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Proposal

Toward Realizing Energy Systems to Support Society5.0

(Ver.6)

June 17, 2024 Hitachi-UTokyo Lab

Proposal

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Appendices

Executive Summary

Since 2016, the Hitachi-UTokyo Lab Energy Project has been presenting proposals of visions and scenarios for energy systems.
Version 5 of the Proposal published in 2023 discussed three points; namely, “geopolitical changes,” “sustaining the global trend toward decarbonization,” and “national and regional circumstances related to energy.” In particular, discussions on the energy sector, such as the 6th Basic Energy Plan, which tackles the long-term energy supply and demand outlook for 2030, and the start of discussions on a global clean energy strategy, as well as developments in the environmental sector, such as ESG investment taking into account governance, and COP26, have been summarized to identify issues for achieving carbon neutrality (CN) by 2050 and the sustainability of society beyond 2050.
This document, Version 6 of the Proposal "Toward Realizing Energy Systems to Support Society 5.0,” comprehensively analyzes the changes from Version 5 and the various trends associated with those changes, discussing the issues and ways to address them.

Chapter 2: Changing global landscape and an integrated energy transition

Through an analysis of the international landscape in terms of climate, energy, and the environment, the sixth edition of this proposal argues that energy-related transitions must be achieved in close connection with other agendas as the world faces complex crises such as climate change, loss of nature, and war. As for such an “integrated transition,” this edition points out the importance of unique local initiatives and the need for the government to support local government decision-making and human-resource development. Moreover, it explains that it is important for industry to invest in innovation and to transform its industrial structure in a manner that can achieve prosperity in the coming green economy. It also stresses that—against the backdrop of growing energy demand in the Asia-Pacific region—Japan should play a role in the framework for an integrated energy transition in the region. A variety of research institutes and social organizations have been making recommendations regarding Japan’s energy future, and Hitachi-UTokyo Lab has emphasized that it will provide materials that will contribute to promoting an integrated energy transition centered on energy while incorporating the perspectives of various actors in each sector and looking at the path to such a transition from multiple angles.

Chapter 3: The ideal form and growth strategies for energy systems that incorporate social and industrial reforms

After revising the energy scenarios in response to the increase in ICT demand at data centers, etc., we determined the necessity of carrying out the following measures by 2030 to realize the CN scenarios: (1) accelerate the introduction of renewable energy (88 GW of solar power generation and 15 GW of wind power generation) and secure decarbonized power sources such as operation of all existing nuclear power generation plants, (2) avoid waste in a short period of time from PV introduction and solve environmental issues in installation, (3) operate hydrogen and ammonia power generation exceeding 10 GW, (4) use of heat from fossil fuel power generation through cogeneration, and (5) ensure energy resilience and security during rare windless and continuous cloudy weather, fuel shortage, and disasters. Also, toward 2040-2050, innovation should be carried out by developing and investing in: (1) the further increase of CN power sources such as solar, wind, and nuclear power, (2) the commercialization and widespread adoption of CO_2 capture by DAC, and (3) the production of synthetic fuel from the captured CO_2 and its use in the transportation and industrial sectors. In addition, the issues and countermeasures for the bulk power system to deal with the rapid expansion of the amount of renewable energy introduced are discussed in consideration of the discussions in Version 5 of the Proposal.

Chapter 4: Contribution from the regions to balance CN and S+3E energy supply and demand

In Version 5, the demand adjustment potential created by local communities in 2030 was determined to be 33.2 TWh/year nationwide based on the results of quantitative evaluation. To actualize this potential, we presented examples of regional economic revitalization through local production and local consumption of renewable energy using digital technology and negative emissions that are in harmony with natural restoration leveraging regional characteristics. As a means for a social transition that balances the economy and the environment, an example for the use of environmental credits to maximize the use of renewable energy within the region based on energy cooperation and enable circulation within the region was presented. Likewise, as a measure to reduce CO2 storage volume, an example of blue carbon management by seaweed farming was shown.

Chapter 5: Seventeen recommendations "toward realizing energy systems to support Society 5.0"

On the basis of the above changes in energy transition in FY2023, we revised the 18 recommendations formulated in Version 5 and formulated 17 new recommendations.

Short Term

Chapter 2: Changing global landscape and integrated energy transition

1. Governance that accelerates integrated transition even in the face of rapid geopolitical change
2. Identification of pathways to innovation and structural transformation for a green economy
3. Promotion of international collaboration on climate, energy, and environment in the Asia-Pacific region
4. Decision-making frameworks and human-capital development for integrated transition in the region
5. Consensus-building platform based on scientific evidence and inclusive dialogue

Chapter 3: The ideal form and growth strategies for energy systems that incorporate social and industrial reforms

6. Review of energy scenarios in light of drastically changing global affairs
7. Backcasting and forecasting gaps and countermeasures for energy systems
8. The importance of medium- to long-term institutional design and measures beyond the short-term market principle
9. Rebuilding the electric power market and merging the environmental value market
10. Building social systems through the participation of local communities and consumers

Chapter 4: Contribution from the regions to balance CN and S+3E energy supply and demand

11. Contribution from the regions to balance CN and S+3E energy supply and demand
12. Measures to facilitate the transition of local communities
13. Objective analysis of social changes associated with CN and formulation of growth strategies
14. Development of negative emission technology in harmony with nature to expand transition options and their likelihood

Medium to long term

Chapter 2: Society based on the realization of carbon neutrality by 2050

15. Regional transition paths
16. Strategic industrial policies for the sustainable development of the regions

Chapters 3 and 4:Technical measures for energy systems

17. Countermeasure technologies for energy scenarios towards achieving carbon neutrality

Chapter 1 Introduction

The spike in fuel prices following the Russian invasion of Ukraine in February 2022 led to higher energy costs and higher prices for various related goods. Amidst the continuing conflict between Russia and Ukraine, the fuel supply chain in Europe, including that for liquefied natural gas, has undergone major changes, and fuel and electricity prices in the region have stabilized to some extent from the situation in the spring of 2022. On the other hand, the rapid growth of the ICT field as led by generative AI has given rise to concerns of a surge in future energy demand. Along with the rapid increase in information traffic from data centers, progress is also being made in making equipment and networks more efficient, but the future vision of energy consumption in the ICT field is becoming increasingly uncertain.

Japan will formulate the 7th Strategic Energy Plan in 2025, which will tackle issues and measures for achieving a balance between stable energy supply between 2035 and 2040 based on the greenhouse gas reduction target for 2030 and decarbonization and industrial growth. Further, Japan plans to submit its nationally determined contribution (NDC) to the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2025 to provide concrete action guidelines until 2035. Japan must consider national sustainability from a broad perspective other than the reduction of greenhouse gases.

The Hitachi-UTokyo Lab has been studying transition scenarios and energy system issues and countermeasures focusing on the regions in Japan to realize the energy transition. As a result, 18 recommendations were compiled in Version 5, focusing mainly on the short term up to 2030 and on the medium- to long-term looking ahead to 2040 to 2050. In Version 6, these 18 recommendations were reviewed from the perspective of the future vision of energy consumption in the ICT field and the balance of the environment and the economy in local communities, after outlining the current global landscape related to climate and energy. We have compiled these into 17 new recommendations. On the basis of the results of studies conducted by Hitachi-UTokyo Lab, which has expanded the scope of the study from electric power systems to energy systems in general, this Proposal describes in detail the study of energy systems and the process of coming up with the 17 recommendations that should be discussed with many stakeholders.

Chapter 2 Changing global landscape and integrated energy transition

2.1 Introduction

Since then-Prime Minister Suga declared in October 2020 that Japan would achieve carbon neutrality by 2050, Japan has rapidly implemented extensive decarbonization measures. In "expert interviews" conducted by Hitachi-UTokyo Lab, experts offered their thoughts on the changes that have occurred in the approximately three years since the declaration.

As for the public sector, the "Basic Energy Plan" and "Global Warming Countermeasures Plan" of the Japanese government have been given clear, long-term targets, and to promote emission reductions, important legal reforms have been made. At the same time, as for the energy sector, institutional arrangements such as the long-term decarbonized-power-source auction and a fossil-fuel levy have been implemented. And efforts to become carbon neutral (CN) are spreading rapidly among local governments.

As for the private sector, the decarbonization initiatives that had previously been led by global corporations have become mainstream. Currently, most of the major publicly traded companies in Japan have set a goal to become carbon neutral. In financial markets, environmental, social, and governance (ESG) investment has become a major trend, and in addition to information disclosure based on international standards set by the International Sustainability Standards Board (ISSB) and other bodies, mechanisms to promote the "greening" of business and energy transition, such as green bonds and transition finance, have been created.

As for the social sector, the growing awareness of the "Sustainable Development Goals" (SDGs) has increased the activities of citizen organizations involved in sustainability, which have become more influential on the activities of governments and corporations. Media coverage of environmental and energy issues, including climate change, is increasing, and public awareness is growing.

The expert interviews, however, also revealed that along with the above-described developments over the past few years, new challenges have emerged. Some examples of these challenges are listed as follows:

- How can Japan achieve both greening and a stable supply of energy?
- How can we invest agilely in the innovation that will support the green economy of the future?
- How do we achieve economic security, including securing critical minerals, in parallel with decarbonization efforts?
- How do we address environmental challenges other than climate change (such as biodiversity and chemical pollution)?
- How do we integrate climate and energy policies under the jurisdiction of different ministries?
- What kind of energy transition will be made in conjunction with the countries of the Global South?

In consideration of these new challenges, it is necessary to understand Japan's role in the global effort toward a sustainable world, identify the "next challenges" facing Japan's socio-technological transition, and understand the present state of the energy transition in the Asia-Pacific region and Japan's role in that transition.

2.2 Transition scenario envisioned by Hitachi-UTokyo Lab

Hitachi-UTokyo Lab aims to contribute to the challenge of achieving a multidimensional social transformation by creating a "transition scenario" (Figure 2.1) that outlines the path to achieving carbon neutrality in Japan. The aims of this transition scenario are twofold: (i) identify hidden challenges and important turning points by examining the process of long-term change toward carbon neutrality along multiple pathways and (ii) show how to achieve a fair and sustainable transition to carbon neutrality[1].

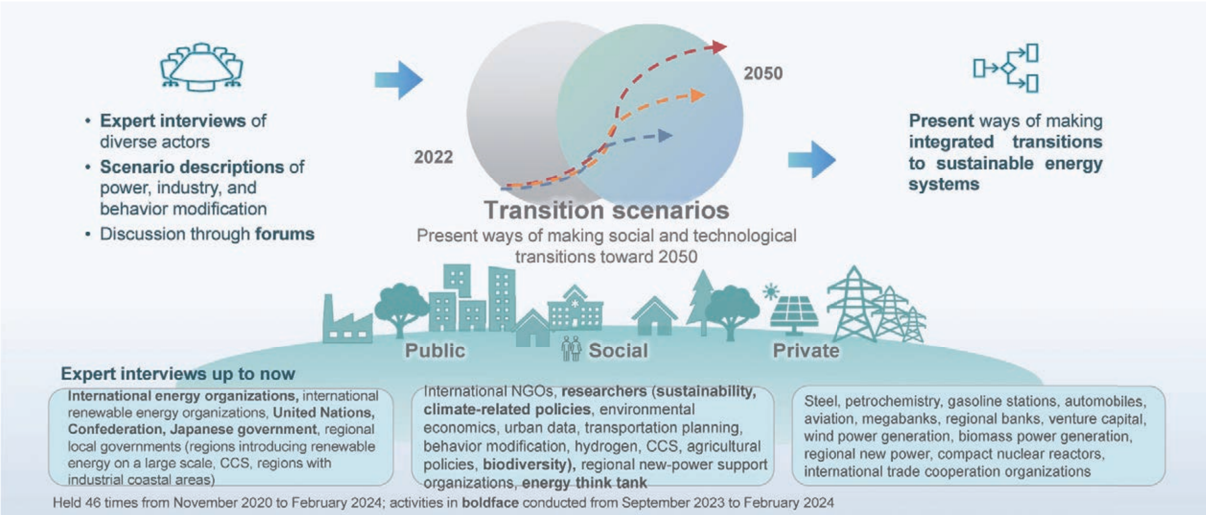


Figure 2.1 Socio-technical scenarios based on a transition model

Drawing on existing research and reports as well as knowledge gained from the interviews with experts and stakeholders from the public, private, and social sectors (Table 2.1), this study analyzes a variety of actors and qualitatively describes the path of long-term change from 2020 to 2050 in important domains of the decarbonization process. Specifically, it describes plausible developments of events involving relevant actors over two time periods, 2020-30 and 2030-50, for 12 domains categorized into three fields, i.e., electricity, industry, and behavioral change (Table 2.2).

The team in charge of research on transition scenarios at Hitachi-UTokyo Lab continues its research while sharing its research results with experts in various fields at the Industry-Academia Collaboration Forums and Closed Workshops convened by the Lab.

Table 2.1 Relevant fields of interviewed experts (FY2020-23)

Sector	Public	Social	Private
Affiliation	International energy organizations, international renewable energy organizations, United Nations, Confederation, Japanese government, regional local governments (regions introducing renewable energy on a large scale, potential CCS, regions with industrial coastal areas)	International NGOs, researchers (sustainability, climate-related policies, environmental economics, urban data, transportation planning, behavior modification, hydrogen, CCS, agricultural policies, biodiversity), regional new-power support organizations, energy think tanks	Steel, petrochemicals, gasoline stations, automobiles, aviation, megabanks, regional banks, venture capital, wind power generation, biomass power generation, regional new power, compact nuclear reactors, international trade cooperation organizations

Note: Hitachi-UTokyo Lab conducted a total of 44 expert interviews between 2020 and 2023 (13 in FY2020, 12 in FY2021, 13 in FY2022, and 8 in Fy2023).

1 The transition scenarios considered at Hitachi-UTokyo Lab are influenced by the way of thinking about change in socio-technical systems based on "Multi-level Perspective (MLP)" theory by Frank W. Geels proposed in Frank W. Geels. 2002. "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study," Research Policy 31, 1257–1274 and Frank W. Geels, et al. 2020. "Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050)." Technological Forecasting and Social Change, 151, 119258.

Table 2.2 Configuration of domains of transition scenarios

Category	Domain	Number of domains
Electricity	Coal-fired, gas-fired, solar, wind, hydroelectric/geothermal, biomass, nuclear, and hydrogen/ammonia	**8**
Industry	Iron and steel, transportation, and petrochemicals	**3**
Behavioral change	Behavioral change	**1**

In 2023, Hitachi-UTokyo Lab launched a new period of activities called "Phase 3," which built on our previous activities. Presently, along with the prolonged invasion of Ukraine by Russia and the escalation of multipolar conflicts around the world, the lack of climate-change countermeasures and ecological crises, including biodiversity, are recognized as serious issues. These issues are combining with the political importance of the Global South, the uneven progress of the digital economy, and Japan's slow industrial transformation to create conditions that will significantly affect Japan's energy transition. In response to those issues, in Phase 3, the research team working on transition scenarios redefined its mission and research agenda with the aim of clarifying Japan's transition strategy and role in the global transition that will allow Japan to prosper within the "planetary boundaries"[2] (Table 2.3).

Table 2.3 Missions and research topics for SWG3 Phase 3

<table>
<tr><td>Mission</td><td colspan="2">To clarify Japan's transition strategy and Japan's role in the global transition that will ensure Japan's prosperity within the planetary boundaries.</td></tr>
<tr><td rowspan="2">Research topic</td><td>I. Transition in Japan</td><td>· A vision of governance for accelerating the transition of Japanese cities and regions
· An integrated framework for removing barriers to the restructuring of Japanese industries</td></tr>
<tr><td>II. Japan's role in global transition</td><td>· Supply security and economic security
· Japan's role in global just transitions</td></tr>
</table>

2 The Global Environmental Boundaries (GEF) are the limits that must be maintained to ensure the safety of human existence in relation to the impact of human activities on various aspects of the global environment. According to a 2023 study, safe levels of the nine boundaries have been exceeded in six areas, including biodiversity conservation and the nitrogen and phosphorus cycles. Stockholm Resilience Centre. 2023. "Planetary boundaries," https://www.stockholmresilience.org/research/planetary-boundaries.html, Accessed on April 15, 2024.

2.3 Climate, energy, and environmental landscapes

If we look at the circumstances surrounding the global climate, energy, and the environment over the past few years, it has become clear that the energy transition in Japan is closely linked to a number of serious sustainability issues and cannot be achieved by focusing solely on energy. In particular, the highly prioritized conditions outlined by the planetary boundaries, namely, avoiding a multidimensional global environmental crisis and achieving sustainable development, are about to affect the pathways of energy transition in Japan significantly. To understand the current status of efforts concerning carbon neutrality in Japan, Hitachi-UTokyo Lab seeks to gain insights into the transition in Japan while understanding the macro-level changes in climate, energy, and the environment over the past few years.

In the research of planetary boundaries, climate change is a critical issue, but it is not the only one. Biodiversity loss is a significant challenge that requires urgent action. Human activities are causing a rapid decline in species, leading to what is termed the “sixth mass extinction[3]. It is increasingly clear that this loss of nature has serious consequences for human activities, including the economy.

To overcome this situation, the Kunming-Montreal Global Biodiversity Framework was adopted at COP15 of the Convention on Biological Diversity, held in December 2022. The framework set out a “World in harmony with nature” as the vision for 2050 and stipulated that urgent action be taken to halt nature loss and change course to nature recovery by 2030[4]. Moreover, preparations to establish a new international legal framework to regulate serious pollution by plastics, based on a draft resolution at the Environment Assembly of the United Nations Environment Programme in 2022, are currently underway[5].

Meanwhile, the need to address climate change around the world is becoming more urgent. According to the World Meteorological Organization’s (WMO) “State of the Global Climate,” 2023 was the hottest year on record; namely, the global average temperature in 2023 increased by 1.45 degrees Celsius compared to that in pre-industrial times[6]. This increase is a significant deviation from the previous record highs of 2016 and 2022. What’s more, ocean heating, acidification, and rising water levels, melting of Antarctic sea ice, and glacial retreat are at historic highs[7].

The critical situation regarding climate change suggests once again that greenhouse gases are not being reduced across the globe at a fast enough rate. According to the WMO report, concentrations of the three major greenhouse gases (i.e., carbon dioxide, methane, and nitrous oxide) in the Earth’s atmosphere reached their highest levels ever recorded in 2022, and real-time measurements of those gases from various regions continued to increase into 2023[8].

Atmospheric carbon dioxide has a long lifespan, and as CO_2 emissions continue to increase, long-term increases in global temperature are expected to continue. Serious risks from rising average global temperature—causing serious harm to people’s lives—are already becoming apparent. The AR6 Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC), published in 2023, warned that options for “climate-resilient development” are diminishing over time and that the window of opportunity for such development is rapidly closing[9].

3 Ceballos, Gerardo, et al. 2015. “Accelerated modern human-induced species losses: Entering the sixth mass extinction,” *Science Advances* 1(5), https://www.science.org/doi/10.1126/sciadv.1400253, Accessed on April 15, 2024.

4 UN Convention on Biological Diversity. “2050 Vision and 2030 Mission”, https://www.cbd.int/gbf, accessed Mar 22, 2024.

5 Environment Assembly of the United Nations Environment Programme. 2022. “Resolution adopted by the United Nations Environment Assembly on 2 March 2022,” https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/39764/END%20PLASTIC%20POLLUTION%20-%20TOWARDS%20AN%20INTERNATIONAL%20LEGALLY%20BINDING%20INSTRUMENT%20-%20English.pdf?sequence=1&isAllowed=y, Accessed on April 14, 2024.

6 World Meteorological Organization (WMO). 2024. “Climate change indicators reached record levels in 2023: WMO,” 19 March, https://wmo.int/news/media-centre/climate-change-indicators-reached-record-levels-2023-wmo, Accessed on March 22, 2024.

7 WMO. 2024. “Climate change indicators reached record levels in 2023: WMO.”

8 WMO. 2024. “Climate change indicators reached record levels in 2023: WMO.”

9 Intergovernmental Panel on Climate Change (IPCC). “Headline Statements” in “AR6 Synthesis Report,” https://www.ipcc.ch/report/ar6/syr/resources/spm-headline-statements/, Accessed Mar 22, 2024

While these climate, energy, and environmental issues have global implications, their causes and countermeasures must be based on an awareness of the uneven state of economic development and natural destruction around the world. As reiterated in a document released by the G20 Energy Ministers Meeting held in Goa, India in 2023, emerging and developing countries are currently under pressure to ensure energy access and transition to clean energy simultaneously while facing serious climate disasters[10].

In the past, the viewpoints of developed countries in the Northern Hemisphere, including Japan, have had a stronger influence on climate-change measures owing to their economic power. However, it has been pointed out once again that climate change cannot be tackled solely by countries that have completed an accelerated period of economic development; in other words, climate-change measures must be consistent with the unique circumstances and development policies of countries in the South, namely, the "Global South." The injustice that has arisen between countries and companies in the North—which have benefited economically from historic emissions and environmental exploitation—and countries in the South—which continue to bear the increasing burden of climate disasters and environmental pollution—is a challenge that must be considered in climate-change measures. Japan's energy transition must therefore be coordinated with the efforts of other countries in the Asia-Pacific region.

The situation encompassing the global climate, energy, and the environment is intertwined with major issues facing our world today, namely, sustainability and digital technologies. In particular, serious global geopolitical and security risks that have arisen over the past few years have cast a shadow over global efforts towards sustainability. In the Global Sustainable Development Report (GSDR), an interim report on the United Nations 2030 Agenda for the Sustainable Development Goals, released in 2023, pointed out that global efforts toward sustainable development have been severely affected by the combined impacts of the COVID-19 pandemic, economic turmoil, climate-related disasters, and wars that have occurred over the past few years[11]. The report recommends actions and investments to drive science-based transformation that will overcome these crises. Energy transition in Japan also requires an integrated approach that focuses on the interconnectedness of efforts in other areas concerning sustainability.

Currently developing rapidly, digital technology is expected to play a key role in addressing the above-described issues. It is believed that innovation in digital technology can contribute to energy efficiency and emission reductions in various fields. However, it must be noted that the exponential expansion of digital technology itself could significantly increase the burden on the global environment.

Held in October 2023, the Internet Governance Forum (IGF) featured numerous sessions involving a wide range of discussions and proposals on the relationship between digital technology, sustainability, and the global environment[12]. At the IGF, it was noted that while digital technologies have the potential to contribute significantly to sustainability, including in regard to climate change and biodiversity, the expansion of the Internet and related technologies such as artificial intelligence (AI), the Internet of Things (IoT), electric vehicles (EVs), and self-driving mobility will increase -computational power consumption and increase energy demand. Moreover, the energy consumption associated with electronic devices, data centers, and communication networks—as well as the processes involved in manufacturing and disposing of electronic devices—can lead to increased energy consumption and carbon emissions. On top of that, hazardous chemicals and electronic waste ("e-waste") are a concern because they are not properly managed, especially in developing countries.

Focusing on the above-described situation, the IGF discussed the following measures: (i) the need for energy-efficient algorithms and ecosystem-friendly hardware, (ii) policies for increasing corporate transparency regarding the environmental impact of digital services, (iii) reducing the risks to energy fairness caused by digital technology, and (iv) the need to integrate ecological sustainability into the design process. In today's world, where innovation and the spread of digital technology are advancing exponentially, it is urgent to understand the environmental footprint of digital technology accurately and address it through a wide range of stakeholders.

Chapter 3 of this proposal provides a more detailed analysis of the impact the above-described challenges will have on Japan's electricity supply and demand.

As described above, in today's world, climate change and other issues related to the global environment are creating multiple crises, which are, in turn, causing a serious setback in efforts to build a sustainable world. While digital

10 G20 Research Group. 2023. "Outcome Document and Chair's Summary," G20 Energy Ministers Meetings, Goa, India, July 22. http://www.g20.utoronto.ca/2023/230722-energy.html, Accessed on March 22, 2024.

11 Department of Economic and Social Affairs, UN. 2023. The Global Sustainable Development Report (GSDR) 2023, https://sdgs.un.org/gsdr/gsdr2023, Accessed on March 22, 2024.

12 Internet Governance Forum (IGF). 2023. "IGF 2023 Reports," https://www.intgovforum.org/en/igf-2023-reports?field_theme_copy_target_id%5B%5D=2843&sort_by=changed_1&sort_order=DESC&feed_me=, Accessed on March 22, 2024.

technologies such as AI are expected to play an important role in various fields, including the energy sector, the impact of their rapid spread on the global environment is a growing concern. This situation shows that measures to combat climate change should be implemented while not only addressing environmental issues such as biodiversity loss but also achieving sustainability goals such as regional revitalization, industrial transformation, and gender equality. It can therefore be said that Japan's energy transition should be achieved through an integrated approach coordinated with transitions in other areas.

2.4 Next challenges concerning socio-technological transition in Japan

Given the global landscape discussed so far, how can we understand the state of transition in Japan over the past few years and the current pressing challenges? Based on the ongoing research at Hitachi-UTokyo Lab, this article will provide some insight into key challenges in the public, private, and social sectors while mentioning government environmental policies, local conditions, changes in Japanese industry, and recommendations from domestic research institutes.

2.4.1 Governance, decision-making, and talent needed for integrated transition

Since then-Prime Minister Suga's declaration in 2020, Japan's climate-change measures have made rapid progress across various sectors; however, a new approach to governance is needed if Japan is to achieve its climate, energy, and environmental goals alongside other policy priorities.

Japan's climate-change measures cover a wide range of fields. Even if the government's climate "mitigation" efforts only are focused on, it is clear that they require cooperation in a variety of areas covering energy, industry, agriculture and forestry, ecosystems, land use, and transportation. Moreover, efforts to link climate-change measures to a green economy are closely related to sustainable transformation in a wide range of areas covering diplomacy, resources, labor, consumption, finance, local government, and education.

Currently, Japan does not have a governance organization that can promote large-scale, long-term efforts in these broad areas comprehensively and thereby help Japan achieve its goal of carbon neutrality by 2050. However, individual efforts by existing policy actors may not necessarily be effective in planning and execution of those efforts. In particular, it might be necessary to establish an integrated governance mechanism for effective and sustainable science-based policy formulation and monitoring-based evaluation of each actor's independent transition to carbon neutrality and a green economy.

In particular, as research on the planetary boundaries has made clear, the global-environmental crisis is occurring in many different ways, including not only climate change but also loss of biodiversity and pollution from new chemicals (including plastics), nitrogen, and phosphorus. For example, it is known that the loss of biodiversity weakens the ability of humans to adapt to climate change[13].

As already discussed, in Japan, "GX" (green transformation)-related policies are limited to concerns around decarbonizing energy and industry, rather than policies concerning the natural environment as a whole, and they are currently primarily implemented by the Ministry of Economy, Trade and Industry. On the contrary, measures related to biodiversity have traditionally been under the jurisdiction of the Ministry of the Environment. In Japan, as a basic plan for the conservation and sustainable use of biodiversity in accordance with the Kunming-Montreal Biodiversity Framework, the National Biodiversity Strategy 2023-2030, sets the goal of "Nature Positive" (i.e., nature revitalization) by 2030[14]. Until now, policies to address issues related to climate change and the natural environment have been developed as separate issues. However, each aspect of the natural environment, including climate change and biodiversity, are closely linked[15], and it is important to take an approach that integrates decarbonization efforts with efforts to restore nature and move toward a circular economy while comprehensively

13 Stockholm Resilience Centre. 2023. "Planetary boundaries," https://www.stockholmresilience.org/research/planetary-boundaries.html, Accessed on April 15, 2024.

14 Ministry of the Environment. 2023. "Cabinet Decision on the 'National Biodiversity Strategy 2023-2030'" March 31, https://www.env.go.jp/press/press_01379.html, accessed April 15, 2024.

15 Pörtner, H. O., et al. 2021. Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change. IPBES secretariat, Bonn.

understanding the synergies and trade-offs in each area.

Local communities are crucial agents for concrete efforts toward an integrated transition in Japan. Local units such as prefectures, cities, towns and villages have their own distinctive social and economic structures based on their own unique natural and historical conditions. In them, actors from the public, private, and social sectors are closely linked and engage in interdependent activities. Meanwhile, many regions in Japan today are facing a declining population and loss of existing industries as well as the associated challenges in terms of finances and the welfare of residents. As a result, achieving an energy transition at the national level cannot be separated from achieving sustainable development and the well-being of residents through decarbonization and a green economy at the local level.

For regions formed on various scales to achieve long-term, multidimensional transitions under unique conditions, support for local governments and other diverse actors will be necessary. In Japan, government support for local governments has been provided under programs such as "Environmental Model Cities[16]," "Environmental Future Cities," "SDG Future Cities[17]," "Decarbonization Leading Regions," and "Model Cities for Solving Local SDG Issues[18]". For example, the Decarbonization Leading Regions program will support more than 100 regions that are trying to align their efforts with Japan's 2030 carbon-reduction targets while targeting the goal of creating a "decarbonization domino" that will spread their efforts and impacts to other regions[19]. Although the above-described government initiatives currently have different emphases, more-effective regional development could be achieved by supporting efforts that integrate decarbonization efforts with diverse environmental-challenge areas and related sustainability issues.

The Hitachi-UTokyo Lab has previously conducted research on several regions that focus on large-scale introduction of renewable energy, local production, and consumption of energy, the transformation of large-scale industrial clusters, and urban development that treats forests as common assets. The interviewees have provided opinions on governance and decision-making concerning regional revitalization based on energy transition. Their opinions can be summarized as the following four key points. First, local governments are expected to develop specific pathways to decarbonization and a green economy tailored to local conditions and to follow them over the long term. They must therefore secure human resources who are deeply committed to the unique natural environment and social context and able to connect with external actors, resources, and knowledge to implement new initiatives. Second, they mentioned the usefulness of using scientific methods to analyze the initiatives of each region that have developed under different conditions and capabilities and to share practical knowledge with each region. Third, local governments and regional actors suggested the need for closer collaboration between central and local governments to achieve decarbonization and greening of the economy together in a way that overcomes possible discrepancies between their own initiatives and government decision-making. Fourth, central government ministries and agencies were called upon to make decisions not only with those involved in the old energy system but also with a variety of actors who have been largely ignored in energy debates in the past.

The Japanese government is expected to support mechanisms for local governments to attract talent who are rooted in the local context while bringing in specialist skills and knowledge to drive the transition. Rather than just allocating policy funds, it is also expected to work to strengthen capacity to plan and implement new projects related to the integrated transition. In addition, the government is being called on to aim for integrated decision-making in areas related to climate, the environment, and energy through the participation of a wide range of actors. It is also important that the government supports regional and municipal efforts through scientific analysis and evaluation of local conditions and policies.

16 According to the Cabinet Office, a "FutureCity" is a city that "challenges common issues, such as the environment and aging, for all of humanity," and an "Eco-Model City" is a city that "sets lofty goals and takes on pioneering initiatives to create a low-carbon society that will concretely and clearly show the low-carbon society that Japan should aim for in the future." The government selects and subsidizes each of these cities. Cabinet Office Regional Revitalization Promotion Office. 2020. "What is the 'Eco-City' Concept?", https://future-city.go.jp/about/, accessed April 15, 2024.

17 According to the Cabinet Office, "SDGs Future Cities" are cities with "outstanding efforts by local governments to achieve the SDGs," and the government selects and subsidizes these cities. Cabinet Office, Office for Regional Development. 2020. "Selection of 'SDGs Future Cities' and Other Cities", https://www.chisou.go.jp/tiiki/kankyo/teian/pdf/result01.pdf, accessed April 15, 2024.2024.

18 According to the Cabinet Office, the purpose of the "Model Cities for Solving Local SDG Issues" is to "support small municipalities with limited human resources and expertise in utilizing human resources with experience and knowledge in regional revitalization, implement advanced and trial solutions to urgent and serious regional issues common to small municipalities, and promote regional revitalization and sustainable urban development in line with the principles of the SDGs by publicizing the plans and results of the solutions," and the government selects and subsidizes such cities. Cabinet Office Regional Revitalization Promotion Office. 2024.

19 "Regional Revitalization SDGs Problem-Solving Model City Call for Applications", https://www.chisou.go.jp/tiiki/kankyo/2024sesaku/11_bosyuuyouryou.pdf, accessed April 12, 2024.

2.4.2 Progress in Japanese industry and challenges to overcome

As previously mentioned, since the 2050 Carbon Neutrality Declaration was announced by then-Prime Minister Suga in 2020, Japanese industry has been rapidly promoting measures related to decarbonization. Decarbonizing the energy sector as well as hard-to-abate sectors is a key factor in not only mitigating climate change but also transitioning Japan to a green economy in the future.

Each industry association has developed its own vision and scenario to reduce greenhouse-gas emissions and develop innovative technologies. In 2021, The Japan Business Federation (Keidanren) established the "Keidanren Carbon Neutral Action Plan," which promotes "reducing emissions from domestic business activities," "strengthening inter-agency cooperation," "promoting international contributions," and "developing innovative technologies."

Keidanren reports on the progress of each industry association in accordance with its action plan (Table 2.4). Its November 2023 report indicated that 42 industries, or about 70% of all participating industries, have developed a vision for carbon neutrality[20].This proportion represents 97% of the emissions of all industries. According to this report, total CO_2 emissions from all sectors in 2022 was approximately 4.3 billion tons, a decrease of 3.5% from the previous year and 20.1% from 2013. In the industrial sector, CO_2 emissions were reduced by 6.3% compared to the previous year and by 20.6% compared to 2013; however, in other sectors, CO_2 emissions increased compared to the previous year. The report stated that these reductions are due to changes in economic activity, switching to low-carbon energy, and energy-conservation efforts.

Major industry associations affiliated with Keidanren have reported on their multifaceted efforts toward carbon neutrality. Many carbon-intensive industries are promoting the introduction of renewable energy and reducing CO_2 emissions by recovering and using exhaust heat and by-product gases generated during manufacturing and fuel use. They are also reducing emissions in the value chain of their businesses, including procurement, provision of products and services, specifications, and disposal, and they are actively disseminating information about products and services that contribute to reducing emissions while quantifying the amount of reduction. Many industries have also contributed to reducing global emissions by transferring technology overseas and disseminating products and services as well as by working to reduce emissions overseas

Table 2.4 Visions of various industries for achieving carbon neutrality in 2050

Sector	Industry	Vision (basic policy, etc.)
Energy transition	Power	While pursuing an energy mix that achieves the S+3E goals simultaneously, the public and private power sectors will continue to work on two pillars: "low-carbonizing and decarbonizing electricity" and "promoting electrification," such as making maximum use of established decarbonized power sources (nuclear and renewable energy) and utilizing heat pumps. At the same time, they will work together with the government to commercialize innovative technologies (small modular reactors, next-generation solar power, storage batteries, hydrogen and ammonia power generation, CCUS/carbon recycling, etc.) through "innovation" to solve issues aimed at further enhancing electricity-supply services.
	Oil	By accelerating efforts to decarbonize supply chains and products and engaging in research and development and social implementation of innovative decarbonization technologies that can utilize existing infrastructure (CO_2-free hydrogen, synthetic fuels, and carbon capture/storage and carbon capture/utilization (CCS/CCU) (carbon recycling), etc.), the oil industry aims to achieve net-zero (carbon neutrality) CO_2 emissions (Scopes 1 + 2) associated with its business activities. Moreover, by striving to achieve net- zero (carbon neutrality) CO_2 emissions (Scope 3) associated with the products we supply, the industry will contribute to the realization of CN throughout society.
	Gas	Under the policy of aiming for carbon neutrality of gas production, the gas industry will work on thorough shift to natural gas, advanced utilization of natural gas, decarbonization of gas itself (e.g., utilization e-methane and hydrogen), and technological development related to CCS/CCU.

20 Japan Business Federation (Keidanren). 2024. "Keidanren Carbon Neutral Action Plan: Vision for Carbon Neutrality in 2050 and Key Points regarding FY2023 Follow-up Results (FY2022 Actual Results) [Final Version]," https://www.keidanren.or.jp/policy/2023/072_gaiyo.pdf, accessed April 15, 2024.

Industry	**Steel**	To achieve carbon neutrality, the steel industry will work in a multifaceted manner by combining all possible means, such as expanding the use of scrap, in addition to the challenge of developing ultra-innovative technologies, such as “drastic CO_2 reduction in blast furnaces using COURSE50 and ferro coke + CCUS” and “hydrogen-reduction steelmaking.”
	Chemicals	Under the policy of promoting and accelerating the creation of innovations that contribute to solving global problems and to the growth of a sustainable society by unveiling the potential of “chemistry,” the chemicals industry will work on carbon recycling of raw materials (such as the use of CO_2 as a raw material and waste plastics), process and structural transformation to minimize energy use (such as membrane-separation processes), and other initiatives.
	Cement	The cement industry’s goals are threefold: (i) reducing the clinker/cement ratio to reduce emissions in the clinker manufacturing process, (ii) expanding the use of alternative waste materials including biomass and reducing carbon emissions through future co-firing of hydrogen and ammonia, and (iii) developing carbon capture, utilization, and storage (CCUS) technologies such as a manufacturing process for efficient CO_2 capture and mineralization using the captured CO_2.
	Paper Manufacturing	The paper-manufacturing industry will promote energy conservation and fuel switching in production activities (active introduction of energy-saving equipment and technologies), expand the use of renewable energy, and develop innovative technologies (e.g., highly efficient pulp-manufacturing methods). Moreover, as for a unique initiative, it will reduce CO_2 emissions over the life cycle through the development and use of environmentally friendly materials derived from woody biomass (cellulose nanofiber, etc.) and expand contribution as a CO_2sink through afforestation.
	Electrical and Electronics	In accordance with a policy of contributing to the resolution of social issues related to climate change and energy constraints through the various business fields of each company from the perspectives of “technology development,” “co-creation/collaborative creation,” and “resilience,” the electrical and electronics industry will work to implement next-generation energy-saving and decarbonization-technology innovations (smart grids, water-electrolysis hydrogen production, power semiconductors, quick charging/wireless charging, etc.) and advanced information-utilization solutions (automatic-driving support systems, smart factories, high-precision weather observation, etc.).
Transport-related	**Automotive**	The automotive industry will promote the popularization of electric vehicles (HVs, PHVs, EVs, FCVs, etc.) and the creation of a hydrogen society (expansion of fuel-cell mobility, etc.), etc.
	Maritime	The maritime industry will promote conversion to zero-emission vessels using new fuels such as carbon-recycled methane, ammonia, and hydrogen.
	Railways	To achieve net zero CO_2 emissions in all phases of the energy cycle, from energy production to energy use, the railways industry will strive to accelerate the development and introduction of renewable-energy sources, deploy battery-powered trains, and develop fuel-cell trains.
	Real estate and buildings	In a society where carbon neutrality has been achieved in 2050, it is assumed that “energy-saving and renewable energy-conscious buildings, including zero-emission buildings (ZEB) and zero-emission houses (ZEH),” “buildings that use building materials with low environmental impact,” and “towns that combine renewable-energy equipment, storage batteries, energy interchange, etc. to reduce CO_2 emissions throughout regions” will be widespread, and the industry will contribute to this trend through initiatives such as ZEB/ZEH conversion and using home energy-management systems/building energy-management systems (HEMS/BEMS) for individual buildings, and zero-emission technology (ZET) conversion and Community Energy Management System (CEMS) for entire towns.

Source: Nippon Keidanren. 2023. “Keidanren Carbon Neutral Action Plan: Vision Toward Carbon Neutrality in 2050 and FY2023 Follow-up Results (FY2022 Records),” https://www.keidanren.or.jp/policy/2023/072_gaiyo.pdf, accessed March 22, 2024.

and disseminating products and services as well as by working to reduce emissions overseas through international contributions[21]. Furthermore, each industry recognizes that innovation plays an important role in significantly cutting carbon emissions, and in regard to medium- to long-term research and development, which cannot easily succeed through the private sector alone, Keidanren says it will "continue to work in cooperation with the government."

Several major industry groups[22] reviewed by Hitachi-UTokyo Lab cited the following initiatives for which government support is needed to achieve carbon neutrality: improving the environment related to systems and production bases, providing support through economic systems such as finances, tax systems, and price compensation, sharing the burden of costs associated with initiatives shared by society as a whole, and establishing new financial methods and a grand design.

The Japanese government is implementing its own policies related to “green transformation (GX),” including the cabinet decision on the “Basic Policy for Achieving GX” in February 2023 and the enactment of the “GX Promotion Act” and the “GX Decarbonized Power Source Act.” It aims to “shift the fossil energy-centered industrial and social structure to a clean-energy-centered one,” and this shift is regarded as a “major shift in industrial and energy policy in the postwar period”[23]. Against the background of the need to respond to the energy crisis exacerbated by Russia’s invasion of Ukraine in 2022, the government is promoting GX through concrete policy initiatives such as the following: (i) decarbonization efforts toward GX based on the premise of securing a stable energy supply; (ii) realization and implementation of the "growth-oriented carbon-pricing concept"; (iii) an international development strategy; (iv) promotion of GX throughout society; and (v) evaluation of the progress of implementation of new policy initiatives to achieve GX. The “Basic Policies for Realization of GX” call for supporting upfront investments of 20 trillion yen over the next 10 years, and through the use of new financial instruments, the public and private sectors will work together to implement more than 150 trillion yen in GX investments over the next 10 years[24]. At present, the government’s GX-related policies are in the planning stage, and it is difficult to evaluate their impact on each industry accurately. However, in the expert interviews, comparing those policies with the preceding the EU Green Deal and the US Inflation Reduction Act (IRA), the interviewees stressed the need for selective innovation support with an eye to Japan’s future industrial competitiveness as well as the need to accelerate efforts in accordance with short-term, medium-term, and long-term timelines.

In particular, they expressed the opinion that such industry-specific initiatives and GX policies require ongoing analysis in terms of the following three points: first, whether the GX-related policies and investments being implemented in a wide range of fields are paving the way for prosperity in a green economy in Japan; second, whether the necessary transformation of Japan’s industrial structures is being appropriately promoted by cooperation between the government and companies; third, whether the effects of GX-related policies, including nature regeneration in local areas and labor advancement, are being evaluated and verified through scientific analysis.

In fact, the UN’s Principles for Responsible Investment (PRI) has expressed concerns about the GX Policy announced by the Japanese government in terms of its consistency with the implementation of the Paris Agreement[25]. The PRI points out that Japan’s GX Policy “does not contain sufficient information to clarify how it and related policies will enable the economic transition necessary to achieve the goals of the Paris Agreement and address the interconnected energy and climate crises,” and that “it does not include a strategy on how to decarbonize the power sector by 2035, and the proposed energy mix still has a large share of fossil fuels.” The PRI also recommends that the Japanese government ensure greater transparency and coordination among relevant ministries and agencies regarding “the current assumptions that underpin the GX Policy to ensure consistency with the net-zero target by 2050” in preparation for the submission of the NDC scheduled for 2025 and the publication of the

21 Japan Business Federation. 2024. “Keidanren Carbon Neutral Action Plan”

22 Hitachi UTokyo Lab conducted a simple analysis of reports from the following industry groups: Japan Business Federation. “Vision for Carbon Neutrality in 2050 and 2023 Follow-up Results” November 2023; Japan Iron and Steel Federation. “Carbon Neutral Action Plan Report” February 2023; Japan Automobile Manufacturers Association. “2050 Carbon Neutral Scenario” September 2022; Japan Cement Association. “Long-term Vision of the Cement Industry Aiming for Carbon Neutrality” Revised March 2022; Japan Chemical Industry Association. “Chemical Industry’s Stance on Carbon Neutrality” May 2021; Japan Gas Association. “Bon Neutral Challenge 2050” 2021;
Petroleum Association of Japan. “Vision for Carbon Neutrality in the Oil Industry” 2021; Federation of Electric Power Companies. “Efforts by Electric Power Companies to Achieve Carbon Neutrality in 2050” February 2022.

23 Ministry of Economy, Trade and Industry. 2022. “Basic Policy for Realizing GX: Roadmap for the Next 10 Years,” https://www.meti.go.jp/press/2022/02/20230210002/20230210002_1.pdf, accessed April 11, 2024.

24 Manufacturing Industries Bureau, Ministry of Economy, Trade and Industry. 2023. “Sector-specific investment strategies for realizing GX,” https://www.meti.go.jp/shingikai/sankoshin/seizo_sangyo/pdf/015_02_00.pdf, accessed April 15, 2024.

25 Principles for Responsible Investment. 2023. “Achieving Net Zero in Japan: Policy Imperatives and Investor Priorities”, accessed April 25, 2024.

7th Strategic Energy Plan in 2024.

In Japan, it is necessary to disseminate a decarbonization vision and roadmap that is consistent with the Paris Agreement while investing in innovation that will contribute to building the next generation of industrial structure.

2.4.3 Scenarios and visions presented by domestic think tanks

Hitachi-UTokyo Lab has also been investigating the major climate, energy, and environment scenarios and proposals published by research institutes in Japan since then-Prime Minister Suga's declaration in 2020. Although further detailed study of these documents is needed, comparative analysis of the arguments presented by the various institutes in their context may enable a critical understanding of the various options for possible pathways for Japan today.

Major scenarios and recommendations issued by these research institutes in Japan since 2020 generally agree on the need for decarbonization of the entire country's industries as a measure against climate change. However, the scenarios and recommendations issued by each organization tend to reflect different historical backgrounds, social attributes, and interests (Table 2.5). For example, the Institute of Energy Economics, Japan, which was established in the 1960s, places emphasis on quantitative analysis regarding oil, gas, and electricity, and it has published many papers based on economic analysis of fossil-energy trends that highlight the importance of stable fossil-fuel supplies and negative-emission technologies to achieve carbon neutrality[26]. In contrast, the Renewable Energy Institute, which was established by major companies in the communications and digital fields following the Great East Japan Earthquake and the Fukushima Daiichi Nuclear Power Plant accident in 2011, has proposed measures to increase the proportion of renewable energy to 80% or more by 2035[27].

Unlike the above-mentioned proposals, proposals to discuss energy from a broader perspective, while still based on concern for energy, have been put forward. For instance, the Nikkei Decarbonization Project, organized by the Nikkei Shimbun newspaper, includes a committee of climate-policy experts, UN finance advisors, and many people involved in ESG finance as well as major domestic and international companies from a wide range of industries, including

Table 2.5 Major recommendations and overview concerning energy transition in Japan

Organization	Main document	Key points
Institute of Energy Economics, Japan (IEEJ)	IEEJ Outlook 2024 (October 2023)	Under the current extended scenario, it will be difficult for the world to achieve CN in 2050. The report mentioned the pursuit of an economically rational energy mix, including the use of natural gas.
Renewable Energy Institute	Proposal for the 2035 Energy Mix (1st Edition) (April 2023)	Increase the renewable-energy-electricity target to over 80% by 2035, speed up approval procedures for wind-power generation, and mandate installation of solar-power generation.
Research Institute of Innovative Technology for the Earth (RITE)	Scenario Analysis for Carbon Neutrality in 2050 (January 2022)	Even if significant technological advances are anticipated, high emissions-reduction costs must be incurred to meet 2050 CN target. A flexible CN strategy is essential.
Nikkei Inc.	Declaration from the NIKKEI Decarbonization Project (2021-)	It is necessary to aim for a just transition that neither harms the sustainability of society nor creates people or communities that are left behind in the midst of industrial and social transformations.
Institute for Global Environmental Strategies (IGES)	Net Zero World: Japan in 2050 (Tentative) (June 2020)	Rather than achieving CN through a lock-in scenario involving little social change, it is recommended to choose a transition that reforms social systems and infrastructure.

26 Institute of Energy Economics, Japan. 2024. “Business Overview,” https://eneken.ieej.or.jp/about/business.html, accessed April 15, 2024.

27 Renewable Energy Institute. 2023. “Recommendations for the 2035 Energy Mix (First Edition): Aiming for Decarbonization of Electricity through Renewable Energy,” https://www.renewable-ei.org/pdfdownload/activities/REI_2035_Study_JP.pdf, accessed April 15, 2024.

electricity, thermal power generation, real estate, shipping, beverages, and consulting[28]. The project emphasizes social sustainability and declares that it will promote a "just transition" in which people and regions are not left behind by industrial and social transformation. Moreover, the proposal by the Institute for Global Environmental Strategies (IGES), which includes many international researchers in the field of sustainability, is interested in changes that include not only energy but also labor, production, and consumption, and the IGES has attempted to describe the path to sustainable change by contrasting a "transition scenario" in which decarbonization is achieved through multiple changes in various fields with a "lock-in scenario" in which socio-economic stagnation occurs without structural transformation[29].

In the above-described manner, research institutes and think tanks are researching the transition of energy in Japan and recommending actions on it and the entire society surrounding it; however, even if each organization emphasizes neutrality and researches on the basis of scientific methods, their activity policies, shared concepts, and emphases are linked to the views of social groups that can exert significant influence on the research and its funding base. It can thus be expected that a systemic transition related to energy will be accompanied by a renewal of common language and concepts themselves.

In particular, mainstream energy think-tanks in Japan have a strong influence on public discussions related to energy in Japan through their relationships with the government and major energy companies. However, they involve little participation from practitioners in the digital field, sustainability science, and regional revitalization, and they tend to largely follow the framework of energy research in Japan established during Japan's earlier period of economic growth.

Recognizing the social construction of such knowledge, Hitachi-UTokyo Lab aims to chart a path for an integrated transition centered on energy change while listening to the voices of a wide range of actors from the public, private, and social sectors through interviews and dialogues. This approach also means shedding light on aspects like decision-making, industrial transformation, and international cooperation that have been marginalized in traditional energy discussions in Japan. We also hope to provide a reference for building a broad consensus while comparatively analyzing opposing perspectives on certain issues[30]. Through these efforts, we aim to contribute to realizing a green and prosperous future through energy transition while staying grounded in relation to the current complex crises.

2.5 The Asia-Pacific transition and Japan

As already discussed, while aiming for an integrated transition in Japan, it will be difficult to achieve decarbonization, particularly in energy, through domestic efforts alone, and cooperation with other countries and parties beyond Japan's borders will be essential. In particular, in the Asia-Pacific region, which is also home to Japan and its neighboring important economic community, Japan will need to secure the resources it needs through close cooperation while also playing an active role and contributing to the various needs for the transition in the region.

It is widely understood that it will be difficult for Japan to achieve an integrated transition by using domestic resources only. In particular, the production of electric vehicles, the demand for which is expected to grow significantly in the future, requires large quantities of important minerals (such as graphite, lithium, nickel, and cobalt) that are not needed for production of conventional vehicles[31], and those raw materials must be secured in large quantities and in a stable

28 NIKKEI Decarbonization Project. 2022. "Declaration from the NIKKEI Decarbonization Project," https://events.nikkei.co.jp/sengen_march2022/, accessed April 15, 2024.

29 Institute for Global Environmental Strategies. 2020. Net Zero World: Japan in 2050 (Tentative), https://www.iges.or.jp/jp/pub/net-zero-2050/ja, accessed April 15, 2024.

30 In particular, in Japan, it will be necessary to make greater efforts to understand the issues and analyze the path of change from a holistic perspective that places the traditional discussion of energy transitions in a broader context that includes issues such as the comprehensive global environmental crisis as outlined in the Planetary Boundaries, the correction of gender bias as outlined in the SDGs, and the spread of sustainable production and consumption practices.

31 International Energy Agency (IEA). 2021. "The Role of Critical Minerals in Clean Energy Transitions". https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

manner. In addition, although it has been pointed out that to achieve carbon neutrality, Japan must introduce CCS on a large scale, it is currently considered difficult to secure sufficient geographically suitable storage sites within its borders.

Meanwhile, the Asia-Pacific region has unique needs. According to a report by the Asia-Pacific Energy Research Centre (APERC), the energy-research arm of Asia-Pacific Economic Cooperation (APEC), the population and economic activity of the Asia-Pacific region is expected to expand from now onwards, and the region's GDP is expected to more than double between now and 2050. At the same time, electricity generation is expected to increase by 45 to 60% between 2018 and 2050[32]. By 2050, solar and wind power should account for 27 to 45% of renewable energy; however, achieving an energy transition based solely on renewable energy is considered difficult. In a carbon-neutral scenario, although coal-fired power generation is expected to decrease significantly, gas-fired power generation is expected to continue, so it will be necessary to introduce CCS. According to a study by the International Energy Agency (IEA), energy demand will increase significantly, in Southeast Asia, and electricity generation is predicted to increase four to five times between 2018 and 2050[33]. The IEA's Sustainable Development Scenario projects that renewable-energy generation in the region will increase significantly between 2020 and 2050. As a result, the region is faced with the challenge of simultaneously meeting rapidly growing energy demand and transitioning to renewable energy sources.

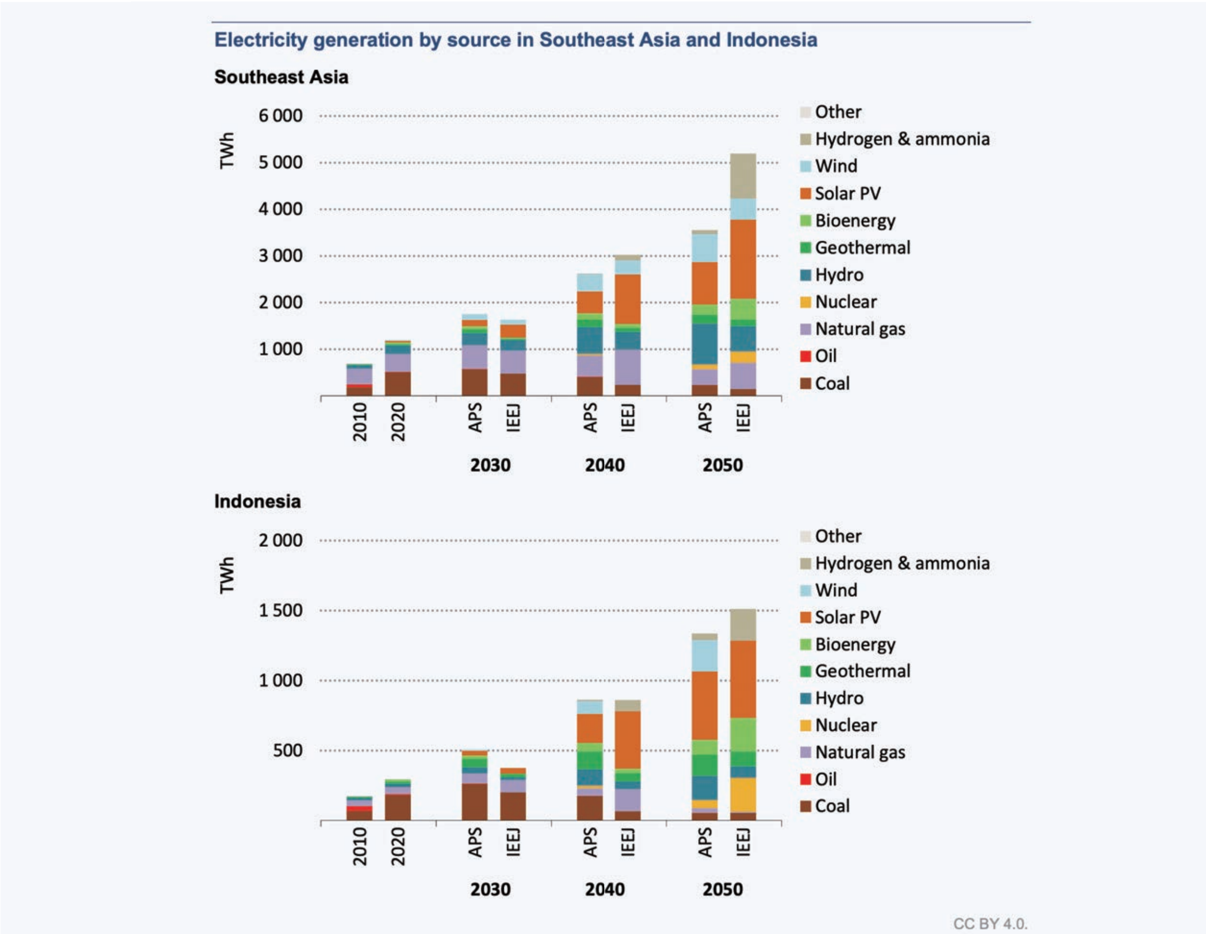


Figure 2.2 Projected power generation by source in Southeast Asia and Indonesia (2010-2050, scenario according to IEA (IEEJ))

Source: International Energy Agency (IEA). 2023. Decarbonisation Pathways for Southeast Asia, 41, https://iea.blob.core.windows.net/assets/4d0d7d7d-0ace-4de4-94cf-7c51a0a1517a/DecarbonisationpathwaysforSoutheastAsia.pdf, accessed on April 15, 2024.

32 Asia Pacific Energy Research Centre (APERC). 2022. APEC Energy Demand & Supply Outlook 8th Edition 2022, Volume 1, https://www.apec.org/docs/default-source/publications/2022/9/apec-energy-demand-and-supply-outlook-8th-edition---volume-i/222_ewg_apec-energy-demand-and-supply-outlook_vol-1.pdf, Accessed on April 15, 2024.

33 International Energy Agency (IEA), Decarbonisation Pathways for Southeast Asia, 41.

The Japanese government has launched several initiatives to meet the needs in Japan and the Asia-Pacific region through mutual collaboration. One of these initiatives is the Asia Zero Emission Community (AZEC). In a joint statement in March 2023, eleven countries, including Japan, Indonesia, and Australia, stated that they would share information, discuss, and take action on energy efficiency, renewable energy, hydrogen, ammonia, energy storage, bioenergy, carbon capture and utilization storage, investment in decarbonization infrastructure, financial support for clean-energy supply chains, development of decarbonization-technology standards, harmonization and interoperability, and strengthening human resources[34]. According to AZEC's English website, the community "aims to work with Asian countries that are actively working toward carbon neutrality while facing challenges similar to those of Japan in regard to decarbonization," "to advance energy transitions tailored to each country's circumstances," and "provide financial, technical, human resource, and policy coordination support to partner countries, making the most of Japan's resources and experience."[35]

Figure 2.3 AZEC Summit (December 18, 2023, Prime Minister's Office)
Source: Prime Minister's Office. 2023. "AZEC Summit Meeting," https://www.kantei.go.jp/jp/101_kishida/actions/202312/18azec.html, accessed April 15, 2024.

In December 2023, AZEC issued a joint statement at its summit in Tokyo. According to the statement, although AZEC partner countries have different national circumstances, such as "industrial structure, social background, geographical conditions, and stage and speed of development," they "share the understanding that there are diverse and realistic paths to carbon neutrality/net-zero emissions, and that it is important to utilize diverse energy sources and technologies to design and implement those paths." AZEC called for sharing of information and best practices related to decarbonization through cooperation between partner countries, policy coordination, and human-resource exchange and development. Moreover, it has invited the Economic Research Institute for AESAN and East Asia (ARIA) to establish an "Asia Zero Emission Center" as a platform for mutual learning and collaboration on policies, standards, and frameworks as well as support for visions, roadmaps, and policy formulation.

In the expert Interviews (2023) and the Open Forum (February 2024) held by Hitachi-UTokyo Lab, the significance of the AZEC initiative led by the Japanese government and the favorable response to the initiative from ASEAN countries were evaluated positively. However, it was mentioned that active discussions and decarbonization initiatives including China, India, and the Middle East are already underway in the Asia-Pacific region, and that Japan should participate in these frameworks appropriately, and rather than taking a self-centered approach, it should promote projects in a manner that is in harmony with these existing frameworks. In particular, the entry of India, which is a major contributor to the growing energy demand in the Asia-Pacific region, into the IEA and the application of Indonesia, an important country in the ASEAN region, for membership of the Organization for Economic Co-operation and Development (OECD) mean

34 Ministry of Economy, Trade and Industry. 2023. "Asia Zero Emission Community Joint Statement (provisional translation)," https://www.meti.go.jp/press/2022/03/20230306005/20230306005-23.pdf, accessed April 15, 2024.

35 Asia Zero Emission Community. 2024. "AZEC, Asia Zero Emission Community," https://asiazeroemission.com/about-azec, accessed on April 15.

that these regional agendas will have increasing international influence. In addition, the protracted war in Ukraine, security uncertainties in Northeast Asia and the Middle East, and the outcome of the 2024 European Parliamentary and U.S. presidential elections could affect these regional initiatives and Japan's participation in them.

Hitachi-UTokyo Lab will continue to study the role Japan can play in international collaboration, particularly in the Asia-Pacific region, to achieve an integrated energy transition in the region.

2.6 Chapter 2 Summary

In this chapter, the changes in global conditions related to climate, energy, and the environment over the past few years were reviewed, and the next challenges facing integrated transition in Japan were proposed from the viewpoint of changes in the public, private, and social sectors in Japan after 2020. These challenges are summarized below.

- The global environment and sustainability are at increasing risk due to compound crises such as climate change, loss of nature, and war. The energy transition must therefore be achieved in close cooperation with other agendas.
- Japan's energy transition must be positioned as part of an integrated transition that includes regional revitalization. To satisfy this requirement, it is necessary to (i) support the transition to a green economy in regions from a long-term, multidimensional perspective through closer cooperation between central government ministries and local governments and (ii) develop mechanisms and human resources that go beyond traditional decision-making methods and achieve integrated governance.
- While decarbonization has progressed across industries and companies in Japan, it is necessary to strategically invest in innovation to avoid structural lock-in (inertia) of existing industries and to shift to a next-generation industrial structure, including that of the digital sector.
- In response to the three above-described challenges, Japan is expected to play a unique role in cooperation with other countries in the Asia-Pacific region, which is experiencing a significant increase in energy demand and large-scale introduction of renewable energy.

Hitachi-UTokyo Lab aims to incorporate the perspectives of diverse actors across each sector and explore the visions of "integrated energy transition" and "green prosperity" from multiple perspectives.

Chapter 3 The ideal form and growth strategies for energy systems that incorporate social and industrial reforms

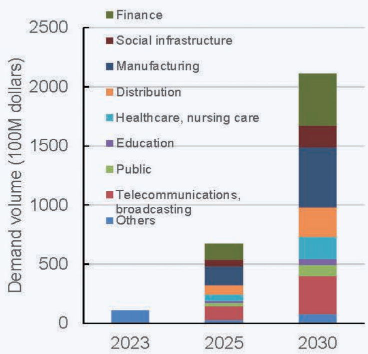
This chapter reviews the energy scenarios toward carbon neutrality (CN), identifies new issues, and presents countermeasures, taking into account the changes in global affairs after the release of Version 5 and the growth scenarios for industries as determined by digital technology.

3.1 Review of energy scenarios in light of drastically changing global affairs

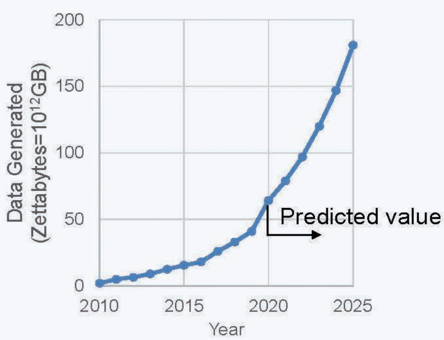
This section examines the possibility of balancing the increase in energy supply needs of AI and data centers, which is expected with the growth of industries, with the transition to CN in 2050, and what issues and countermeasures should be considered along with the energy balance.

As mentioned in section 2.3, the use of AI and data in the industrial sectors has been expanding rapidly in recent years, including its use for operations support, product development support, work efficiency, and creative activities. As shown in Figure 3.1(a), the global market for generative AI is projected to grow rapidly in each application area, and the volume of data handled is also expected to increase as shown in Figure 3.1(b).

The advancement of the information society and the expansion of the amount of information processing through AI and other technologies will also lead to the increase in the power consumption of data centers and other facilities. Specifically, it has been shown that the current trend of increasing computational load will continue into the future, and that power consumption (excluding future technological progress) is expected to reach a maximum of 90 TWh in Japan by 2030, assuming that the latest equipment currently available will be used[36].Further, taking technological progress into account, it is predicted that power consumption will reach 260 TWh by 2050 (about 26% of 2020)[37]. In particular, 50% of the data centers' power will be consumed by servers, 25 to 30% by power and cooling systems, and about 10% by storage systems.



(a) Generative AI market outlook (global)[38]



(b) Volume of data/information handled globally)[39]

Figure 3.1 Example of outlook of use of AI and data in the industrial sectors

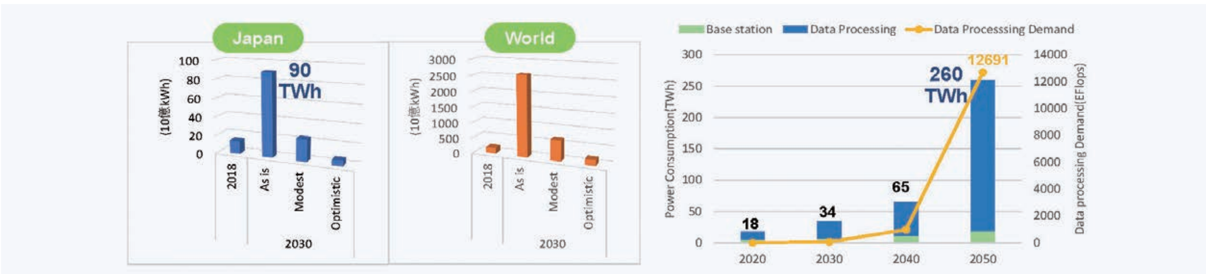
36 Japan Science and Technology Agency: Impact of Progress of Information Society on Energy Consumption (Vol. 4): Feasibility Study of Technologies for Decreasing Energy Consumption of Data Centers, February 2022

37 Energy Transition Initiative – Center for Global Commons (ETI-CGC). 2023. "Challenges and recommendations for Japan's net zero by 2050 - Energy system perspective," December 2. https://www.youtube.com/watch?v=5MbK713H7ZI, Accessed April 23, 2024.

38 Japan Electronics and Information Technology Industries Association (JEITA) "JEITA announces global demand outlook for generative AI market" (2023)
EIA. 2022. "ANNUAL ENERGY OUTLOOK 2022," March 3, 2022.

39 International Data Corporation; Seagate Technology; Statista estimates

From these conditions, Figure 3.2 shows the results of sorting and classifying the 2050 CN vision based on two axes; namely, the rate of introduction of variable renewable energy (VRE) and the progress of electrification in the transportation and industrial sectors, as presented in Version 4. In calculating the transition scenarios up to 2050, we used the energy and economic simulation model based on the “technology selection model” developed by the Fujii-Komiyama Laboratory at the University of Tokyo. Using this model, we calculated a transition plan that minimizes the total cost of energy and systems while maintaining energy supply and demand in different time sections, taking into account 8,760 hours of operation each year. Therefore, this analysis can be said to establish the CN achievement scenario by backcasting from 2050. Figure 3.3 shows the relationship between VRE and electricity demand in 2050 and the rate of increase in total costs for energy scenarios with different technological innovation progress levels and cost conditions (100% renewable energy, thermal power with CCS limit, use of nuclear power, and hydrogen procurement) as shown on the left. The relationship between the self-sufficiency rate and the stockpiling rate for each scenario is shown on the right. For each scenario, the increase in ICT demand will lead to an increase in power supply centered on renewable energy, and the total cost will also increase by 30 to 60% compared to the scenario after the fuel price surge. Next, we analyzed the details of the CN transition scenarios using "(3) use of nuclear power" as an example from the balance of total cost increase, self-sufficiency rate, and stockpiling rate.



(a) Generative AI market outlook (global)

(b) Volume of data/information handled globally

Figure 3.2 Example of outlook of use of AI and data in the industrial sectors

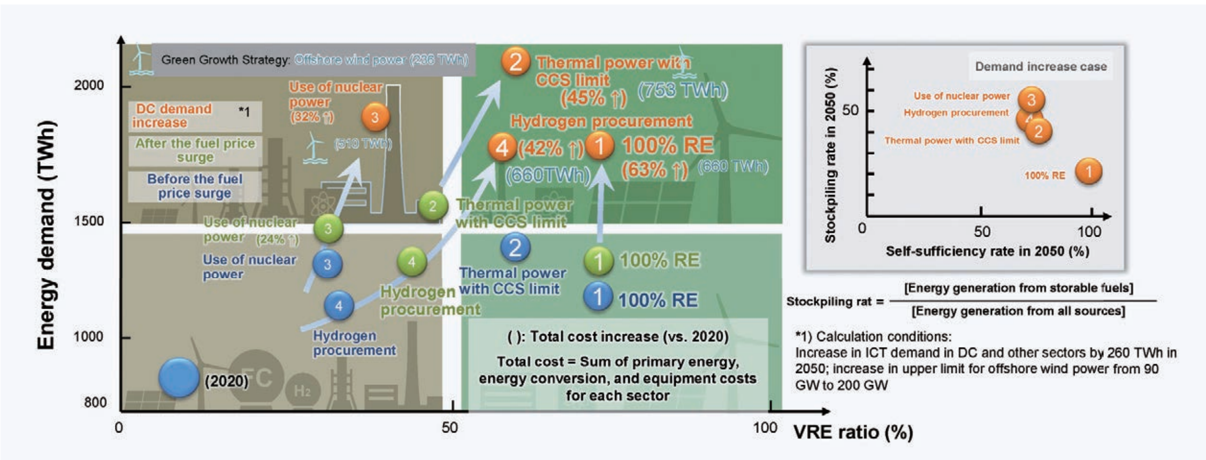


Figure 3.3 Changes in four social visions due to fuel price hikes based on deployment of renewable energy and progress in electrification

Figure 3.4 shows the calculation results of the power supply capacity for each fiscal year of the transition process under the use-of-nuclear-power scenario. For each fiscal year, the conditions before the increase in ICT demand (the conditions in Version 5) and with the increase in power demand (increase of 260 TWh in 2050) are shown side-by-side. In response to the increase in ICT demand, power generation facilities will increase consumption by 146 GW and power generation will increase by 290 TWh in 2040, while power generation facilities will increase consumption by 137 GW and power generation will increase by 333 TWh in 2050. The breakdown of power generation facilities shows that renewable energy, such as wind power and solar power, is increasing, and for example, offshore wind power generation facilities in 2040 need twice as much as planned under the Green Growth Strategy. Thus, in response to the increase in ICT demand, it is necessary to increase the number of decarbonized power sources, such as renewable energy and nuclear power, and it is assumed that the greater the increase in demand, the more difficult it will be to secure power sources.

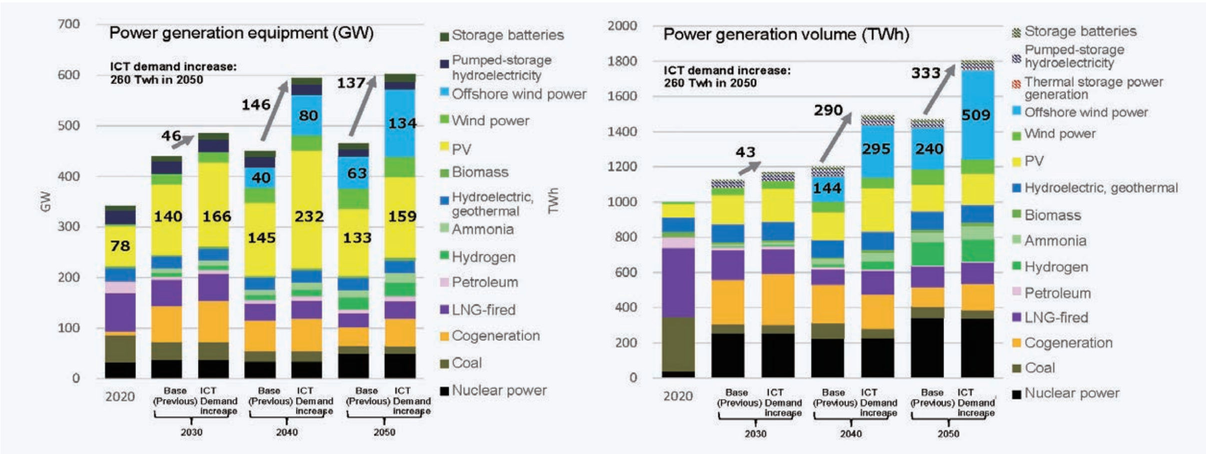


Figure 3.4　Power supply capacity for select fiscal years ("use of nuclear power" scenario)

3.2 Backcasting and forecasting gaps and countermeasures for energy systems

Under the conditions shown in Figure 3.4, the issues for the transition to the power supply mix from 2020 to 2030 were considered.

(1) Solar power generation: From 78 GW in 2020 to 140 GW and 166 GW in 2030, requiring increase of 62 GW and 88 GW

The Japan Photovoltaic Energy Association (JPEA) has set a target of 100 to 125 GW (AC output) by 2030[40]. The 140 GW and 166 GW for 2030 can be said to be high barrier figures. Considering the average area (15 km2/GW), 930 km2 and 1,320 km2 are required to build new solar power generation facilities with capacity of 62 GW and 88 GW, which are 1.5 times and 2 times the area of Tokyo's 23 wards and Lake Biwa, respectively. In terms of capacity, this is equivalent to 340 new mega solar facilities (ca. 260 MW), the largest of its kind in Japan. In addition to resolving the issues related to panel disposal and recycling, it is necessary to promote the selection and effective utilization of installation sites with consideration for the environment.

(2) Wind power generation: From 5 GW in 2020 to 20 GW in 2030, requiring an increase of 15 GW

According to the Japan Wind Power Association (JWPA) data[41],13 GW of onshore wind power and 18 GW of offshore wind power facilities are expected to start operating by 2031. In addition, approximately 9 GW of the onshore wind power has yet to be approved under the business plan, and in addition to raising the pace of approval from 1.2 GW/year to 2 GW/year, it has been shown that it is important to

40 Japan Photovoltaic Energy Association (JPEA) 2021. "Current status of photovoltaic power generation and challenges toward self-reliance and mainstreaming," October 29, 2021. https://www.meti.go.jp/shingikai/santeii/pdf/071_01_00.pdf. Accessed April 23, 2024.

41 Japan Wind Power Association (JWPA), 2021. "2030 Wind power installation towards the realization of carbon neutrality by 2050," March 15, 2021. https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/028_05_00.pdf. Accessed April 23, 2024.

reduce the lead time by advancing environmental assessment and resolving grid constraints. According to the Agency for Natural Resources and Energy data[42], a total of 5.5 GW of offshore wind power is being commercialized: 1.7 GW in the promotion zones for which operators are already selected, 1.8 GW for which public offering has started, and 2.2 GW in five promising zones. It is important to promote harmony with the environment and cooperation with the local community in terms of accelerating project formation, shortening the lead time until operation, and system development.

(3) Cogeneration: 8 GW in 2020 to 81 GW in 2030

In this estimation, it is expected that 1/2 of the electricity generated by fossil fuels will be usable as heat. In addition to conventional cogeneration facilities, it is necessary to make effective use of heat.

(4) Hydrogen and ammonia power generation: From 0 GW in 2020 to 19 GW in 2030

Achieving this through conversion of conventional fossil fuel power generation facilities will require the conversion of 19 large-scale thermal power generation facilities (1 GW/plant). It is necessary to urgently solve problems in terms of environmental, economic, and logistic aspects, such as the development of equipment technology and procurement of fuel.

(5) Nuclear power generation: From 33 GW in 2020 to 36 GW in 2030

The figures are based on the assumption that 36 nuclear power plants (including those under construction) are operable and will operate for 60 years, excluding those that have already been set for decommissioning. There is a need to take safety measures, obtain permits and approvals, and build consensus with the local community and the people.

3.3 Development of technologies that enable analysis and evaluation using data and simulations

As mentioned above, in order to fill the gap between the backcasting scenarios from CN in 2050 and the forecast from the current situation, it is necessary to resolve grid connection and other issues on the power electricity side, in accordance with the transition to decarbonized power sources and the early introduction of renewable energy. In addition to the items indicated in Version 5, the following issues need to be addressed.

(1)Frequency reduction caused by inertia reduction
(2)Frequency fluctuations due to lack of adjustment capacity
(3)Ensuring system stability
(4)Instability due to increase in inverter power supply
(5)Coordination of grid and distributed resources
(6)Improving flexibility of electricity demand
(7)Ensuring reliability of energy supply, including utilization of storage
(8)Eliminating grid congestion in response to increased demand

In this section, the problems and countermeasures for the electric power system envisaged in the process to CN are described in particular for (8), which has become more urgent due to the increase in demand.

As mentioned above, with the increase in ICT demand, it is necessary to increase the number of renewable energy and other CN power source facilities, with the peak of the power tide flowing through the grid likely to expand, and grid congestion expected to occur at many location and time points. For example, the introduction of offshore wind power, mainly in the Hokkaido and Tohoku regions, will require a capacity increase of up to 150 GW by 2040. Also, maintaining a balance between supply and demand in each area is expected to lead to grid congestion caused by renewable energy even in the Kanto area, where demand is high, in FY2024 (the control of renewable energy output is foreseen in all areas in Japan), as renewable energy output control becomes more prevalent

Table 3.1 Outlook of system congestion in the regional grid system (renewable energy output control) (FY2024, Kanto area)[43]

	Annual output control volume	Maximum output control volume	Output control time
154 kV Joetsu Line	1,220 kWh	680 kW	3 hours
66 kV Tamamoro Line	15,440 kWh	830 kW	26 hours

42 Agency for Natural Resources and Energy, 2022. "Current situation of renewable energy in Japan and abroad and proposal of issues of the Procurement Price Calculation Committee for this fiscal year," October 2022, https://www.meti.go.jp/shingikai/santeii/pdf/078_01_00.pdf. Accessed April 23, 2024.

43 Ministry of Economy, Trade and Industry: Subcommittee on New Energy and Grid Working Group Document 5 (2023) , https://www.meti.go.jp/shingikai/enecho/shoene_shinene/shin_energy/keito_wg/pdf/048_05_00.pdf. Accessed April 23, 2024.

(Table 3.1). In addition, due to the spread of renewable energy through non-farm connections, there is a possibility that congestion will occur in the local grids in each area between 2027 and 2028 (Table 3.2).

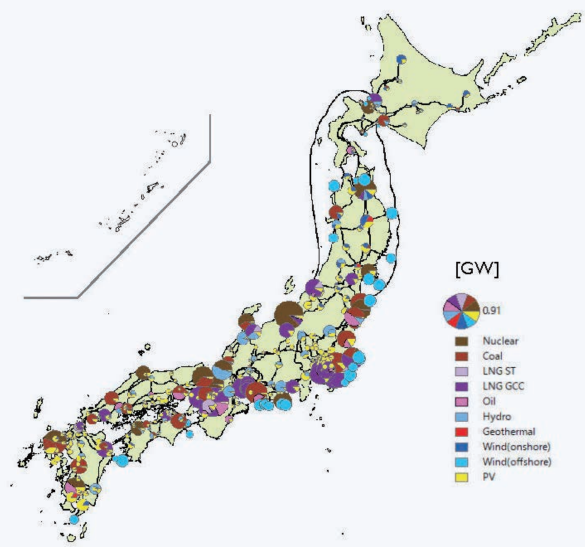
Thus, grid congestion is expected to continue in the future due to non-farm connections (measures to effectively utilize the free capacity of power transmission lines). As countermeasures against these issues, it is important to improve the efficiency of grid operation, such as by maximizing the use of market mechanisms (merit orders) and minimize the electricity cost of the entire Japanese grid, taking into account the possibility of increasing the frequency of output control (priority power supply rules, congestion in regional lines). In addition, it is also necessary to minimize electricity costs and achieve a stable supply by maximizing the use of all resources through optimization of grid operation throughout Japan (power supply replacement, output suppression, transmission line operation, etc. at the entire Japan level for congestion handling). Likewise, simulation evaluation using power supply and demand analysis models is important for quantitative evaluation of the effectiveness of countermeasures to address issues. For example, it is necessary to evaluate the contribution to minimizing costs and managing congestion by implementing complete merit orders nationwide.

As a concrete example, the results of trial calculations on transmission line congestion occurrence and congestion management issues are shown. Here, a simulation tool based on a power supply and demand model covering the entire Japanese grid system[45,46] is used to calculate the power supply configuration that realizes CN[47]. Figure 3.5 shows an example

Table 3.2 Estimated results of grid congestion throughout Japan (number of facilities to experience congestion)[44]

		Expected number of congested facilities		
		Section I	Section II	Section III
FY2027	Bulk power grid	0	0	19
	Local grid	0	0	101
FY2028	Bulk power grid	1	1	25
	Local grid	3	2	95

Section I: Daytime peak demand section, Section II: Nighttime peak demand section, Section III: Sections other than I and II (light load period, etc.)



*Analysis using an optimized power supply and demand model premised on the results of the 2040 cross-section analysis using an energy supply and demand model. It must be noted that the analysis results may vary depending on the assumptions.

Figure 3.5 Example of analysis using the power supply and demand analysis model (analysis of transmission line congestion due to introduction of ca. 200 GW PV)

44 Organization for Cross-Regional Coordination of Transmission Operators, Japan: 70th Meeting of the Wide-Area Grid Development Committee Material (2023), https://www.occto.or.jp/iinkai/kouikikeitouseibi/2023/files/seibi_70_03_01.pdf. Accessed April 23, 2024.

45 Komiyama Ryoichi, and Fujii Yasumasa. 2017. "Assessment of post-Fukushima renewable energy policy in Japan's nation-wide power grid." Energy Policy 101, February 2017: 594-611.

46 Komiyama Ryoichi, and Fujii Yasumasa. 2019. "Optimal integration assessment of solar PV in Japan's electric power grid." Renewable Energy 139, August 2019: 1012-1028.

47 Prepared from analysis by Komiyama Ryoichi and Fujii Yasumasa, 2022, "Power supply and demand analysis of power supply investment and operation optimization considering the transmission grid," Proceedings of the Annual Conference of the Institute of Electrical Engineers of Japan (IEEJ) H6-3, March 1, 2022

of an analysis using a power supply and demand analysis model of transmission line congestion under the condition that PV at about 200 GW is introduced nationwide. Figure 3.6 shows an example of analysis of inter-regional connection line congestion, and Figure 3.7 shows an example of analysis of regional congestion. Figure 3.7 shows the number of transmission lines quantified by the shadow price of transmission capacity constraints (note that the analysis results may vary depending on the assumptions).

Initiatives to efficiently manage local transmission line congestion and minimize power system costs are also crucial for the mass introduction of renewable energy. Sharing data (future vision) on transmission facilities, types and locations of power generation, and distribution of power generation and demand will make it possible to promote more effective facility expansion and institutional improvements through location-based electricity pricing and other mechanisms.

Next, we will discuss the location guidance countermeasures for power consumption bases. As mentioned above, it is important to find appropriate locations for data centers, large-scale factories, and other power-consuming bases in order to control electricity costs. Assuming the implementation of dynamic pricing (market-based pricing) and effective incentives for guiding the location of power demand, data centers (assumed to be base load) would optimally be located in areas where wholesale electricity prices are lower. Market-led optimal allocation of power output, e.g., through the zoning system and nodal system, and the formation of power price signals in the power grids are effective in ensuring incentives for location guidance. In

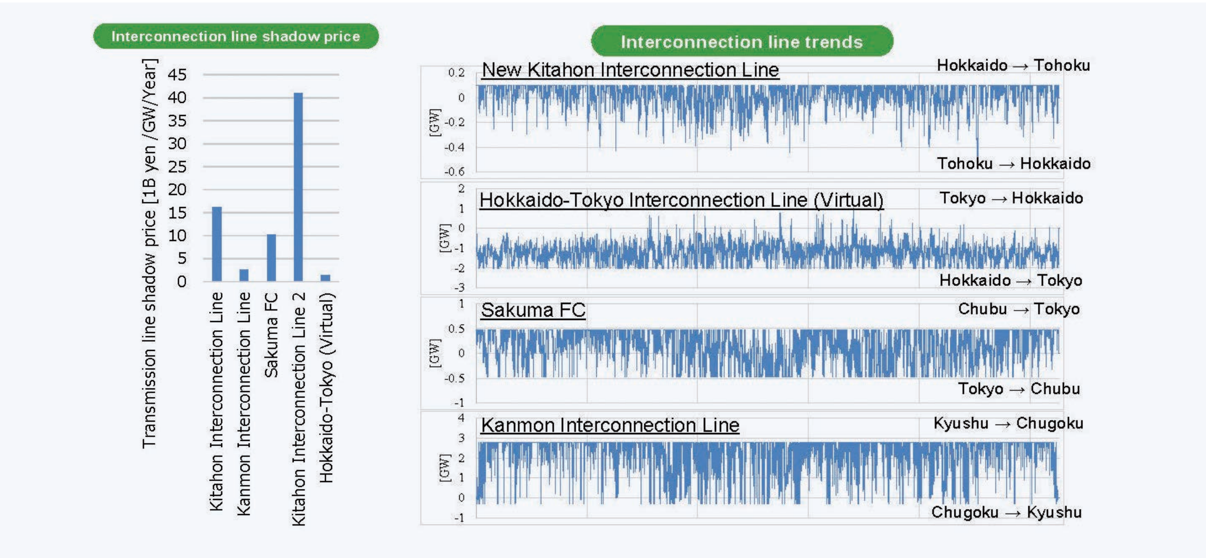


Figure 3.6 Example of analysis of inter-regional connection line congestion

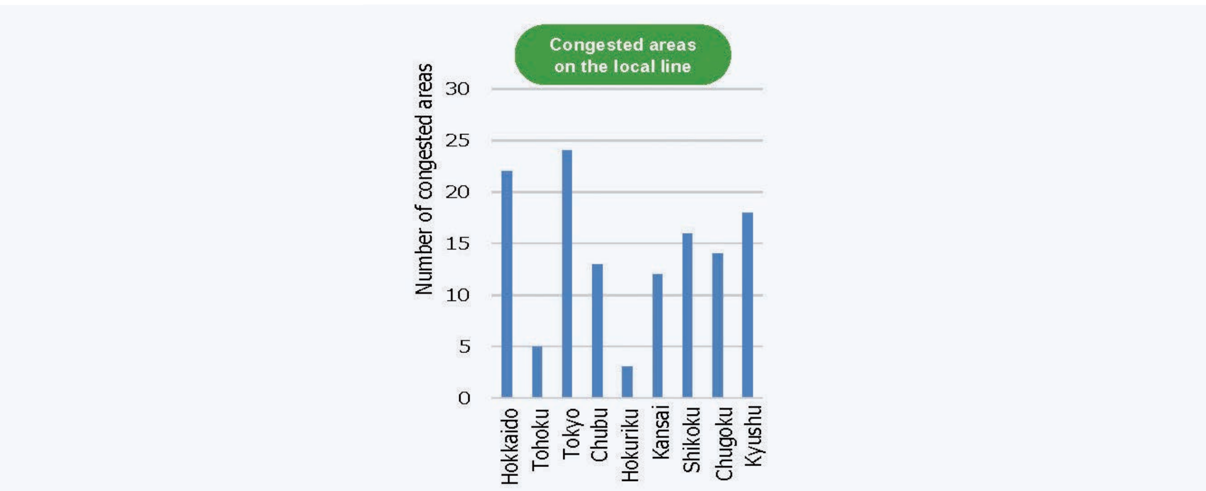


Figure 3.7 Example of analysis of regional line congestion

addition, the reduction in electricity prices will contribute to the incentive to create demand. Figure 3.8 shows the results of estimation of the virtual optimal allocation of data center power consumption (90 TWh), and Figure 3.9 shows trends in electricity prices. As the figures show, it is important to form price signals that reflect the spread of renewable energy and to create incentives for inducing locations for electricity sources and consumption. Meanwhile, it is also necessary to strengthen the power grid in order to meet the demand in metropolitan areas.

Figure 3.10 shows the results of estimation of the power supply and demand balance depending on whether data center location guidance is implemented or not, and Figure 3.11 shows the results of estimation of output suppression in

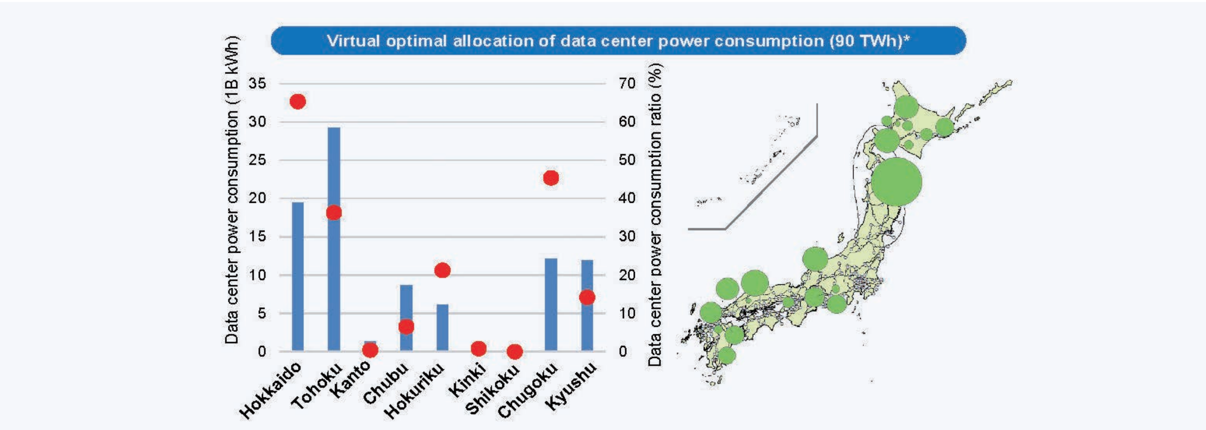
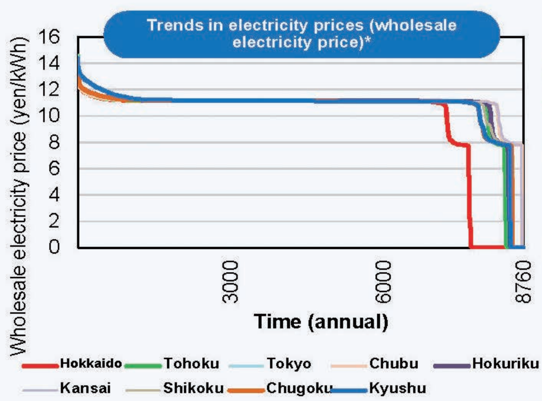


Figure 3.8 Results of virtual optimal allocation of data center power consumption (90 TWh)



Number of hours at 0 yen/kWh

Hokkaido	920
Tohoku	250
Kyushu	220
Chugoku	180
Kanto	20

Figure 3.9 Trends in electricity prices

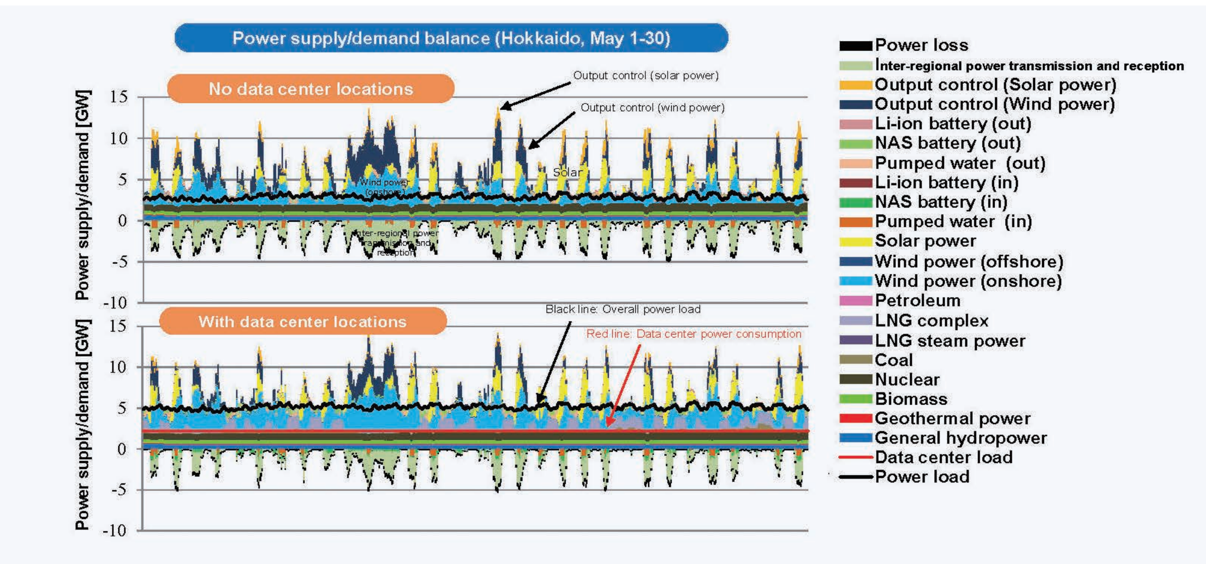


Figure 3.10 Estimation of the supply-demand balance based on the presence or absence of data centers

Japan as a whole[48]. The increase in electricity consumption due to the location of the data centers indicates that the suppression in renewable energy output is decreasing. Therefore, it is necessary to strengthen measures to increase the amount of renewable energy connected by inducing electricity consumption and to ensure supply-demand balance by reducing renewable energy output suppression.

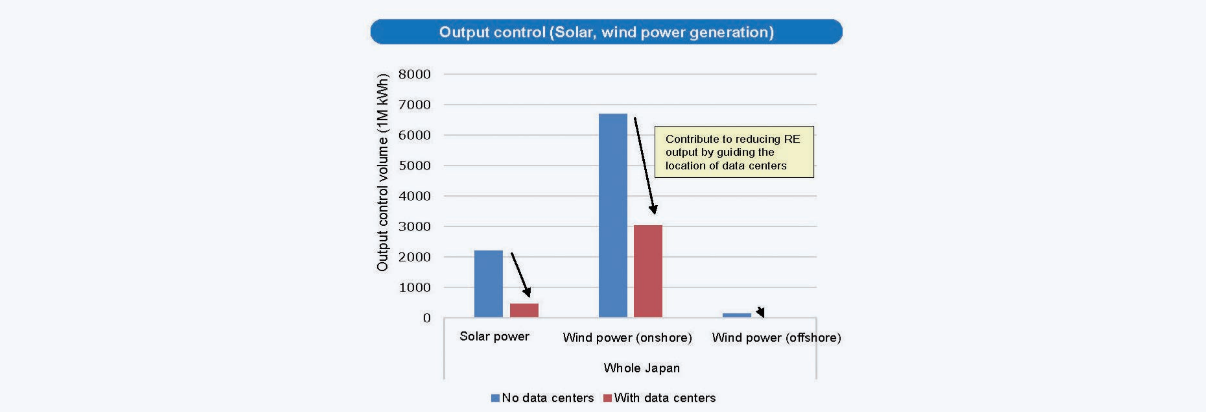


Figure 3.11 Results of estimation of output suppression of solar and wind power generation

3.4 Integrated transition between energy demand, digital growth, and the energy system

Japan's electricity system underwent a comprehensive reform marked by three stages: the expansion of wide-area grid operation in April 2020, full liberalization of retail, and the neutralization of the transmission and distribution sectors through legal separation. Since 2020, problems related to energy supply and demand, such as those stemming from the Russian invasion of Ukraine and the tight power supply and demand conditions in summer and winter, have come to the fore. Assuming the realization of carbon neutrality by 2050, the gradual decommissioning of thermal power plants and the uneven distribution of renewable energy already pose pressing issues. For the time being, the uncertainty regarding the predictability of investments in power sources is expected to continue. In this proposal, we reviewed the energy scenarios incorporating the increase in electricity demand in the ICT sector. Considering the changes in the national landscape, including the future increase in renewable energy sources, the population decline, and the changes in the industrial structure, an integrated transition between energy demand, growth utilizing digital technology, and energy system reform is necessary.

The supply and demand balance of the electricity system raises concerns about supply shortages due to weather conditions. This highlights the utmost importance of predicting and controlling energy demand and supply-demand adjustment through forecasting of hourly and seasonal fluctuations of energy and securing adjustment capacity by linking meteorological data with the electricity system. ICT technology is indispensable for carrying out such advanced prediction and control. Thus, consideration should be given to securing the necessary ICT technology and improving resilience to ensure the minimum operation of the necessary ICT technology at an early stage in the event of a disaster.

Since 2020, electricity system reform through separation of power generation and transmission and distribution sectors has greatly contributed to the development of services utilizing electricity. On the other hand, considering the geopolitical situation of Japan, where all electricity must be generated domestically, the cost of S+3E for electricity is likely to increase accordingly. Changes in power generation, transmission, energy mix, and electricity demand are expected to occur at a faster pace in the future. Market transparency is required to monitor and advise from various perspectives on whether the electricity system is responding to these changes. Likewise, a neutral system to manage

48 A hypothetical analysis using an optimized power supply and demand model based on the installed capacity of solar and wind power generation and the demand for electricity (864 billion kWh) reported in the Ministry of Economy, Trade and Industry's "Outlook for Energy Supply and Demand in FY2030 (Supplementary Material)" (2021). Data center load is assumed to be base load. The analysis does not take into account the cost of telecommunications and other infrastructures, but only electric power. It must be noted that the analysis results may vary depending on the assumptions.

and operate the necessary data and information in an integrated manner is required to achieve this transparency. The neutrality of the electricity system will play a crucial role in supporting the business environment on the energy supply side, as well as the participation of various stakeholders, e.g., supply-demand adjustment through the participation of consumers in the future. It is also important in providing data to objectively verify the system.

3.5 Chapter 3 Summary

The following is a summary of the contents of Chapter 3.

- We revised the energy scenarios in response to the increase in demand for data centers and ICT, as well as the surge in oil price and in consideration of the drastically changing global affairs. As a result, we determined that the following measures must be carried out by 2030 to realize the CN scenarios: (1) accelerate the introduction of renewable energy (88 GW of solar power generation and 15 GW of wind power generation) and secure decarbonized power sources such as operation of all existing nuclear power generation plants, (2) avoid waste in a short period of time from PV introduction and solve environmental issues in installation, (3) operate hydrogen and ammonia power generation exceeding 10 GW, (4) use of heat from fossil fuel power generation through cogeneration, and (5) ensure energy resilience and security during rare windless and continuous cloudy weather, fuel shortage, and disasters. Also, toward 2040-2050, innovation should be carried out by developing and investing in: (1) the further increase of CN power sources such as solar, wind, and nuclear power, (2) the commercialization and widespread adoption of CO2 capture by DAC, and (3) the production of synthetic fuel from the captured CO2 and its use in the transportation and industrial sectors.
- The following countermeasures must be implemented to address issues in bulk power systems in response to the rapid increase in the amount of renewable energy: (1) securing the number of thermal and nuclear rotary machines in operation and introducing inertial control of distributed resources in response to frequency decline due to decreased inertia; (2) utilization of local resources and measures to avoid grid congestion in response to frequency fluctuations due to insufficient adjustment capacity; (3) sophistication of regional power storage and EV control, in addition to the enhancement of HVDC power transmission, in response to the deterioration of grid stability; (4) sophistication of inverter control and high-speed (at the second level) integrated control in response to instability due to the increase in inverter power supply; (5) coordination of grid and distributed resources; (6) improvement of flexibility of power demand; (7) ensuring the reliability of energy supply including utilization of storage; and (8) eliminating grid congestion in response to increasing demand.
- In advancing investigations of the bulk power system for CN, it is necessary to share data and simulation models with many stakeholders, including power distributors and customers, and to develop and utilize simulation evaluation technologies. To achieve CN, we must (1) visualize multifaceted and quantitative issues using numerical simulation models, and (2) evaluate measures as needed, and promote institutional development, as well as investment in facilities and innovation in response to changes in the situation.
- Measures in the energy sector in conjunction with national land planning: In order to create an environment that enables discussions on medium- to long-term policies to address issues not only in energy supply, but also in supply and demand, measures in the energy sector should be linked to long-term national planning.
- The importance of medium- to long-term institutional design and measures beyond the short-term market principle: Securing supply capacity and procuring resources for long-term decarbonization investment and stable supply are difficult to achieve with short-term market signals. Policy discussions with a view to the transition are required, taking into account the unique circumstances of Japan, which is an island country that lacks energy sources.

- Rebuilding the electric power market and merging the environmental value market: It is necessary to promptly break away from the current situation where markets are asymmetrical, i.e., where equal regulations are not imposed on both sides. To realize this, it is necessary to thoroughly visualize the status of power supply operation and monitor the market.
- Building social systems through the participation of local communities and consumers: A sustainable system that encourages consumers to actively invest in the environment must be built. In regard to policies related to global warming (FIT/FIP, etc.), (1) a framework based on the judgment of consumers must be created and must be (2) integrated into the emissions trading system.

Hitachi-UTokyo Lab will continue to work on the development of energy scenario evaluation simulation technology, the evaluation of CN transition scenarios in response to changes in domestic and overseas state of affairs, the selection and development of innovative technologies for solving energy system issues, and the proposal of platforms for sharing data and analysis models among various stakeholders.

Chapter 4 Contribution from the regions to balance CN and S+3E of energy supply and demand

4.1 The role of local communities in realizing a CN society

Local communities are the social infrastructure that supports the lives of people and society. They include households, businesses, and industries—all of which play a role in both supply and demand aspects in the energy system of the future. As shown in Figure 4.1, with the increasing penetration of renewable energy, in addition to receiving a stable energy supply from bulk power systems, they are also expected to supply part of the energy themselves, and to create "adjustment capacity" to contribute to balancing power supply and demand through data-enabled "smart energy use," thereby becoming the main actors for realizing "S+3E[49] of energy supply and demand," together with bulk power systems. In this context, "adjustment capacity" refers to power demand that can be time-shifted without compromising convenience or functionality. For example, if the energy supply from the bulk power system is constrained due to power outages or supply shortages after a disaster occurs, it is necessary to ensure the supply and demand balance for important loads in the region, such as in disaster prevention bases. This can be achieved by utilizing regional resources, including local power sources and EVs.

In Version 5 of the Proposal published in 2023, we proposed a coordination and control platform that will realize regional value creation through smart energy use and provide adjustment capacity to the bulk power system. We also assessed the adjustment capacity that can be created from a region and the value of that capacity. As a result, we clarified the potential to create an adjustment capacity of 33 TWh/year, which is equivalent to the adjustment capacity of pumped storage batteries and grid batteries when CN is achieved[50]. We also proposed measures to promote decarbonization in a region based on a win-win approach for the energy supply side and the demand side, the expectations of actors in the region, and the measures that should be prioritized by taking into account regional and individual characteristics. In this version, we analyzed the changes in the current local communities and described the social transition that is compatible with regional economic growth, i.e., an approach for an integrated transition in the region including measures to facilitate the transition.

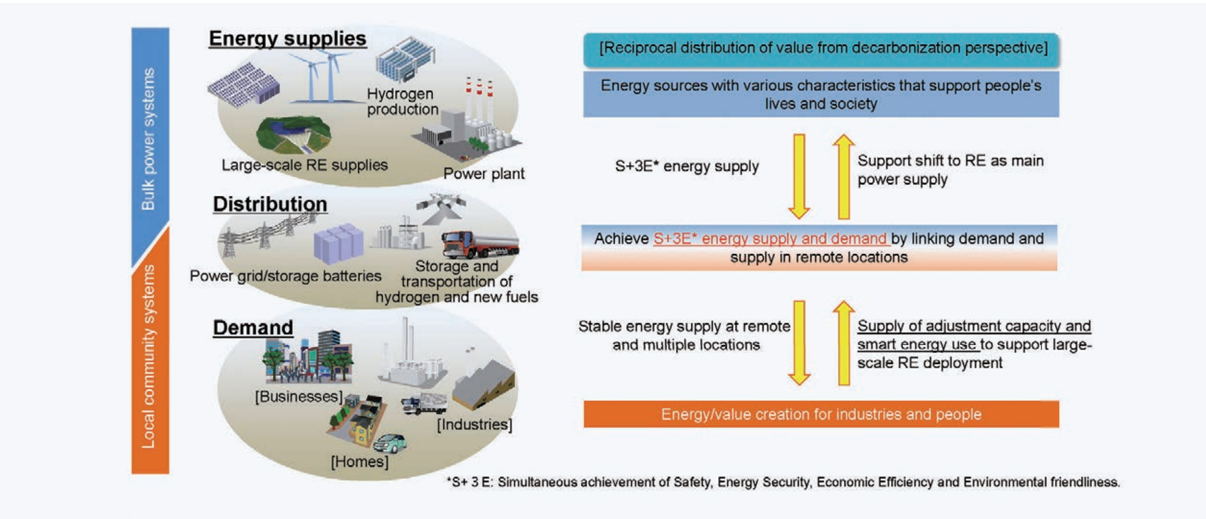


Figure 4.1 Positioning of bulk power systems and local communities

49 S+3E: Achieving Safety, Energy Security, Economic Efficiency, and Environmental Friendliness at the same time

50 Hitachi-UTokyo Lab, 2023. Proposal: Toward Realizing Energy Systems to Support Society 5.0 (Version 5)

4.2 Objective analysis of social changes associated with CN

4.2.1 Inconsistency between the designation of leading decarbonization regions and the current status of CO^2 emissions

Further measures are required to achieve the 2030 CO_2 emissions reduction targets of 46% for Japan, 66% for households, and 50% for businesses and other sectors. To achieve these targets, as mentioned in Chapter 2, the Ministry of the Environment has established and operates a subsidy program for "leading decarbonization regions" aimed at promoting decarbonization in the regions, with local governments, local companies, and financial institutions playing a central role. The program aims to establish outstanding paths for 100 regions by 2025, and to implement them by 2030. More than 73 proposals have already been selected as recipients of subsidies for leading decarbonization regions[51]. (Fig. 4.2)

With the help of these subsidies, comprehensive measures for energy conservation, energy savings, electrification, enhancement of equipment efficiency, and improvement in building insulation performance have enabled reduction of CO_2 emissions per household by about 19% and reduction in energy consumption by about 13% in FY2022 compared to FY2017, when the survey was started (Figures 4.3 and 4.4)[52]. Additionally, coupled with population decline, CO_2 emissions in the household sector as a whole have fallen by 24.5%. However, this is not enough to reduce CO_2 emissions from the household sector by 1.21 t-CO_2 per year per household, which is required to achieve the 66% reduction from FY2013 levels by 2030, as set in the Plan for Global Warming Countermeasures[53].

Furthermore, in the evaluation of CO_2 emissions in FY2022, which includes household energy consumption and transportation, CO_2 emissions from gasoline were 0.92 t-CO_2 per year per household[54], indicating that the delay in electrification of transportation is a major issue. A survey showed that EV chargers are not installed in approximately 75% of work locations of EV users, including PHEVs[55]. Thus,

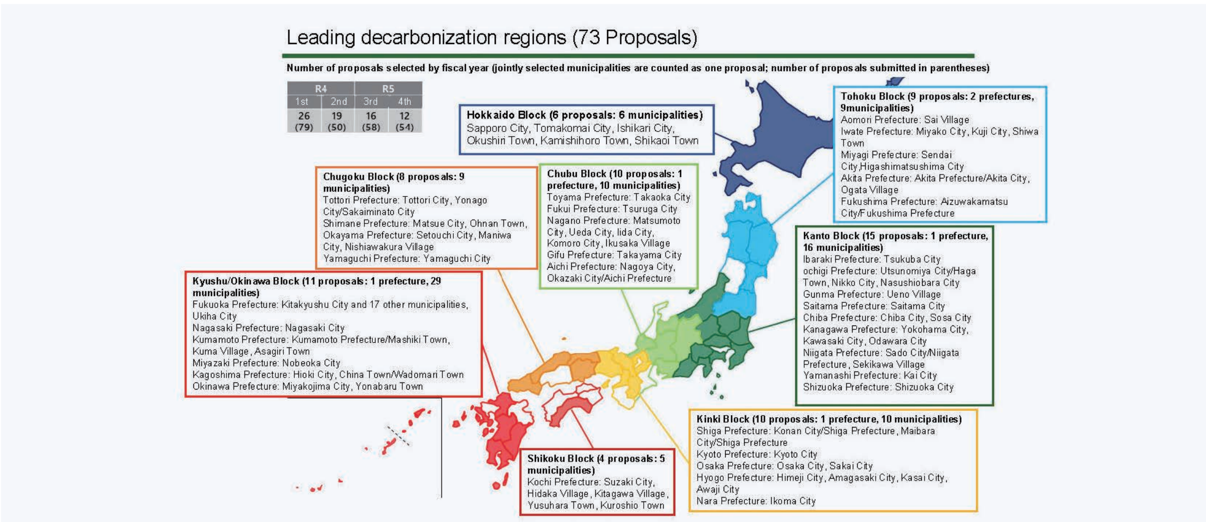


Figure 4.2 Proposal status of leading decarbonization regions (in Japanese)

51 Ministry of the Environment. 2024. "Site supporting the development of decarbonized regions: What is a leading decarbonization region?" https://policies.env.go.jp/policy/roadmap/preceding-region/. Accessed April 23, 2024.

52 Ministry of the Environment, 2024. "Results of the Survey on CO2 Emissions in the Household Sector in FY2022 (Final Report)," https://www.env.go.jp/content/000211408.pdf. Accessed April 23, 2024.

53 The target for reducing greenhouse gas emissions by 2030 in the Plan for Global Warming Countermeasures decided by the Cabinet in October 22, 2021 is 70 million t-CO2 for the household sector. The National Institute of Population and Social Security Research's future projection of the number of households in 2030 based on the 2020 census is 57.73 million. We derived the CO2 emission reduction target per household of 1.21 t-CO2 per year by dividing 70 million t-CO2 by 57.73 million households,

54 National Institute for Environmental Studies. 2024, "Greenhouse Gas Inventory," https://www.nies.go.jp/gio/aboutghg/index.html. Accessed April 30, 2024.

55 Hiroyuki Hatta, 2023. "Market potential of demand response using EVs," Journal of the Institute of Electrical Engineers of Japan, September 2023, Vol. 143, No. 9, pp. 572-575.

the national government, local governments, and companies should work together to create an environment that promotes electrification.

Meanwhile, the yen continues to depreciate after exceeding 150 US dollars/yen, and the prices of imported goods including fuel and raw materials are rising, resulting in increased the energy cost burden and strain on people's daily lives. In this context, Japan must promote decarbonization by avoiding excessive dependence on imported materials and products to find a way to revitalize the local economy.

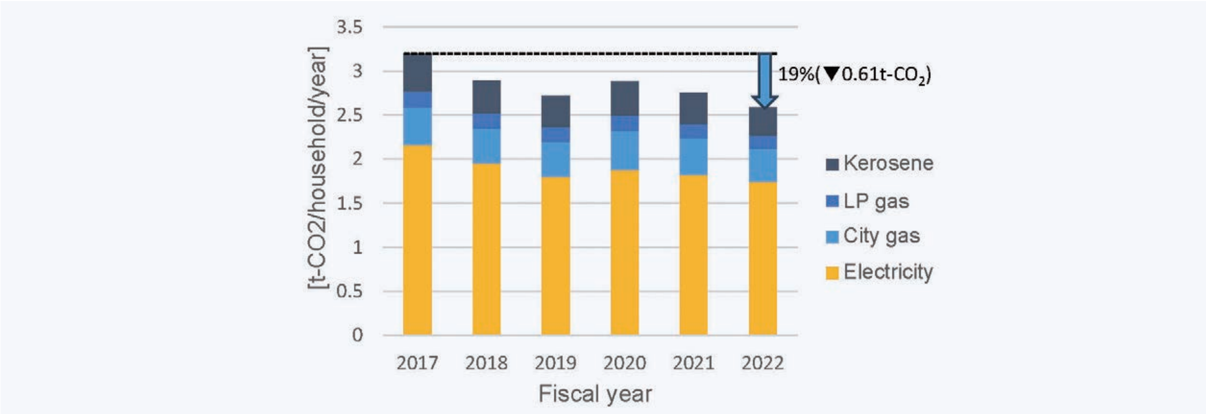


Figure 4.3 Trends in annual CO_2 emissions by energy type per household

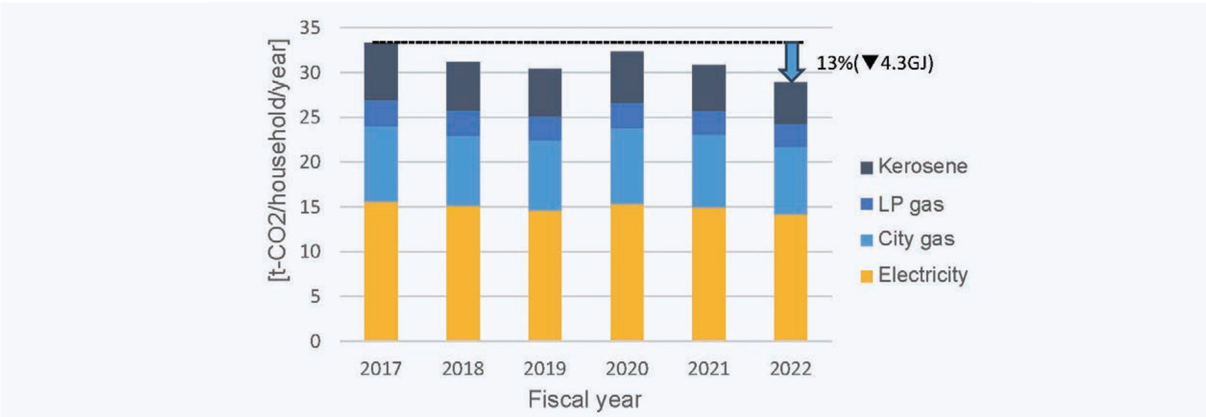


Figure 4.4 Trends in annual consumption by energy type per household

4.2.2 Gap between circulating environmental credits and required amounts

The J-Credit Scheme is one of the systems that have been created as a means to realize an integrated transition that is compatible with both decarbonization and economic circulation[56]. There are differences in the regional characteristics regarding the actors, industries, and financial strength of capital; and the ease of promoting decarbonization measures differs. J-Credit is a scheme aimed at promoting decarbonization of society as a whole while performing economic activities that transfer the decarbonization effects achieved by implementing projects that lead to the reduction and absorption of greenhouse gases to actors who are having difficulty implementing decarbonization measures on their own. (Fig. 4.5)

The government has set a goal of creating J-Credits equivalent to 15 million t-CO_2 (cumulative value) by 2030, and will provide various types of support,[57] but there is a large gap with the emissions that exceed 1 billion t-CO_2 per year. In addition, the industrial, service, and transportation sectors, where CO_2 reduction is significantly impacted by business growth, emit more than 700 million tons of CO_2 annually. [58](Fig. 4.6)

The breakdown of energy consumption in the industrial and service sectors is shown in Figure 4.7, with their share of

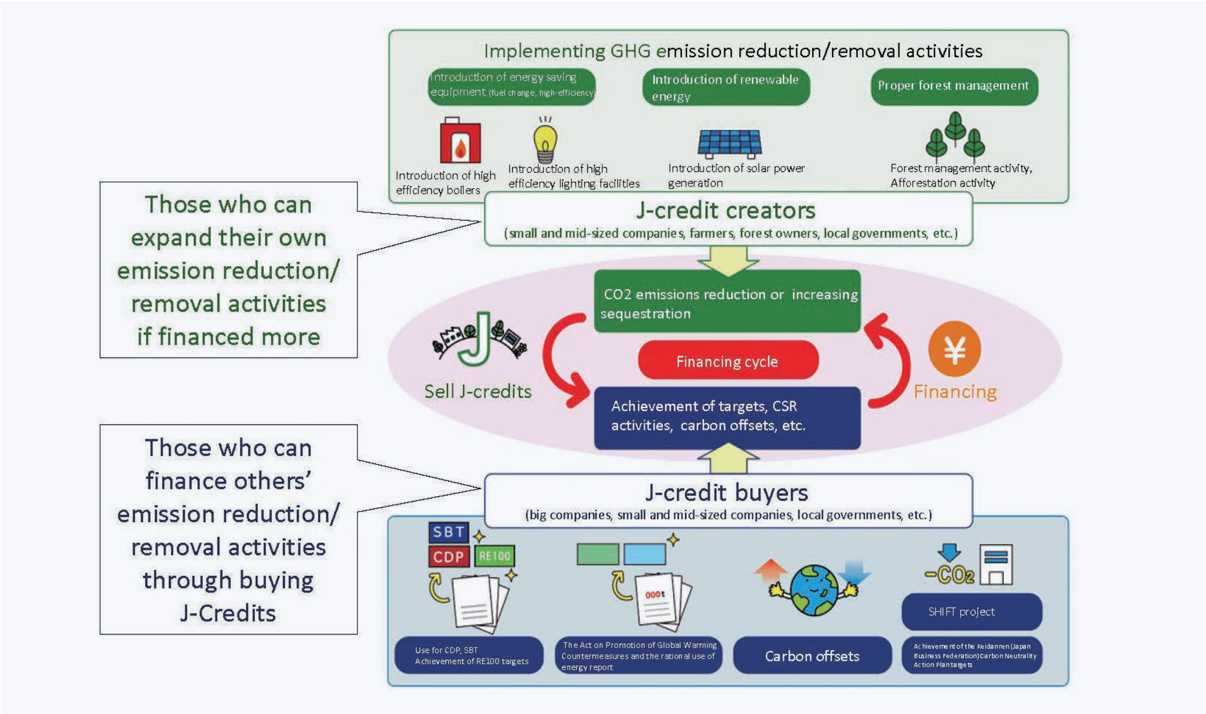


Figure 4.5 J-Credit Scheme (in Japanese)

Figure 4.6 J- Credit creation current status and planned values (results as of March 31, 2023)

56 Ministry of Economy, Trade and Industry. "J-Credit Scheme", https://japancredit.go.jp/about/outline/. Accessed April 23, 2024.

57 Prepared by Hitachi-UTokyo Lab based on the Carbon Credit Report, March 2023, Ministry of Economy, Trade and Industry (METI), 2023

58 The breakdown of GHG emissions in FY2022 is 3.52 million t-CO2 from the industrial sector, 1.79 million t-CO2 from the service sector, and 1.92 million t-CO2 from the transportation sector. Ministry of the Environment. 2024. "GHG Emissions and Removals in FY2022 (Outline)"

electricity being 31%[59]. Maintaining the competitiveness of Japan's industrial and service sectors calls for promoting decarbonization measures, such as by further promoting electrification and energy conservation as shown in Figure 4.8, decarbonizing fuels in industries requiring high-temperature and high-capacity energy, promoting the introduction of solar power for self-consumption, and expanding PPA transactions. For this purpose, national and local governments need to provide appropriate economic support for the introduction of energy-saving and decarbonized equipment, by building a system of engineering services related to the planning and design of such equipment and preparing for the deployment of successful cases. After thoroughly implementing these measures, J-Credits should only be used to cover the shortfall in achieving decarbonization of the industry.

In addition, from the perspective of an integrated transition that is compatible with both the regional economy and the environment, energy utilization and collaboration between different industries can be an important and effective option in which local actors utilize energy from waste heat that cannot be used by specific actors. This calls for the management and sharing of information (data) about which actors need what

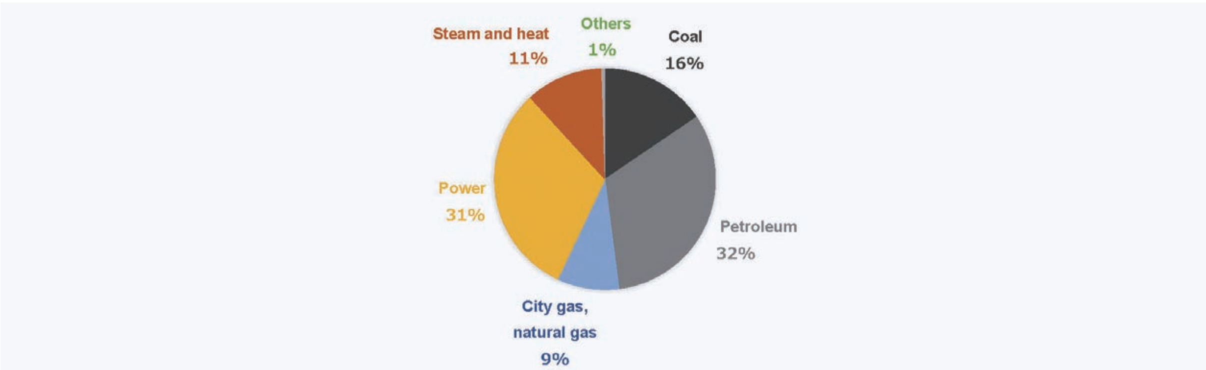


Figure 4.7 Breakdown of energy consumption by companies and offices sectors

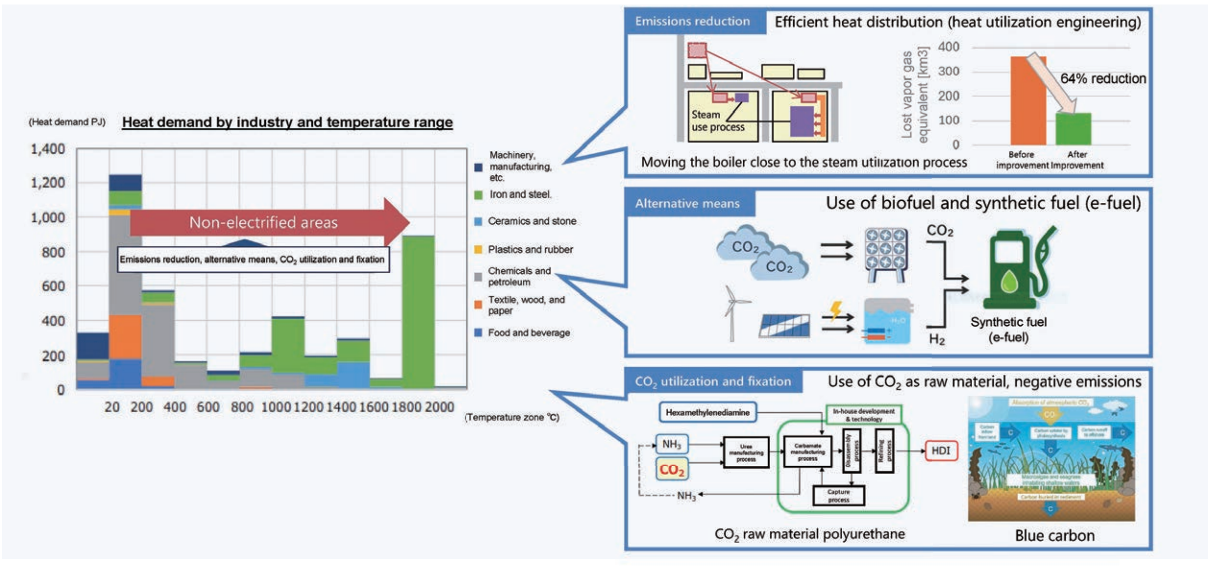


Figure 4.8 CO_2 reduction and fixation methods for use of non-electrified heat[60]

59 Calculated by Hitachi-UTokyo Lab based on Agency for Natural Resources and Energy, 2024, "Energy Supply and Demand Performance in FY2022 (Final Report)" April 2024.

60 Edited based on Hitachi-UTokyo Lab. 2024. "Industry-Academia Collaboration Forum: Toward Realizing Energy Systems to Support Society 5.0: Part 1: Ideal Energy Systems and Growth Strategies that Incorporate Social and Industrial Transformations." The descriptions in the figure are from the following:
Heat demand by industry and temperature zone: NEDO. 2022. "Heat utilization thus far: The 3Rs of heat to pave the way for a decarbonized society" January 27, 2022 https://www.nedo.go.jp/content/100943196.pdf. Accessed April 23, 2024,
Efficient heat distribution: Prepared by Hitachi-UTokyo Lab based on "Hitachi Industrial Equipment Systems. "Minimizing piping color and reducing heat dissipation area by distributing boiler facilities", Accessed April 23, 2024,
Use of biofuels and synthetic fuels (e-fuels): Nagoya University. 2023. Research Results Dissemination Site - Environmental Studies - Article Detailshttps://www.nagoya-u.ac.jp/researchinfo/result/2023/07/co2-e-fuel.htmlhttps://www.nagoya-u.ac.jp/researchinfo/result/2023/07/co2-e-fuel.html. Accessed April 23, 2024
CO2 feedstock conversion: Asahi Kasei Corp. 2020. Introduction of Asahi Kasei's CO2 chemistry for carbon recycling, July 7 https://www.meti.go.jp/shingikai/energy_environment/green_innovation/pdf/001_06_02.pdf. Accessed April 23, 2024. Negative emissions: "Nutrient Supply Management for the Promotion of Blue Carbon" Project Team, "Sewerage Blue Carbon Concept," Japan Society for Environmental System Measurement (2023)

kind of energy and when, and where actors can supply that energy. Such data will not be utilized unless it is purposely collected and shared. It is important that national and local governments act as flag bearers, encourage local actors to see the transition to CN as something that directly concerns them, and create a forum for discussing data ownership and management with national and local governments. Through these discussions, actors should be able to change their own choices and actions, and as needed, seek cooperation outside the region and promote value creation through regional behavioral changes.

4.3 Measures to facilitate the transition of local communities and formulation of growth strategies

4.3.1 Gradual transition while providing value

As mentioned in 4.2, there is a gap between the current state of energy use and the forms of energy use in a CN society, and there is a need for a transition from various aspects, including the perceptions and actions of each actor, the forms of energy use, the structure of the market, and the formation of rules, including subsidies and penalties. Additionally, it is difficult to achieve them at once.

While providing benefits to each actor, it is necessary to carry out a gradual social transition by encouraging the transition of actors, increasing the number of participants in the transition, creating regional benefits by increasing the value, and spreading the efforts nationwide.

To this end, it is important to start the transition from actors with lower barriers to changing behavior and decision-making, or subjects where alternatives already exist, and then to share their success cases widely.

In the design and operation of subsidies, the government should assess the sustainability of the projects being subsidized and monitor the projects so that the number of actors who can use the subsidies will not be limited due to extremely high payment hurdles. It should also work to provide success cases to local governments.

Local governments, on the other hand, should set up a forum for broad discussions with local residents, local industry and business owners, and local financial institution operators about what they want their managed areas to look like in 10 years and what kind of changes they need to bring about in the region. Therefore, it is necessary to promote an open and gradual social transition by discussing the steps of social transition appropriate for the region and disseminating the technologies and human resources that are lacking to realize the steps. In addition, industry, academia, and government should contribute to promoting the transition in society as a whole by actively supporting the provision of information on lacking technologies and human resources to local governments.

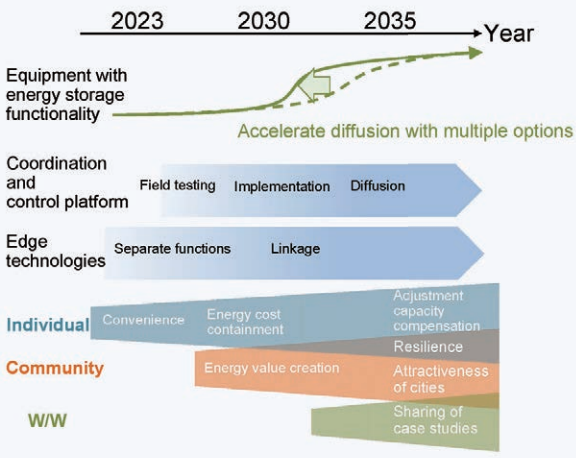


Figure 4.9 Gradual social transition

4.3.2 Revitalization through regional GX and value distribution through local production and local consumption of renewable energy

Attracting renewable energy and industries to the region is a possible means to create environmental credits and revitalize the local economy. In order to avoid excessive concentration of population in urban centers and depopulation in rural areas, industries must be drawn into the regions to contribute to the creation of sustainable economic value. To this end, attracting related facilities must be carried out after depicting the value cycle in the region.

One possible example of this is "local production for local consumption," where renewable energy introduced in the region is fully used through ingenuity in electricity consumption and the flow of value is created within the region. To achieve this, retail power companies should conclude a negotiated contract with renewable energy power generation companies, and at the same time adjust the demand of consumers in the region according to the output of renewable energy to be introduced (energy cooperation). As a result, the renewable energy power generation business will become an investment target with a good return outlook, and regional financial institutions will treat it as an excellent ESG investment project, creating economic benefits for renewable energy power generation operators and regional financial institutions. In addition, renewable energy projects with long-term purchase contracts for generated electricity will be subsidized by the government, making it possible to construct low-cost renewable energy facilities. Retail power providers and local consumers can procure low-cost electricity by effectively utilizing renewable energy generation, and stakeholders who do not need environmental credits can build a value cycle within the region by providing them for a fee to local actors who need them. Through this measure, local renewable energy will become a means of continuous value creation, and appropriate maintenance can be carried out spontaneously in the region.

In order to achieve this win-win situation among stakeholders, it is essential to understand the location and quantity of assets existing among consumers that can create adjustment capacity. A forum should be promptly set up to discuss the construction of a consumer asset database that will serve as the basis for this information. Hitachi-UTokyo Lab invites local governments and companies to participate in the project and demonstrate to society the creation of local value through the collaborative control platform.

Also, in order to establish local production for local consumption as part of the regional economy and maximize resilience in the event of a disaster, parallel discussions should be carried out to review grid utilization rules to encourage local production for local consumption and to redefine the quality of electric power in the event of a disaster. Further, from a medium-term perspective, the maintenance, management, and renewal of the massive solar power facilities installed in the region should be addressed. In addition to the above-mentioned utilization that will lead to continuous value creation, the development of maintenance systems for small-scale solar power generation facilities and the development of technologies for the recycling of solar panels and other resources should be accelerated.

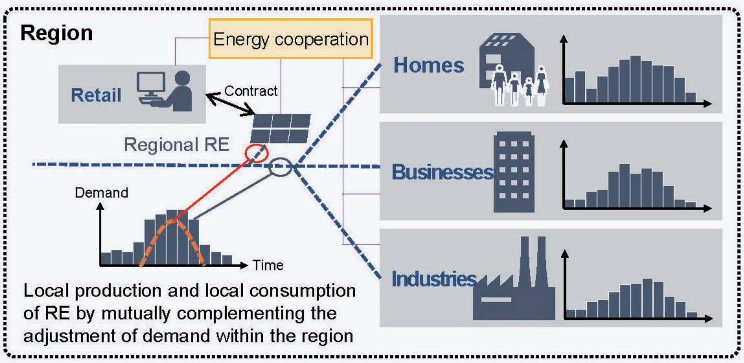


Figure 4.10 Local production for local consumption of renewable energy through energy cooperation

4.3.3 Negative emissions compatible with local economies

As mentioned above, most of the energy consumption in industry is dependent on current fuels, and this includes in large part uses by non-electrified industries. Figure 4.11 shows the final energy use and CO_2 balance in the nuclear power use scenario explained in Chapter 3. Even in 2050, when carbon neutrality is achieved, fuel-based energy consumption will account for half of the energy consumption, and CO_2 storage will be chosen for 300 million tons of the collected CO_2 for export overseas at a cost. This amount of storage must also be reduced from the standpoint of international environmental conservation and social cost control.

A method to combine wood biomass power generation using thinned wood with industrial methods (Countermeasure 1) is a possible measure to reduce CO_2 storage and, at the same time, to achieve economic and natural recovery in the region. In addition, the use of blue carbon, which takes advantage of the characteristics of island countries, is also an important measure (Countermeasure 2). The implementation format for both measures is shown in Figure 4.12[61].

In Countermeasure 1, proper thinning prevents crowding of trees, promotes better photosynthesis, and contributes to the restoration of local forests and the revitalization of the forestry industry, thereby achieving a balance between attaining a negative emission outcome and sustaining the local economy.

Countermeasure 2 promotes CO_2 absorption and solidification through cultivation of seaweed beds with nutrients obtained from sewage treatment, while giving due consideration to the impact on the ecosystem. Furthermore, the absorbed CO_2 is converted into environmental credits, thereby simultaneously improving fishing grounds and creating regional value.

Japan's Ministry of the Environment became the first in the world to report to the United Nations a greenhouse gas inventory calculated by combining the sequestration from macroalgal beds and seagrass meadows, a blue carbon ecosystem[62]. The

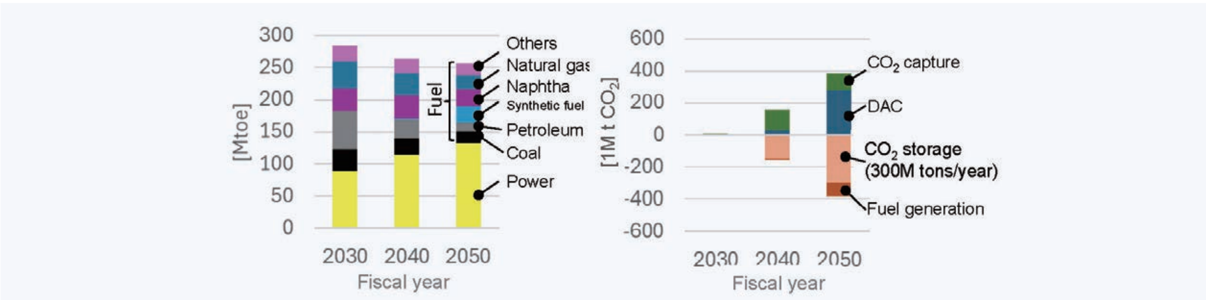


Figure 4.11 Final energy use and CO_2 balance in the nuclear power use scenario

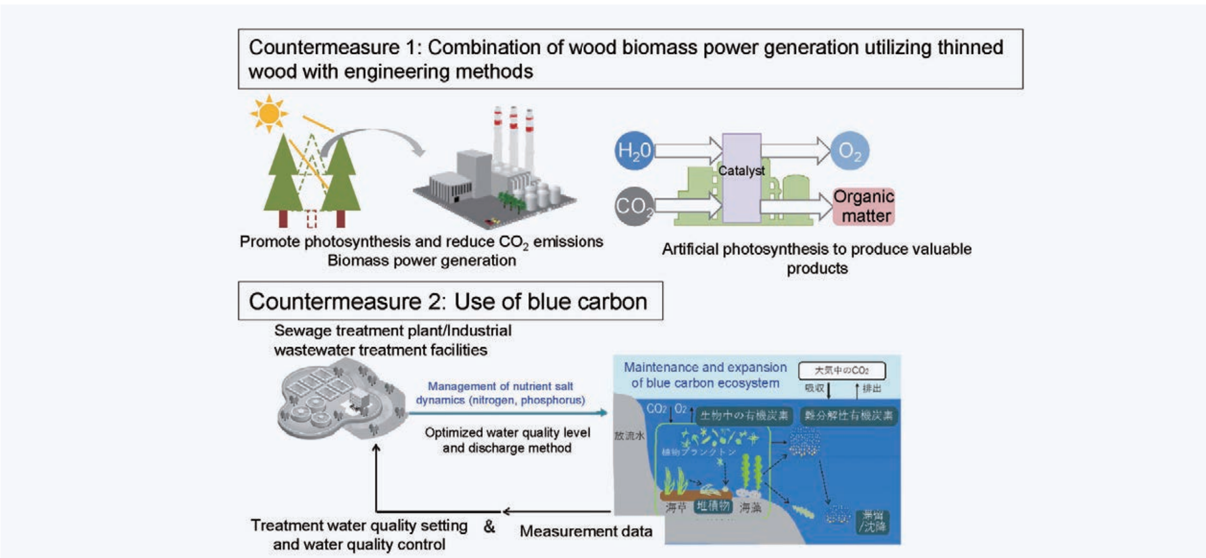


Figure 4.12 Achieving negative emissions to enable value distribution while recovering the destroyed environment

61 "Nutrient Supply Management for the Promotion of Blue Carbon" Project Team, "Sewerage Blue Carbon Concept," Japan Society for Environmental System Measurement (2023)

62 Ministry of the Environment, 2024. "Japan's GHG Emissions and Removals in FY 2022" April 12, https://www.env.go.jp/press/press_03046.html. Accessed April 23, 2024

Hitachi-UTokyo Lab believes that we should support such new initiatives that take advantage of national characteristics and accelerate negative emissions that contribute to the creation of value in the region and the restoration of ecosystems. In collaboration with Imperial College London, a world leader in biodiversity research, we will conduct analysis for the realization of a sustainable blue carbon scheme and reflect the results in our recommendations.

4.4 Chapter 4 Summary

Local communities are the foundation of people's lives and society, and they are expected to play a role in realizing S+3E through smart energy use toward achieving carbon neutrality.

The government's 2030 GHG emission reduction strategy calls for the proactive promotion of decarbonization in the household and business sectors, ahead of industries that require time to reduce emissions.

In this chapter, we examined the requirements and measures through an objective review of regional decarbonization and from the viewpoint of achieving regional integrated transition. The main points are summarized below.

- As a concrete method for the gradual transition towards the realization of an integrated transition that is compatible with both the environment and the economy, we presented an example of regional economic revitalization through local production and local consumption of renewable energy using digital technology and negative emissions that are in harmony with natural restoration leveraging regional characteristics.
- To successfully proceed with the transition of communities, the national government needs to show success stories to municipalities by monitoring not only the actors who are eligible for the subsidies. Local governments should set up a forum for broad discussions with local actors on their vision for FY2050, steps to achieve it, and issues to be addressed. In addition, if there is a shortage of technology and human resources, it should be communicated outside the region to accelerate the transition to a decarbonized society.
- The full use of renewable energy within the region based on energy cooperation and the intra-regional circulation of environmental credits can be a means for a social transition compatible with both the economy and the environment. To encourage this, we should discuss at an early stage the construction of an asset database of customer facilities with adjustment capacity as basic information for energy cooperation, and the revision of rules for grid utilization.
- As a measure to reduce CO_2 storage and simultaneously achieve natural restoration and regional economic revitalization, we presented an example of a blue carbon scheme through cultivation of seaweed beds. Hitachi-UTokyo Lab will support integrated decarbonization measures that take advantage of national characteristics. At the same time, we will proceed with analysis toward the realization of a sustainable blue carbon scheme and reflect it in our recommendations.

Chapter 5 Summary

As a summary of the recommendations, the timing of implementation of the recommendations (short-term: from now to 2030, medium- to long-term: from 2030 to 2050) and the content of the recommendations are described below.

Seventeen recommendations “toward realizing energy systems to support Society 5.0”

[Short-term]

Chapter 2: Changing global landscape and integrated energy transition

1. Governance that accelerates integrated transition even in the face of rapid geopolitical change

In today’s world, climate change, geopolitical issues, and other global environmental issues have created a complex crisis that has seriously stalled efforts to build a sustainable world. Measures to combat climate change must be pursued to not only address environmental issues, such as biodiversity loss, but also achieve regional revitalization, industrial transformation, and gender equality. Accordingly, Japan’s energy transition should be achieved through an integrated approach based on organic relation with transitions in other areas. This integrated transformation can only be accelerated by transforming the very governance that supports it.

2. Identification of pathways to innovation and structural transformation for a green economy

Japan’s green-transformation policy should not just focus on the gradual development of existing industries formed during the period of high economic growth; instead, it should also focus on the following three tasks: (i) transforming the industrial structure into one that will be able to thrive in the green economy of the future, (ii) identifying paths for transformation that include innovation, labor, regional revitalization, resource security, location, and international cooperation, and (iii) making targeted investments in priority sectors.

3. Promotion of international collaboration on climate, energy, and environment in the Asia-Pacific region

Japan cannot achieve its energy transition on its own. Energy demand in the Asia-Pacific region is expected to increase significantly owing to future population growth and economic development. Japan should determine its role in achieving a sustainable transition for itself and the region while building new cooperative relationships with countries in the Asia-Pacific region in a wide range of areas related to climate, energy, and the environment. At the same time, Japan should build on its existing friendly relationships and trust while also working in harmony with existing strategic frameworks in the Asia-Pacific region and the unique needs of each nation’s people.

4. Decision-making frameworks and human-capital development for integrated transition in the region

Local communities play an important role in concrete efforts towards an integrated transition in Japan. The central government is expected to support local governments in decision-making and human-resource development so that they can achieve long-term prosperity for their communities through a green transformation. In particular, local governments are being called upon to draw up specific plans for transition tailored to local conditions and implement them in conjunction with a variety of actors. They aim to secure human resources who have a deep understanding of their unique natural environments and social contexts as well as the ability to implement cutting-edge initiatives. The central government is expected to go beyond allocating policy funds and work to strengthen local planning and implementation capacities for the integrated transition. Furthermore, to overcome potential discrepancies between local governments’ own initiatives and national decision-making, the central government and local governments must cooperate more closely to jointly achieve decarbonization and greening of the economy.

5. Consensus-building platform based on scientific evidence and inclusive dialogue

An integrated energy transition in Japan necessitates a broad intellectual base and participatory decision-making among a variety of actors. In particular, it will be necessary to support effective initiatives through expertise in the energy sector as well as scientific analysis and evaluation of local conditions and policies. It would also be useful to use scientific methods to analyze the initiatives that have developed in each region under different conditions and capabilities and share practical knowledge with each region. Moreover, to avoid “lock-in,” which is an obstacle to a green transition, and ensure long-term prosperity in the future, it is important to make decisions in conjunction with a variety of actors—particularly those who have been marginalized in energy discussions up until now—rather than formulating policies solely among those involved in the traditional energy system. Implementing a platform for consensus building based on scientific evidence and inclusive dialogue will make a just and sustainable transition more likely.

Action by Hitachi-UTokyo Lab

Through analysis of international cases and the latest academic research, we will search for the ideal form of governance that supports an integrated energy transition and provide materials for inclusive consensus building through dialogue with various actors. Moreover, through cooperation with universities and companies, we will strive to develop human resources who can promote an integrated transition with their specialized skills and extensive knowledge.

Chapter 3: The ideal form and growth strategies for energy systems that incorporate social and industrial reforms

6. Review of energy scenarios in light of drastically changing global affairs

We revised the energy scenarios in response to the increase in ICT demand at data centers, etc., as well as the surge in oil price and in consideration of the drastically changing global affairs. As a result, we determined that the following measures must be carried out by 2030 to realize the CN scenarios: (1) accelerate the introduction of renewable energy (88 GW of solar power generation and 15 GW of wind power generation) and secure decarbonized power sources such as operation of all existing nuclear power generation plants, (2) avoid waste in a short period of time from PV introduction and solve environmental issues in installation, (3) operate hydrogen and ammonia power generation exceeding 10 GW, (4) use of heat from fossil fuel power generation through cogeneration, and (5) ensure energy resilience and security during rare windless and continuous cloudy weather, fuel shortage, and disasters. Also, toward 2040-2050, innovation should be carried out by developing and investing in: (1) the further increase of CN power sources such as solar, wind, and nuclear power, (2) the commercialization and widespread adoption of CO2 capture by DAC, and (3) the production of synthetic fuel from the captured CO2 and its use in the transportation and industrial sectors.

7. Backcasting and forecasting gaps and countermeasures for energy systems

The following countermeasures must be implemented to address issues in bulk power systems in response to the rapid increase in the amount of renewable energy: (1) securing the number of thermal and nuclear rotary machines in operation and introducing inertial control of distributed resources in response to frequency decline due to decreased inertia; (2) utilization of local resources and measures to avoid grid congestion in response to frequency fluctuations due to insufficient adjustment capacity; (3) sophistication of regional power storage and EV control, in addition to the enhancement of power transmission, in response to the deterioration of grid stability; and (4) sophistication of inverter control and integrated control in response to instability due to the increase in inverter power supply.

8. The importance of medium- to long-term institutional design and measures beyond the short-term market principle

There is a need to (1) clarify the separation between economic efficiency aimed at short-term merit orders, and medium- to long-term policy objectives such as stable supply and decarbonization, and to (2) further study market design aimed at efficiency.

9. Rebuilding the electric power market and merging the environmental value market

There is a need to move away from the current situation where each market is asymmetrical, i.e., where equal regulations are not imposed on both sides. To realize this, we will visualize the status of power supply operation and thoroughly monitor the market, and further integrate the environmental value market with the aim of creating a virtuous cycle toward CN.

10. Building social systems through the participation of local communities and consumers

A sustainable system that encourages consumers to actively invest in the environment must be built. It is necessary to secure carbon-neutral power sources through corporate PPAs and other consumer-based decisions and to implement policies that integrate measures to curb global warming with a consumer-driven emissions trading system.

Action by Hitachi-UTokyo Lab

The Hitachi-UTokyo Lab will continue to work on the development of energy scenario evaluation simulation technology, the evaluation of CN transition scenarios in response to changes in domestic and overseas state of affairs, the selection and development of innovative technologies for solving energy system issues, and the proposal of platforms for sharing data and analysis models among various stakeholders.

In addition, we will contribute to the construction of a consumer-led system through digital technology that makes it possible to visualize CO_2 emissions based on data and provide information from the consumer's perspective on carbon neutrality.

Chapter 4: Contribution of the regions to balance CN and S+3E of energy supply and demand

11. Contribution of the regions to balance CN and S+3E of energy supply and demand

To successfully proceed with the transition of communities, the national government needs to show success stories to municipalities by monitoring not only the actors who are eligible for the subsidies. Local governments should set up a forum for broad discussions with local actors on their vision for FY2010, steps to achieve it, and issues to be addressed. In addition, if there is a shortage of technology and human resources, it should be communicated outside the region to accelerate the transition to a decarbonized society.

To realize the above demand coordination, it is necessary to promote widespread use of equipment with necessary functions and to implement a coordination and control platform in society at an early stage.

12. Measures to facilitate the transition of local communities

In order to decarbonize industries, there is a need for businesses to proactively promote electrification and energy conservation. For this purpose, the national and local governments need to provide appropriate economic support, build a system of engineering services related to the planning and design of equipment, and prepare for the deployment of successful cases. After thoroughly implementing these measures, J-Credit should be used to cover the shortfall in order to achieve decarbonization of the industries.

Provision of means to support gradual transition, clarification of roles and participation of all, and collaboration among different industries through data linkages will accelerate the regional transition of local communities towards CN. The national and local governments should create a venue where each actor sees the transition as something that directly concerns them, leading to a change in behavior.

13. Objective analysis of social changes associated with 13. CN and formulation of growth strategies

In order to steadily promote CN in local communities, it is necessary to objectively analyze the energy use situation in each sector and to recognize their goals and achievements. Measures should be taken to bridge the gap between goals and achievements in a way that benefits local actors. For example, are the full use of renewable energy within the region based on energy cooperation and a social transition that balances the economy and the environment through intra-regional circulation of environmental credits. An asset database of customer facilities with adjustment capacity, which will serve as the basic information for energy cooperation, should be created to achieve energy cooperation. The establishment of this database and the revision of rules for grid utilization to encourage local use of renewable energy should be discussed at an early stage.

14. Development of negative emission technology in harmony with nature to expand transition options and their likelihood

Negative emissions that are in harmony with natural restoration leveraging regional characteristics expand transition options and their likelihood. As a measure to reduce CO2 storage, Hitachi-UTokyo Lab presented an example of a blue carbon scheme through cultivation of seaweed beds. Support should be given to integrated decarbonization measures that take advantage of national land characteristics, e.g., large marine area.

Action by Hitachi-UTokyo Lab

The Hitachi-UTokyo Lab invites local governments and companies to participate in the project and demonstrate to society the creation of local value through the collaborative control platform. Also, at the same time, we will proceed with analysis toward the realization of a sustainable blue carbon scheme and reflect it in our recommendations.

[Medium to long term]

Chapter 2: Society based on the realization of carbon neutrality by 2050

15. Regional transition paths

Each region in Japan has its own natural environment, social issues, lifestyles, and energy potential, and each region can have its own transition path. The national and local governments should empower the initiative of diverse actors in the region by supporting green transformation, including decision-making and human resource development, and show different transition paths for each region. Moreover, such long-term initiatives should be steadily implemented.

16. Strategic industrial policies for the sustainable development of the regions

Many municipalities are taking the challenge to formulate and implement policies in areas where they have little experience to achieve a sustainable transition beginning with decarbonization. Meanwhile, the national government must promote these initiatives through strategic industrial policies so that each region can achieve a sustainable economy through green transformation.

Action by Hitachi-UTokyo Lab

We will present policy options through analysis of specific conditions and obstacles for regional transitions and research of international cases.

Chapters 3 and 4: Technical measures for energy systems

17. Countermeasure technologies for energy scenarios toward achieving carbon neutrality

Toward 2040-2050, innovation should be carried out for (1) the commercialization and widespread adoption of CO_2 capture through DAC, and (2) the production of fuel from the captured CO_2 and its use in the transportation and industrial sectors.

Local communities face the challenge of maintaining and managing small-scale solar power generation systems installed in large numbers. The development of maintenance systems for renewable energy resources should be promoted, along with the acceleration of the development of recycling technologies.

Action by Hitachi-UTokyo Lab

In addition to technological development, there is a need to train leaders to promote continuous social transition and promote citizen education on CN. Hitachi-UTokyo Lab will continue to make evidence-based proposals and provide opportunities for awareness through industry-academia-government collaborations.

Team Members of Proposal Version 6 (as of March 31, 2024)

1. The University of Tokyo		
Atsushi Tsuda	Overall supervision	Executive Vice President
Shinobu Yoshimura	Coordinator WG1	Professor, Graduate School of Engineering
Ichiro Sakata	WG1	Special Assistant to the President; and Professor, Graduate School of Engineering
Hiroshi Esaki	WG1	Professor, Graduate School of Information Science and Technology
Ryoichi Komiyama	WG1	Professor, Graduate School of Engineering
Akihiko Yokoyama	SWG1	Professor Emeritus
Hiroshi Ohashi	SWG1	Vice President; and Professor, Graduate School of Economics
Yasumasa Fujii	SWG1	Professor, Graduate School of Engineering
Kazuhiko Ogimoto	SWG2	Project Professor, Institute of Industrial Science
Yumiko Iwafune	SWG2	Professor, Institute of Industrial Science
Jumpei Baba	SWG2	Professor, Graduate School of Frontier Sciences
Kenji Tanaka	SWG2	Associate Professor, Graduate School of Engineering
Hideaki Shiroyama	SWG3	Professor, Graduate School for Law and Politics, Professor, Graduate School of Public Policy
Hisashi Yoshikawa	SWG3	Project Professor, Graduate School of Public Policy
Masahiro Sugiyama	SWG3	Associate Professor, Institute for Future Initiatives
Kensuke Yamaguchi	SWG3	Project Professor, Graduate School of Public Policy
Pinar Temocin	SWG3	Project Associate Professor, Institute for Future Initiatives
Hiroaki Inagaki	Secretariat	Associate Managing Director; and Director, Division of University Corporate Relations
Masaru Ohyama	Secretariat	Manager, Division of University Corporate Relations
Ryota Tezuka	Secretariat	Division of University Corporate Relations
Chizuru Katou	Secretariat	Division of University Corporate Relations

2. Hitachi		
Hideyuki Matsuoka	Coordinator	Technology Advisor, Center for Exploratory Research, Research and Development Group
Naohiro Kusumi	WG1	General manager, Center for Sustainability, Research and Development Group
Atsushi Baba	WG1	General manager, Decarbonized Energy Innovation Center, Center for Sustainability, Research and Development Group
Tatsuya Yamada	WG1	Division General Manager, Business Planning & Management Division, Energy Business Administration Division
Yasuo Sato	WG1	Technical Engineer, Energy Solution Division, Control System Platform Division
<u>Masahiro Watanabe</u>	SWG1	Principal Researcher, Decarbonized Energy Innovation Center, Center for Sustainability, Research & Development Group
Yasuhiro Ohata	SWG1	Deputy Department Manager, Business Planning & Management Division, Energy Business Administration Division
Naoki Yoshimoto	SWG1,2	Chief Researcher, Decarbonized Energy Innovation Center, Center for Sustainability, Research & Development Group
Eisuke Kuroda	SWG1	Chief Researcher, Decarbonized Energy Innovation Center, Center for Sustainability, Research & Development Group
<u>Tomomichi Ito</u>	SWG	Principal Researcher, Decarbonized Energy Innovation Center, Center for Sustainability, Research & Development Group
Hideki Hanami	SWG2	CTO, Industrial Digital Business Unit
Tomoyuki Hatakeyama	WG2	Principal Researcher, Decarbonized Energy Innovation Center, Center for Sustainability, Research & Development Group
<u>Tomoko Suzuki</u>	SWG3	Corporate Chief Researcher, Research and Development Group
Hidehiro Iizuka	SWG3	Sub Leader, Planetary Boundaries Project, Center for Sustainability, Research & Development Group
Takashi Fukumoto	SWG3	Sub Leader, Planetary Boundaries Project, Center for Sustainability, Research & Development Group
Yukihide Inagaki	SWG3	Chief Researcher, Planetary Boundaries Project, Center for Sustainability, Research & Development Group
Shinya Ohara	SWG3	Chief Researcher, Planetary Boundaries Project, Center for Sustainability, Research & Development Group
Koji Sasaki	SWG3	Chief Researcher, Planetary Boundaries Project, Center for Sustainability, Research & Development Group

WG1: Overall Vision Working Group, WG2: Global Initiative Review Working Group, SWG1: Energy Systems and Frameworks and Policies Subcommittee, SWG2: Social Implementation Subcommittee, SWG3: Scenario Development Subcommittee. Underlined names are WG leaders

Appendix 1 | Energy technology selection model (dynamic cost minimization-based model)

In Chapter 3, to quantitatively present the supply-demand structure of energy systems and the necessary measures for the transition to CN in 2030 and 2050, we use an energy-economic simulation model based on the technology selection model developed by the Fujii-Komiyama Laboratory of the University of Tokyo. The features of this model are as follows:

- The cost optimization of energy supply-demand structure under CO_2 emission constraints for the entire energy supply in Japan can be calculated.
  Evaluation of the entire energy system that assumes the following, as shown in A1.1, is carried out.
  Detailed analysis of energy sectors (primary energy, conversion sector, final consumption sector [industries, households, businesses, passengers, freight])
  (Temporal resolution -> 1 hour value, analysis at 8,760 hours per year -> Renewable energy output variability is taken into account in detail)
- Individual technologies on the energy supply side (primary/secondary energy) and demand side (steel, cement, chemicals, consumers, transportation, etc.) are accumulated and analyzed. Possible to consistently analyze CN and energy supply/demand of transitions to achieve it.
- Diverse technological elements, including innovative technologies, are taken into account: next-generation vehicles (EVs, FCVs), energy storage (Li-ion batteries, NAS batteries, thermal storage), CCUS (direct capture of CO2 in the atmosphere, methanation, FT synthesis) energy carriers (hydrogen, ammonia, methanol, synthetic gas, synthetic oil), power generation technologies (hydrogen power, ammonia power, offshore wind power, fuel cells, thermal power storage), energy-saving technologies (heat pump), etc.

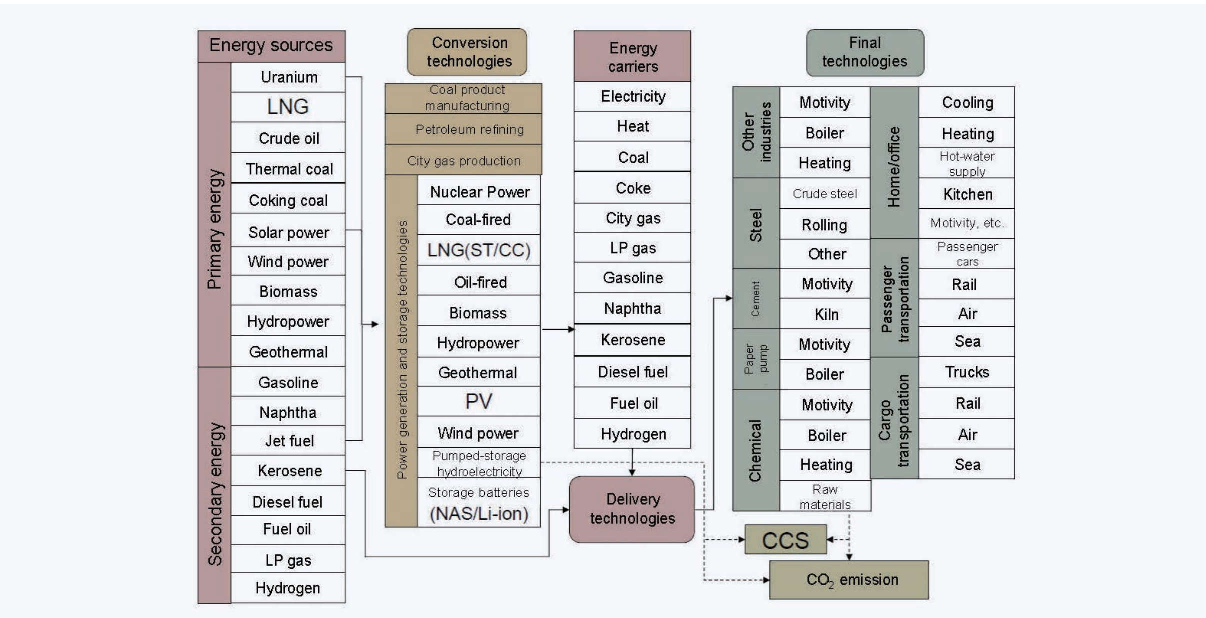


Figure A1.1 Standard energy systems

Figure A1.2 shows the main conditions (base conditions) of the simulation performed in Section 3.1. The conditions for each energy scenario are shown in Table A1.1. From Version 5, the upper limit on the introduction of renewable energy (offshore wind power) has been increased and updated in order to respond to the increase in electricity demand from data centers and other facilities.

- **Assumption: All major decarbonization tech (RE, nuclear, hydrogen, CO_2 capture) are deployed**
- **Cost-optimized simulations for 2050 CN and transitions**

CO_2 emissions (reduction targets)
2030: Compared to 2013 -46 %
2050: Net zero (-100 %)

Power generation/tech deployment conditions (2050)

Solar power (PV): New installations and no upper limit on capacity
JPEA's target is 300 GW in 2050 (*1)

Wind power: New construction with target of 40 GW for onshore and 90 GW for offshore turbines
Targets proposed by JWEA to government (*2)

Nuclear power: New installations with upper limit of 50 GW
・Restart of existing plants / extension of operational life (from 40 to 60 years) (excluding plants to be decommissioned)
・Completion and start of three new plants (currently halted construction)
・New construction of SMRs, etc.

Hydrogen power: Import volume: 20 million t / Import price: 20 yen/Nm3
Target values in "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" (*3)

Conditions for CO_2 capture tech deployment
Introduction of CO_2 capture tech to reach emission reduction targets
CCS (Carbon Capture, Utilization & Storage)
DAC (Direct Air Capture of CO_2)

*1) Source by JPEA (published by 8th March 2021)
https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/026_05_00.pdf
*2) Soource by JWPA (published by 24th March 2021)
https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/039/039_008.pdf
*3) Green Growth Strategy Through Achieving Carbon Neutrality in 2050
https://www.meti.go.jp/policy/energy_environment/global_warming/ggs/pdf/green_honbun.pdf

Figure A1.2 Maini simulation conditions (base conditions)

Table A1.1 Conditions of each energy scenarios

	(1) 100% RE	(2) Thermal power with CCS limit	(3) Use of nuclear power	(4) Hydrogen procurement
Nuclear plant life (years)	Stopped	60	←	←
Nuclear plant cap. upper limit (GW)	0	24	50(SMR)	←
Thermal power with CCS upper limit (ton)	200 mil.	100 mil.	200 mil.	←
Hydrogen import upper limit (ton)	20 mil.	←	←	No upper limit
Hydrogen price (¥/Nm^3)*1	20	←	←	←
FCV price (compared to current)	0.68	←	←	0.20
EV price (compared to current)	0.68	←	←	←
Solar power upper limit (GW)	None	←	←	←
Onshore wind power upper limit (GW)	40	←	←	←
Offshore wind power upper limit (GW)	90→200	←	←	←
Solar power construction cost (10k yen/kW)	15	←	←	←
Onshore wind turbine construction cost (10k yen/kW)	21	←	←	←
Offshore wind turbine construction cost (10k yen/kW)	51	←	←	←
CCS cost (¥/tonCO_2)	7450	←	←	←
DAC cost (¥/tonCO_2)	10,340	←	←	←
LIB battery cost (¥/Wh)	10	←	←	←
	RE only (e.g. PV and wind power)	Limited CCS for thermal power	Additional SMRs after 2040	Import of hydrogen from overseas

CN: Carbon Neutrality, CCS: Carbon dioxide Capture and Storage, DAC: Direct Air Capture, EV: Electric Vehicle, FCV: Fuel Cell Vehicle, SMR: Small Modular Reactor, LIB: Lithium-ion Battery

*1) Annual cost: Sum of energy cost (=fuel cost) from primary energy to final energy consumption and capital investment cost in 2050
*2) Capital costs of hydrogen importers are not taken into account.

Appendix 2 | Examples of issues and solutions of energy systems

Figure A2.1 shows issues and countermeasures in bulk power system accompanying a rapid expansion of renewable energy and Figure A2.2 shows issues and countermeasure of accompanying large-scale deployment of inverter power supplies as in renewable-energy power supplies and storage systems.

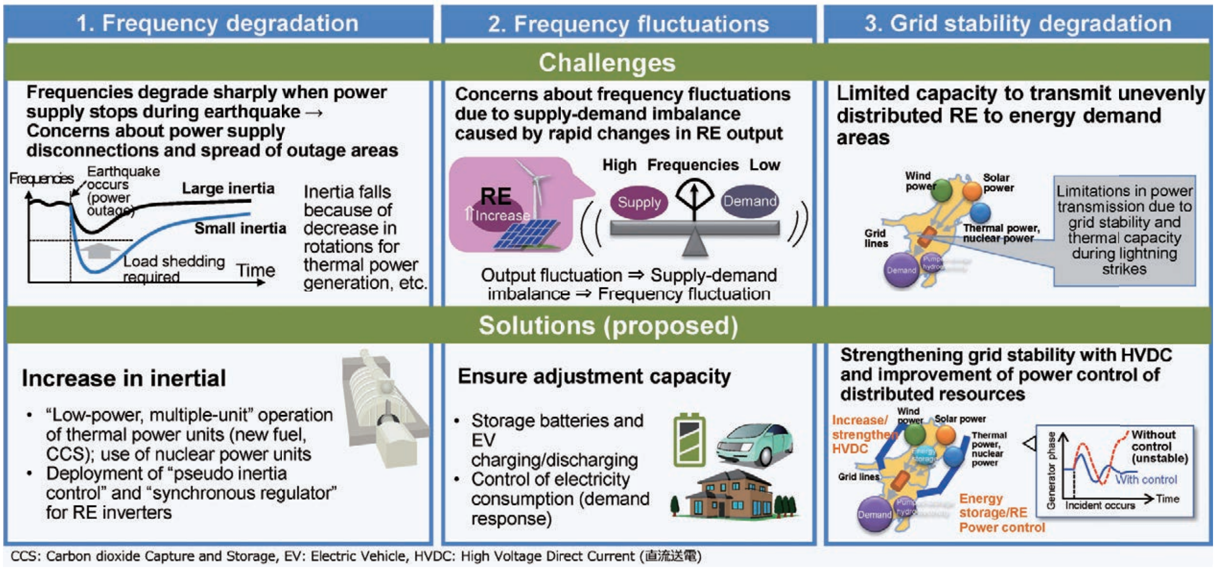


Figure A2.1 Issues and countermeasures in the bulk power system accompanying a rapid expansion of renewable energy

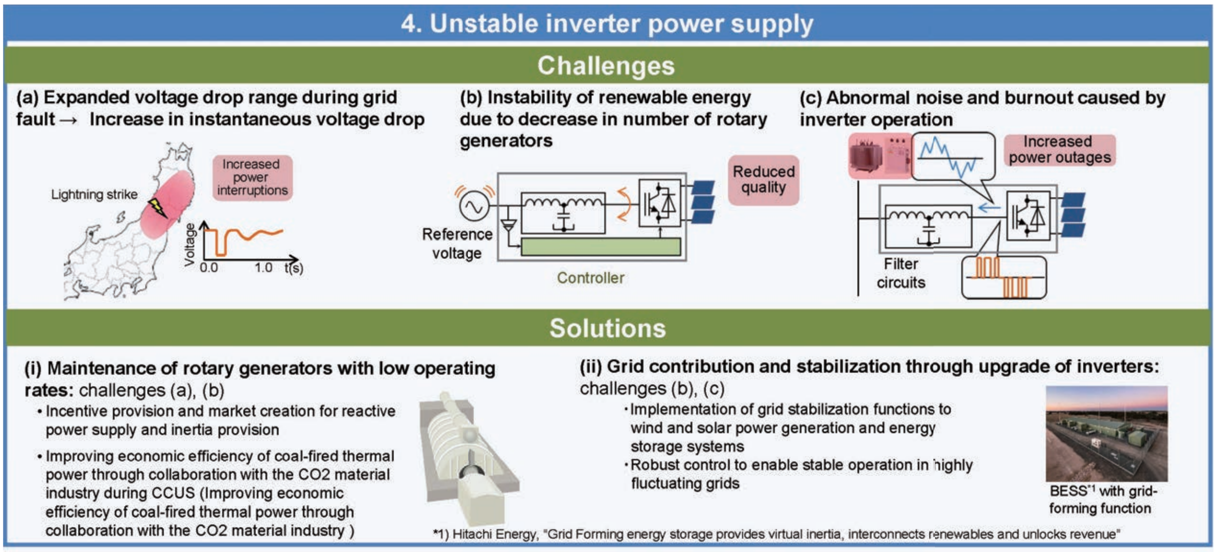


Figure A2.2 Issues and countermeasure accompanying large-scale deployment of inverter power supplies


H-UTokyo Lab.
Hitachi and UTokyo Joint Research