separately determined by the Committee.
 (a) Power generation must not be based on fossil fuels like oil, coal, or natural gas.
 (b) Electricity shall not be generated by nuclear power generation.
 (c) The emission of greenhouse gases and toxic gases such as sulfur and nitrogen oxides during power generation must be zero or significantly less.
For now, the power generation methods that satisfy the above conditions are as follows.
(i) Wind power generation
(ii) Photovoltaic power generation
(iii) Biomass power generation
(iv) Hydroelectric power generation
(v) Geothermal power generation
(vi) Fossil fuel/biomass co-firing power generation
Reference: Agency for Natural Resources and Energy: Green Energy CO2 Reduction Equivalent Certification System Operation Rules, 2021.
(原題)資源エネルギー庁:グリーンエネルギーCO2 削減相当量認証制度 運営規則,2021.

(6) Systemic risk
Systemic risk refers to the risk that the insolvency of an individual financial institution or the dysfunction of a particular market or settlement system will spread to other

financial institutions, other markets, or the financial system as a whole.
In the financial system, individual financial institutions are interconnected through various transactions and fund settlements in the settlement network.

Reference: Bank of Japan: What is systemic risk？
（原題）日本銀行:システミック・リスクとは何ですか？
https://www.boj.or.jp/about/education/oshiete/kess/i06.htm (Japanese)

(7) Zero Carbon
The term "zero carbon" refers to the overall reduction of greenhouse gas emissions, such as carbon dioxide (CO_2) and methane (CH_4), which are gases that help keep the earth warm and are emitted when we produce electricity and drive gasoline-powered vehicles.

Reference: Kansai Electric Power Group. What is Zero Carbon?
（原題）関西電力グループ:ゼロカーボンとは
https://media.kepco.co.jp/_ct/17528022 (Japanese)

(8) Sovereign Risk
Sovereign Risk refers to the credit risk of a nation (country), precisely the possibility that government bonds or agency debt will be downgraded or defaulted. When this risk increases, it affects the supply-demand balance for government bonds and other securities, causing long-term interest rates to rise, often leading to a decline in investment and consumption.
Reference: Nomura Securities Co., Ltd.: Sovereign Risk, Glossary of securities industry terminology
https://www.nomura.co.jp/terms/japan/so/s_risk.html

(9) Digital Transformation
Digital transformation is how a company responds to disruptive changes in its external ecosystem (customers, markets) while

driving change in its internal ecosystem (organization, culture, employees).
The third platform (cloud, mobility, big data/analytics, and social technologies) will drive new products, services, and business models through both online and real-world applications.
Transform the customer experience online and in the real world through new products, services, and business models.
(big data/analytics, social technologies) to create value and establish a competitive advantage by transforming the customer experience online and in the real world through new products, services, and business models.

Reference: Ministry of Economy, Trade and Industry Study Group for Digital Transformation: DX Report, 2018
（原題）経済産業省デジタルトランスフォーメーションに向けた研究会:DX レポート,2018

(10) The New Normal
The spread of the new coronavirus infection has forced significant changes in Japan's social economy. The rapid spread of the new coronavirus infection and the declaration of a state of emergency issued on April 7, 2020, triggered the rapid development of telework, telemedicine, and distance education. Under these circumstances, the transition to the "new normal," a new way of life in the so-called "with Corona" and "after Corona," came to be called for.
The "with Corona" and "after Corona" lifestyles, or the "new normal," were being sought. On the other hand, when the emergency was lifted on May 25, 2020, there was a movement to return to the "old normal.
Reference: Cabinet Secretariat, Advisory Council on the Use of IT in the New Normal Era: Advisory Council on the Use of IT in the New Normal Era Final Report, 2020

(原題)内閣官房ニューノーマル時代のＩＴの活用に関する懇談会:ニューノーマル時代の IT の活用に関する懇談会　最終報告書,2020

(11) Facilitator

In the narrowest sense, it means "a person who works to make a meeting effective, who facilitates the smooth running of the meeting, and who manages the process of proceedings." In the broadest sense, it means "a person who works to support and facilitate an organization's creation, change, problem-solving, consensus building, and learning while creating opportunities for knowledge creation of all kinds and facilitating the process of such creation. A person who promotes the process.

Reference: NPO Japan Facilitation Association,
https://www.faj.or.jp/facilitation/application/ (Japanese)

A catalytic presence that combines the functions of moderator, problem-solving facilitator, and expert advisor in the field.

Reference: Science Council of Japan, Committee on International Cooperation for Promoting Science-Based Disaster Risk Reduction: Recommendation " Building a sustainable global society by strengthening disaster resilience: Developing an "Online Synthesis System (OSS)" and fostering "Facilitators" to realize consilience, 2020.

(12) Planetary health

Planetary health is a nascent concept focused on the interdependence of human health, animal health, and the health of the environment. Defined as the health of human civilization and the state of the natural systems on which it depends, planetary health calls urgent attention to the extensive degradation of our planet for human advancement. The concept focuses on reversing this trend by better balancing human needs with the preservation of the Earth to sustain the health and well-being of future generations. To accomplish this will require a multidisciplinary, cross-sector, and trans-border approach to change mindsets and behaviors at every level, from global to local.

Reference: The Rockefeller Foundation Planetary Health 101; Conversations on Planetary Health, 2017

1) The concept of planetary health is based on the understanding that human health and civilization depend on thriving natural systems and wise management of those natural systems. However, natural systems are more degraded than ever before in human history.
2) Environmental threats to human health and civilization are characterized by surprise and uncertainty. Our societies face clear and powerful dangers that require urgent and transformative action to protect present and future generations.
3) Current governance systems and the organization of human knowledge are inadequate to address threats to planetary health. We seek to improve governance to support integrating social, economic, and environmental policies and creating, integrating, and applying interdisciplinary knowledge to strengthen planetary health.
4) Solutions are within reach and should be based on a redefinition of prosperity that focuses on improving the quality of life and health for all while respecting the integrity of natural systems. For this purpose, societies must take initiatives to address the drivers of environmental change by promoting sustainable and equitable consumption patterns, controlling population growth, and harnessing the power of technology for transformation.

Reference: Sarah Whitmee 他：Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health, Lancet 386, 10007 (2015).

(13) Poisson process

A Poisson process can be thought of as a mathematical description of a phenomenon in which a random phenomenon is waiting to occur, such as waiting for a telephone call, where the course of events before a specific point in time does not affect future occurrences, and the process is uniform in time. It is a stochastic process $X(t, w)$ $(t \geq 0)$ with a continuous time variable t, where $X(t+h)-X(t)$ is independent of the past X(s) (s<t) and follows a Poisson distribution with mean λh when the current time is t and h>0. Therefore, its sample function (which considers the number of observations as a function of t) is a monotonically non-decreasing staircase function with a jump of 1.

Reference: Heibonsha: The Encyclopedia, 2nd edition, Poisson process.

(14) Risk communication
Activities to share diverse information and perspectives through dialogue, co-consideration, and collaboration among various segments of society for more appropriate management of risk
(Source: Ministry of Education, Culture, Sports, Science and Technology, Committee on Safety, Security, Science, Technology and Social Cooperation: Measures to promote risk communication, 2014.

(15) Resilience
The concept of resilience, the ability to overcome hardship, was defined by the United Nations (UN) in 2009 by UNISDR (now UNDRR) in a glossary of terms [15]. In 2017, the UN General Assembly expanded the definition [16] as follows (underlining added in the 2017 definition).

"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."
(Source: UNISDR: 2009 UNISDR Terminology on Disaster Risk Reduction, 2009.
UNDRR: Terminology "Resilience,"
https://www.undrr.org/terminology/resilience

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https://www.mhlw.go.jp/stf/houdou/2r98520000014j2yimg/2r985200000167hm.pdf, 2011.3.24.
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<Reference 1>

Deliberation process

2021	
July 30	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 4th Meeting): Activity plan for the 25th term
October 21	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 5th meeting): Draft framework of recommendations
November 9	25th Term, 5th meeting, Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture: Reports from each WG
November 6	Public Symposium: "What is Resilience to Overcome National Disasters in the 21st Century: Strategies for Building Consilience for Disaster Risk Reduction "
December 25	25th term, 3rd meeting, Subcommittee on Social Contribution to Earth and Planetary Science, Committee on Earth and Planetary Science: "How to Ensure Resilience to Overcome National Disasters"
2022	
January 6	25th term, 6th meeting, Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture: Reports from each WG

March 3	Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 6th meeting): Draft framework of recommendations
March 8	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th term, 7th meeting): Reports from WGs
March 17	Committee on Civil Engineering and Architecture (25th Term, 8th meeting): Status of activities of committees and subcommittees
May 16	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th term, 9th meeting): Reports from each subcommittee
May 23	Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 8th meeting): "Expression of Interest" of IRDR Subcommittee
July 7	Academic Forum "How to Ensure Resilience to Overcome National Disasters," hosted by the Science Council of Japan and co-hosted by Committee on Civil Engineering and Architecture
August 2	Subcommittee on IRDR, Committee on Civil Engineering and Architecture, and Working Group on IRDR Activity Promotion (joint meeting) (25th period, 7th meeting): Draft framework of recommendations
August 8	Committee on Civil Engineering and Architecture (25th Term, 10th meeting): Reports from Working Group and Working Subcommittee
October 17	Advice from the Scientific Advice and Response Committee
October 22	Public Symposium "How to Ensure Resilience to Overcome National Disasters that are Expected to Occur in the First Half of the 21st Century," hosted by Subcommittee on IRDR, Committee on Civil Engineering and Architecture

November 1 Subcommittee on IRDR, Committee on Civil Engineering and Architecture, and Working Group on IRDR Activity Promotion (joint meeting) (25th Term, 8th meeting)
Recommendation matters
(1) Responses from the Committee on Response to Recommendations, etc.
(2) Deliberations by the Subcommittee on Advanced Infrastructure and the Subcommittee on Social Contribution, Committee on Earth and Planetary Science
(3) Holding of JHoP Responsible Persons Meeting
(4) Discussion on the framework of recommendations

December 15 Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 11th meeting): "Expression of Interest" of the IRDR Subcommittee

December 27 Subcommittee on Earth and Planetary Science Social Contribution, Committee on Earth and Planetary Science, (25th Term, 4th meeting): Discussion on the draft of Expression of Intention "How to Ensure Resilience to Overcome National Disasters."

2023

February 28 2023 Subcommittee on Advanced Infrastructure, Committee on Civil Engineering and Architecture (25th Term, 12th meeting)
Draft "Expression of Intention (Recommendation) " jointly signed by" Subcommittee on IRDR, Subcommittee on Advanced Infrastructure, and Subcommittee on Earth and Planetary Science Social Contribution, Committee on Earth and Planetary Science.

March 1 Subcommittee on IRDR, Committee on Civil Engineering and Architecture and Working Group on IRDR Activity Promotion (joint meeting) I (25th term, 9th meeting)
(5) Domestic Component 3) Approval of Draft Recommendations related to Recommendations

August 29 Science Council of Japan Executive Committee Meeting (351st meeting)
Approved the recommendation "How to Ensure Resilience to Overcome Catastrophic Disasters."