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Inspire the Next

Proposal

Toward Realizing Energy Systems to Support Society 5.0

(Ver. 4)

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Hitachi-UTokyo Laboratory

Contents

Chapter 1 Executive Summary

Since 2016, the Energy Project of Hitachi-UTokyo Laboratory has been proposing visions and scenarios for energy systems. Version 2 of "Toward Realizing Energy Systems to Support Society 5.0" published in 2019 presented proposals toward an 80% reduction in CO_2 emissions as set forth in the Paris Agreement. Then, in 2021, Version 3 presented proposals on technologies, systems, and policies toward carbon neutrality and declared the beginning of activities for formulating social transition scenarios.

Now, with Environmental, Social, and Governance (ESG) investing taking hold and discussions beginning on Japan's Sixth Strategic Energy Plan and Clean Energy Strategy along with other social movements, Version 4 summarizes issues in achieving carbon neutrality by 2050 and social sustainability from 2050 on and presents the results of discussing initiatives for solving those issues. This version is organized as follows.

① Chapter 3: To achieve carbon neutrality, it will be necessary to analyze the current state of various domains and to uncover pathways for social and technical transitions essential to achieving a common vision of the future. Hitachi-UTokyo Laboratory has formulated "transition scenarios" by describing scenarios covering multiple cases and time profiles and has derived insights from those scenarios.

② Chapter 4: Simulation-based analyses are important for formulating future plans. This proposal presents the results of quantitative analyses that take into account seasons, time periods, climate, and demand fluctuation and concludes that costs will be minimized if energy systems for achieving carbon neutrality consist not only of renewable energy and new fuels but also conventional thermal power plants equipped with Carbon Capture and Storage (CSS) and nuclear power plants used in combination. Studies on achieving carbon neutrality and formulating transitions must involve quantitative discussions and evaluations that include alternative means of configuring power supplies, supplying power, and reducing emissions. In addition, upgrading of the power transmission system deemed essential to carbon neutrality must begin as early as possible in conjunction with the expanded use of renewable energy.

③ Chapter 5: Achieving carbon neutrality will require decision-making by all concerned including individuals, companies, and public institutions. All members of a local community must agree upon a common regional stance including resilience, intelligent regional reform based on data must take place in a step-by-step manner, and a transition must be promoted based on win-win relationships.

④ Chapter 6: Stable power supplies independent of fuel market conditions will be essential to the stable supply of energy in the process of shifting to carbon neutrality. In addition, a drastic reform of the manufacturing supply chain with a view to economic security guarantees must be promoted as well as an environment that can achieve optimization throughout manufacturing including product lifecycles, all on the basis of data usage. Furthermore, given that large amounts of renewable energy waste and the appropriate processing of recovered CO_2 are issues of concern in a carbon neutrality society, it will be necessary to achieve a recycling-based society that can utilize this waste as resources. There will also be a need for ongoing planning of systems and policies to provide assistance in solving critical social issues, supporting innovation to accelerate reforms, and constructing a decision-making platform for developing land, communities, and cities based on data usage.

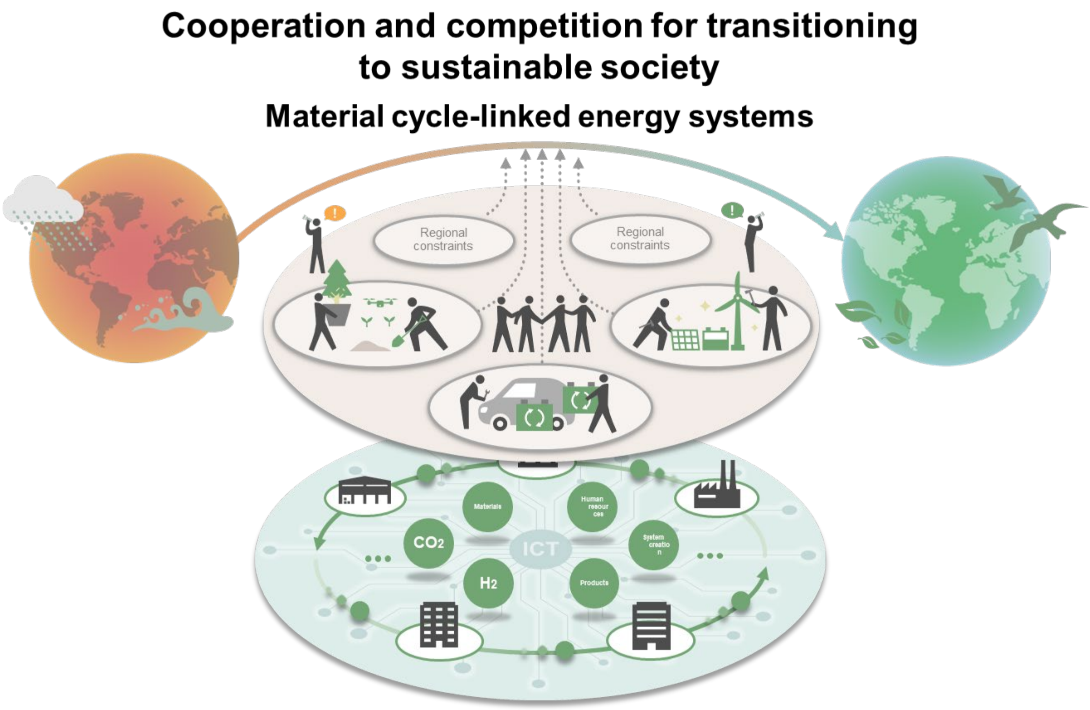

Figure 1-1 Vision and concept of a sustainable society

Chapter 2 Introduction

The Glasgow Climate Pact negotiated at the 26th United Nations Climate Change Conference (COP26) held in November 2021 is a global agreement on limiting global warming to a temperature increase of 1.5°C by 2050. It represents a shared recognition across nations and industries that the environmental carrying capacity as specified by a planetary boundary for environmental balance on earth is being saturated. In short, there is a renewed consensus that global warming is an issue that must be addressed on a global scale.

Since 2016, the Hitachi-UTokyo Laboratory has been proposing visions and scenarios for energy systems to support Society 5.0. Version 2 of the Proposal published in April 2019 (hereinafter, “Version 2”) presented a future vision of reconstruction premised on a variety of factors. These included a diversification of energy values setting as a specific target an 80% reduction in CO_2 emissions relative to 2013 as set forth in the Paris Agreement, the coexistence of local communities seeking individually distinctive energy systems, and a bulk power system having the role of connecting multiple local communities and coordinating the entire system. Version 2 also pointed out the need for shared recognition and consensus building among a wide range of stakeholders on diverse measures for future energy systems and on an evaluation platform to assess those measures. It also discussed systems and policies as well as human resource development to support conceptual and concrete design work.

Next, in light of a declaration made on achieving carbon neutrality by more than 120 countries and regions including Japan and the Green Growth Strategy announced by the Japanese government in December 2020, Version 3 of the Proposal published in March 2021 (hereinafter, “Version 3”) described a number of key issues including the formulation of transition strategies toward carbon neutrality, the managing of both reform and value creation in local communities, the creation of an optimal balance among safety and the economy, environment, and energy (S+3E) in the bulk power system, and the formulation of systems, policies, and human resource development to drive solutions to the above. Then, in recognition of these issues, the Proposal described the need for constructing a versatile energy distribution system and an energy data usage system under the premise of full participation, for promoting societal-level measures taking into account the configuring of power demand toward the conversion of renewable energy into society’s main power supply, for formulating evidence-based policies supporting the execution of those measures, and for constructing international frameworks in parallel such as for border adjustments to preserve national interests. In addition, with the aim of creating a robust carbon neutral society, Version 3 also described the need for creating and sharing “transition scenarios” showing pathways to structural reform that need to be taken by each field and declared the beginning of activities toward the formulation of social transition scenarios. To achieve carbon neutrality in this way, it will be necessary to grasp scientific and technical innovation, social systems, and economic mechanisms as an integrated whole and to foster cross-sector human resource development to guide stakeholder discussions beyond individual industries and academic fields and across all generations.

In looking to achieve a carbon neutral society, discussions are apt to concentrate on shifting to an energy balance to drive a transition from primary energy such as oil and gas to renewable energy. A society that has achieved carbon neutrality does not simply control the various sources of greenhouse gases by individual means. Rather, it makes plans for a variety of transitions that involve industry and public works and services and that extend even as far as our personal lives.

Since the carbon neutrality declaration made by various countries, the simultaneous adoption by countries around the world of similar measures, such as the shift toward power generating fuels with low carbon intensity (natural gas), accelerated measures toward the use of electric vehicles (EV), and mass deployment of variable renewable energy (VRE), has raised great concerns about sharply rising prices for both specific energy resources and non-energy resources and about economic security guarantees. Furthermore, as reflected by the invasion of Ukraine by Russia, sudden changes in the supply and demand of energy are beginning to cast a long shadow on people’s sense of safety and security. It is therefore important when creating transition scenarios to ask the right questions such as what structure is desirable for a carbon neutral society, what factors such as obstacles and driving forces make up a transition process, and what strategies should be adopted in that process. These scenarios must be aware of the need for integration and existence of uncertainty in the above while taking into account social norms. In parallel with the creation of transition scenarios beyond 2050, Hitachi-UTokyo Laboratory has discussed quantitative evaluation of power systems and transition directions as well as issues and directions of systems and policies toward carbon neutrality based on changes to date in power systems. The following summarizes the proposals we have made with regard to new items of concern and solutions to issues based on the above discussions.

In our quantitative evaluation of power systems, we studied the hypothesis that carbon neutrality is not achieved by simply promoting an energy mix that shifts toward decarbonized power supplies and promoting electrification to achieve efficient use of energy. Rather, we found that the diversity of a system configuration that should be targeted originates in conserving energy and overcoming spatial and temporal mismatches in energy usage and in making various reforms in energy demand including aggressive use of decarbonized fuel. We also pointed out here the need for feasibility testing on the mass deployment of renewable energy and the importance of sharing roadmaps for the construction of power systems toward carbon neutrality.

In local communities, carbon neutrality that makes best use of that region's characteristics should be promoted based on urban development in Japan and new forms of land development based on cooperation with the residents of that community. We showed by simulations that cooperation with respect to energy demand according to the realities of that region could contribute to a stable supply of energy while demonstrating the economic advantages of the region.

Social issues such as tightening in the supply and demand for power and steep rises in the price of fossil fuels have become apparent following reforms in power systems. It will be extremely important in the process of transitioning to carbon neutrality to ensure a stable supply of power unaffected by the fuel market. In addition, the transition to carbon neutrality in the industrial sector will require a mechanism for analyzing raw-material and energy supply chains and product value chains based on data and for appropriately evaluating the value of carbon neutrality. Companies that are aiming for drastic reform in their manufacturing supply chains with a view to economic security must be supported as prime movers in their industries and sustainable and clean economic growth must be actively promoted.

Common to the above proposals is the promotion of carbon neutrality while solving complex social issues. Such complex social issues should not be swayed by current public opinion but should rather be tested quantitatively based on data. A platform is therefore needed for testing how energy-related data relates to data on industrial activities such as raw-material procurement and manufacturing processes and to data on urban environments including the daily lives and lifestyles of residents. Construction of this platform will make it possible to solve energy problems while achieving economic growth and sustainable local communities.

In this Proposal, we first summarized comprehensive and extensive insights obtained from creating transition scenarios. We then described evidence used for the quantitative evaluation of power systems and stated those points that deserve attention in the transition to carbon neutrality based on the evidence obtained. We also presented points to keep in mind in achieving carbon neutrality in sectors other than the energy sector based on future social trends and industrial trends in Japan, discussed the direction of data usage, and explained the need for achieving a recycling-based society as required by a sustainable society looking beyond 2050.

Chapter 3 Transition scenarios: Social and technical pathways toward carbon neutrality by 2050

3.1 Challenges in achieving carbon neutrality and necessity of transition scenarios

Overcoming the challenges in achieving carbon neutrality[1] in Japan will require extremely wide-ranging and long-term reforms involving the government, industry, and civic life. There is, of course, an urgent need for switching from conventional energy systems centered about fossil fuels to those centered about renewable energy, but there is also a need for a switchover in supply-chain and manufacturing methods in a variety of industries as well as for change in civic life including such factors as location of residence, mobility, consumption, food, and labor.

However, it is difficult to obtain an overall image and understand complex interrelationships with respect to the changes that must take place and the issues that are expected to arise in achieving carbon neutrality. This is because there is a variety of actors in each field each existing under specific conditions while having complex relationships with each other. Each of these actors behaves on the basis of various constraints and uncertainties. Switching over to a new system therefore requires studies that take into account a variety of scenarios.

The Hitachi-UTokyo Laboratory aims to contribute to ways of meeting the above challenges by treating a switchover to carbon neutrality in Japan as a multidimensional process entwined with "transitions" and to create "transition scenarios" that delineate those pathways. A transition scenario brings to light hidden issues and important junctures by studying the process of long-term change involving a variety of actors based on multiple pathways and presents the way that fair and sustainable change toward carbon neutrality should take place.

This chapter provides an overview of transition scenarios based on the initial version of the scenarios that we created.

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[1] The term "carbon neutrality" is widely used on the international stage while the use of "carbon neutral" as a noun is Japanese usage that deviates from English grammatical rules. The Hitachi-UTokyo Laboratory nevertheless uses the latter in conformance with Japanese government materials.

3.2 Methodologies of transition scenarios

Achieving the goal of carbon neutrality in Japan is not simply a matter of improving technologies associated with electric power and power grids or making an effort to that end in industry. This is because a fundamental change in energy systems is accompanied by major changes in people's lives, in society, and in economic activities. It is therefore important that social changes in addition to technical changes be described in scenarios involving transitions and in material dealing with efforts toward carbon neutrality in a variety of related fields. In addition, presenting this goal in a more concrete manner will require quantitative analyses from the present into the future and scenarios that can qualitatively present a vision of future society and a strategic process to that end.

According to Saartje Sondeijker, who has written detailed research papers in this field, a transition scenario refers to structural social changes toward sustainability with the aim of clarifying the process of system-related changes toward a desirable future while emphasizing integration, awareness of uncertainty, inclusion of norms, and participation. Here, a method can be used that gradually draws up a transition for the entire system while repeatedly asking the following questions[2]:

・What kind of shape should a desirable future take?

・What structural changes must be made to achieve that future?

・What kind of obstacles or drivers exist with respect to those changes?

・What kind of strategies should social actors adopt?

Additionally, from the beginning of the 2000s, researchers of socio-technical transitions came to expand their discussions to include socio-technical scenarios. This research began with the formulation of qualitative storylines, but more recently, it has involved trials for bridging these storylines with quantitative model analysis and the development of a method for formulating socio-technical scenarios that design plausible

[2] Saartje Sondeijker. 2009. *Imagining Sustainability: Methodological building blocks for transition scenarios*. Erasmus University Rotterdam. http://hdl.handle.net/1765/17462.

transition routes for scenarios based on quantitative models[3].

Against the above background, Hitachi-UTokyo Laboratory has decided to refer to the concept of socio-technical scenarios and techniques for creating them with the goal of drawing up social transitions centered about a switchover in energy systems to achieve carbon neutrality in Japan while sharing basic ideas on "transition scenarios" that present the means of a structural switchover for achieving a sustainable society. In this Proposal, such a social transition is called a "transition scenario."

Here, the process of formulating transition scenarios as taken up by Hitachi-UTokyo Laboratory involves studies that point to changes in the existing socio-technical systems toward desirable systems of the future while focusing on the "structure" of those systems, the variety of "actors" involved in those systems, and the decision-making required.

Specifically, we used the following process to formulate a scenario.

(1) Interviews with experts

With the aim of achieving carbon neutrality in Japan, we interviewed experts in related areas who have experience and knowledge in their respective fields to obtain a basic understanding of the process of formulating scenarios rooted in reality[4]. Furthermore, in creating scenarios, we referred to discussions conducted with experts in various fields at "open forums" and "closed forums" held by Hitachi-UTokyo Laboratory. The domains targeted for expert interviews are listed in Table 3-1.

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[3] Geels, F. W., McMeekin, A., and Pfluger, B. 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. In addition, the following report written by a member of the Hitachi-UTokyo Laboratory presents a more detailed discussion on socio-technical scenarios in relation to energy transitions. Yi-chun Chen et al. 2021. "Research Trends in Socio-technical Scenarios Surrounding Energy Transitions and Implications for Japan," 40th Annual Meeting of the Japan Society of Energy and Resources, August.

[4] These interviews were conducted 25 times from the second half of 2020 to the end of 2021 in cooperation with key stakeholders in relation to the social, private, and public sectors. Specific information was obtained on factors affecting future energy systems, obstacles to achieving carbon neutrality, policies needed for long-term reforms, etc.

Table 3-1 Domains targeted for expert interviews

Sector	Domain
Social	International NGOs, researchers (climate-related policies, environmental economics, urban data, transportation planning, behavior modification, hydrogen, CCS)
Private	Automobiles, steel, petrochemistry, gasoline stations, banks, investors, wind power generation, biomass power generation, regional new power, compact nuclear reactors
Public	Japanese government, international organizations

(2) Actor analysis

Based on discussions held during the course of these expert interviews, we identified the main actors in various fields and analyzed their interests. This work identified the main entities having key roles in various fields and provided important knowledge for describing scenarios from detailed perspectives. The statements made in these interviews revealed a total of several hundred actors, but those deemed to be main actors are shown in Figure 3-1. As shown in Table 3-2, a variety of actors made contributions in each domain and each understood that climate change is giving rise to a complex situation[5].

[5] In this research, the concept of "actor" is used as a basic unit in the analysis of social phenomena or descriptions of scenarios. While "stakeholder" is used to mean a specific organization or an entity that behaves passively or reactively to specific situations, "actor" is useful in shedding light on the active aspects of entities making up individual sectors and domains and in understanding the dynamics that can affect a particular context while an entity's behavior changes under macro and micro conditions. C.f. Oshiba, Ryo. 1998. "A Re-examination of the Roles of Actors in International Relations." The Japan Association of International Relations (119), 1-10; Bryson, John. M. 2004. What to do when stakeholders matter: stakeholder identification and analysis techniques. *Public Management Review*, 6 (1), 21-53. https://doi.org/10.1080/14719030410001675722, Accessed on March 14, 2022.

Figure 3-1 Main actors in a transition to a carbon neutral society

Table 3-2 Examples of interviews and actor analyses

Domain	Actors	Reality As Seen by Actors
Finance	Major financial institutions Information disclosure bodies Climate action NGOs Investors Global corporations Small/mid-size companies	・Environmental information disclosure bodies are expanding the number of companies willing to make a commitment through diverse techniques while constructing a global expert network. ・Climate action NGOs, which are having increasing impact, are preparing shareholder proposals with respect to major financial institutions that demand business plans consistent with the Paris Agreement. For their part, major financial institutions are continuing with specific investments amid talks with those investors and with borrowers who are opposed to such high standards. ・If standards are not met, there are concerns of being left out of the global supply chain, but Tier 2 companies and beyond have been slow to respond. Financial institutions are concerned about a lack of personnel with knowledge of systems and technologies related to the environment, decarbonization, etc.
Urban	Citizens Urban planners Urban transport researchers Local	・Actions toward urban development centered about pedestrians are accelerating especially in Europe and the United States. These include converting streets into public spaces, establishing automobile-free districts, and expanding bicycle lanes. The number of cities in which citizens can participate in a local government's budget planning through a digital platform is increasing.

	governments Automobile manufacturers	・The possibility exists of reducing energy consumption by improving the quality of public transportation. The analysis of spatial, economic, and energy data that involves a city and its residents can accelerate these actions.
Oil	Gasoline stations Trade associations Petrochemical operators	・Gasoline stations also serve to supply energy to a community for heating and generating electricity at the time of a disaster, so contributing to energy stability in a community is another role that they play. ・In addition to gasoline, gasoline stations can also be classified as a business that provides life-related services to a community with declining population, but whether they can significantly expand in the future is an issue of concern. ・The pathway to converting gasoline stations to charging stations for EVs is considered to be difficult by some operators from the viewpoint of high facility investment costs, uncertainty in making a profit, etc.
LPG	Local gas operators	・Some companies have adopted a sales strategy of providing essentially CO2-free electricity and environmental value as a set with a focus on community development.

(3) Description of domain scenarios

We described a qualitative scenario for each relevant domain using the knowledge gained from interviews and actor analyses and the clues provided by publicly released reports and statistics.

Here, as described in detail later, we envisioned two different situations for 2050—the case of using diverse energy sources including existing power supplies and the case centered on renewable energy—and described “domain scenarios” while identifying main actors for a total of 12 fields = 12 domains divided into the categories of power, industry, and behavior modification. In this effort, we attempted to describe a “likely” future through the behavior of main actors and a socially realistic sequence in the social, private, and public sectors along a time axis divided into the time intervals of 2015 – 20, 2020 – 30, and 2030 – 50 (Figure 3-2).

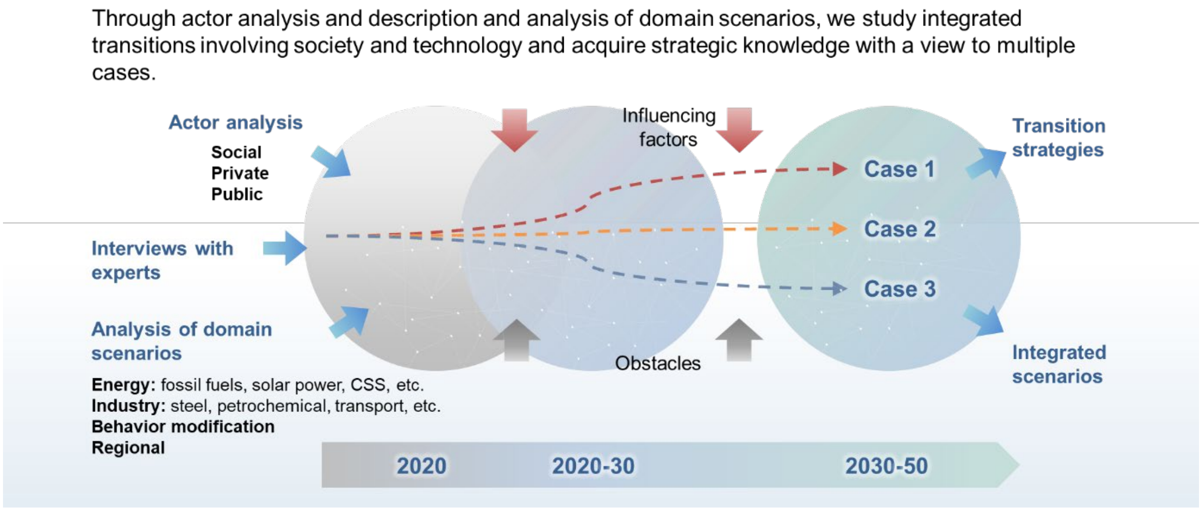


Figure 3-2 Socio-technical scenario based on a transition model

3.3 Two pathways toward carbon neutrality in Japan

On setting out to study a future vision of carbon neutrality in Japan at Hitachi-UTokyo Laboratory, we decided to perform this study for two cases at the time point of 2050, one using diverse forms of energy from a configuration of power generating sources and the other centered on renewable energy. Specifically, from among multiple cases related to Japan's power supply configuration in 2050 as shown in a report[6] published in 2021 by the Research Institute of Innovative Technology for the Earth (RITE), we selected the "reference value" case and "100% renewable energy" case (Figure 3-3) as a basis for describing scenarios for 12 domains divided into the categories of power, industry, and behavior modification (domain scenarios). In this Proposal, we call these cases "diverse energy" and "100% renewable energy" and set three time periods for each resulting in a scenario-description matrix with a total of 72 elements. We also described an "integrated scenario" that integrates the scenarios covering these various domains and presents an overall future vision of these two different cases.

The configuration of the 12 domains targeted by Hitachi-UTokyo Laboratory's transition scenario is shown in Table 3-3.

[6] Research Institute of Innovative Technology for the Earth (RITE). 2021. "Scenario Analysis of Carbon Neutrality by 2050 (Interim Report)." https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf. Accessed on January 5, 2022.

Table 3-3 Domain configuration

Category	Domains	Number of domains
Power	Coal firing, gas firing, solar power, wind power, hydropower/geothermal, biomass, nuclear power, hydrogen/ammonia	8
Industry	Steel, petrochemical, transport	3
Behavior modification	Behavior modification	1

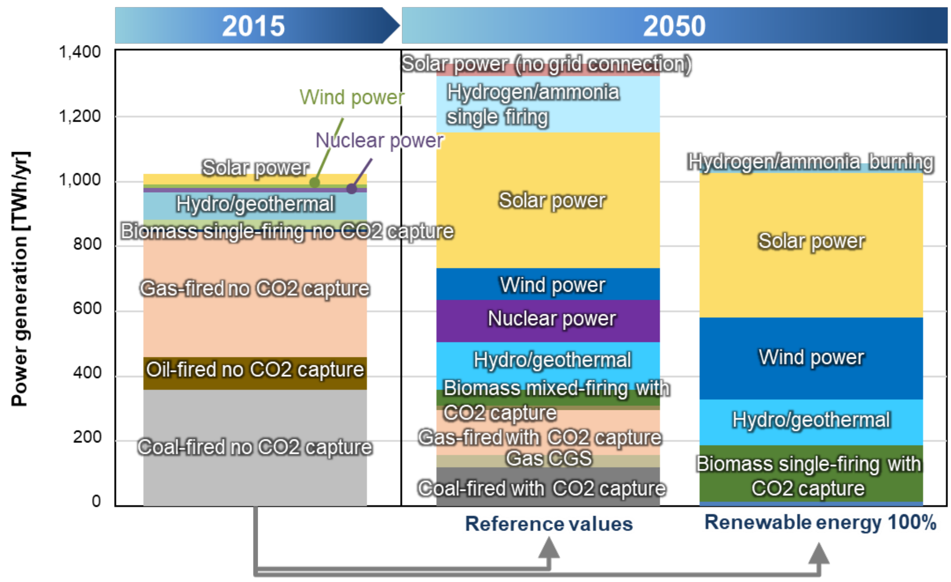


Figure 3-3 Power source configuration in Japan using a RITE report as reference: 2015 and 2050.

Source: Research Institute of Innovative Technology for the Earth (RITE). 2021. “Scenario Analysis of Carbon Neutrality 2050 (Interim Report).” https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf. Accessed on January 5, 2022.

For each domain, we described in detail what actors exist in the social, private, and public sectors and what kind of behavior each could adopt along a time axis divided into three time periods beginning in 2015, 2020, and 2030.

An overview of each domain scenario is given in Appendix 4. Detailed domain scenarios and an integrated scenario will be released separately.

Since a domain scenario describes long-term changes involving a variety of actors over time, this chapter cannot describe each domain scenario in detail. However, reading that overview can provide the reader with some of the main results.

For example, in the case of gas-fired power, it became clear that the future vision of society is quite different between the two cases. As described in Table 3-4 for the case of "diverse energy" in which gas-fired power generation is continued by adopting carbon capture, this type of business is expected to continue through the development of a CO_2 capture system from 2020 to 2030 and the construction of an international CO_2 capture and transport system from 2030 to 2050. For the case of "100% renewable energy," on the other hand, gas-fired power generation operators will be forced to switch to biomass power generation, for example, while having to deal with issues such as consensus building with labor unions and local citizens. Additionally, as an alternative to work in gas-fired plants, the government will have to promote the creation of green jobs (human-oriented and rewarding work in preserving and restoring the natural environment[7]). However, to continue gas-fired power generation in the "diverse energy" case, establishing social acceptance for carbon capturing, creating a carbon-storage framework with other countries, etc. are major issues that will have to be addressed.

[7] International Labor Organization (ILO). 2016. "What is a green job?" Accessed on January 25, 2022. https://www.ilo.org/global/topics/green-jobs/news/WCMS_220248/lang--en/index.htm.

Table 3-4 Overview of two cases in gas-fired power generation

	2015 – 20	2020 – 30	2030 – 50	Key Points
Diverse energy	Revision to Japan's Energy Saving Act calls for a fade-out of inefficient gas-fired power and its replacement by new types of gas-fired power generation.	The government aims to preserve the gas-fired power generation business. Gas-fired power operators will develop CO_2 capture systems using government funds and promote their commercialization.	The gas-fired power generation business will continue through the construction of a CO_2 capture and transport system using the LNG infrastructure and achievement of CO_2 storage in cooperation with ASEAN through government leadership.	1. Obtain social acceptance of CSS within Japan and seek international cooperation including the Asia Pacific region through government leadership. 2. Engage in consensus building with local governments and citizens concerned about decline in the local economy due to withdrawal of power plants, etc.
100% renewable energy	Revision to Japan's Energy Saving Act calls for a fade-out of inefficient gas-fired power and its replacement by new types of gas-fired power generation.	Investment stagnates due to the government's decision to completely discontinue gas-fired power generation. Business operators are forced to switch to biomass power generation, etc.	Gas-fired power generation operators are forced to withdraw from their core business and switch to other lines of business and struggle with consensus building with labor unions, local governments, and citizens. The government will promote the creation of green jobs.	1. Gas-fired power generation operators will have to undergo major changes such as switching to biomass power generation. 2. The government will also have to advance policies for regional development and creation of green jobs.

Additionally, in the transport domain, the switchover to EVs from internal combustion vehicles will, in particular, bring about changes in that supply chain and in urban mobility. As shown in Table 3-5 for the case of 100% renewable energy, the use of vehicle-mounted batteries from 2020 to 2030 will be important for the sake of system stability, but from 2030 to 2050, walking, bicycles, etc. will take on importance as a means of individual mobility. For the automobile industry, battery manufacturing ability and reduction of carbon emissions over the entire lifecycle of an automobile is important for maintaining competitiveness, but technology development and environmental facilities using batteries for system stability is likewise important.

Table 3-5 Overview of two cases in transport

	2015 – 20	2020 – 30	2030 – 50	Key Points
Diverse energy	The automobile industry is an important field supporting the Japanese economy through value of shipments, employment, and an extensive ecosystem.	Japan's battery manufacturing ability will increase due to the spread of EVs. Competitiveness will be maintained by adopting life cycle assessment techniques. Both private and public sectors will promote a shift toward electrification in relevant industries including products and services.	New green materials will be used in areas where electrification is difficult. Environmental facilities for using vehicle-mounted batteries as an adjusting force in system stabilization will be developed.	・Enhancing Japan's battery manufacturing ability and reducing emissions over the entire lifecycle of an automobile including manufacture, use, and disposal are important for maintaining competitiveness.
100% renewable energy	The automobile industry is an important field supporting the Japanese economy through value of shipments, employment, and an extensive ecosystem.	Introduction of renewable energy such as solar power and wind power will progress rapidly. The use of vehicle-mounted batteries for system stability will become increasingly important. Aggregators of distributed power supplies and providers of charging services will play an important role.	Costs will increase for the sake of system stability and electricity rates will rise. Walking and bicycles will attract attention as means of individual mobility as the creation of compact cities progresses. A modal shift will take place in long-distance transport as well.	・Technology development and environment facilities will become important for using EV batteries including used batteries for the sake of system stability.

In the above way, each domain features a variety of actors' interests and a separate context. It is clear that the above two cases surrounding energy each evolves under its own conditions[8].

What kind of vision would therefore appear if we were to connect the variety of transitions shown by each

[8] For example, in the case of "diverse energy" in which carbon-capture-type thermal power generation is preserved, both social acceptance of CCS in relation to coal-fired and gas-fired power generation and international cooperation in CCS are important. However, in the case of "100% renewable energy," thermal power generation operators must deal with switching to another type of business and face issues related to employment, regional life, etc. Additionally, in regard to transport in the case of "100% renewable energy," the role played by EVs will take on importance for the sake of regional system stability.

domain for each of these two cases? Table 3-6 presents such an overview for the cases of "diverse energy" and "100% renewable energy" for the two periods of 2020 – 30 and 2030 – 50.

Table 3-6 Overview of integrated scenario (2020 – 30, 2030 – 50)

	Diverse Energy	**100% Renewable Energy**
2020 – 30	The government's announcement in 2020 of its aim to achieve carbon neutrality accelerated changes at the government, corporate, and citizen levels in Japan. Using the assets of existing thermal power generation, the development of ammonia-mixed-combustion gas-fired power generation and CO_2-capture gas-fired power generation progressed. Technology development and inter-governmental negotiations with respect to carbon capture and storage also took place (**thermal power generation**). Amid increasing participation in the RE100 global initiative that advocates a complete transition to renewable energy, large-scale introduction of solar power and construction of offshore wind power generation facilities increased dramatically (**renewable energy**). At the same time, the government ranked nuclear power as a green and stable decarbonizing power supply and promoted the gradual restarting of nuclear power plants that satisfy safety standards (**nuclear power**). In the steel and petrochemical industries, the need was felt for a change in existing manufacturing methods and investments were made in new manufacturing technologies and carbon capture (**industry**). Amid these developments, a number of countries formulated roadmaps toward the prohibition of selling internal combustion vehicles and the EV market led by North America, Europe, and China rapidly expanded. The transition to EVs made rapid progress in Japan as well (**EVs**). Standards related to the environment and energy became increasingly strict, the influence of transnational citizen groups increased, and whether to continue the generation of electricity by fossil fuels became an important national topic. Nevertheless, no major changes were made in long-established government policies. Rapidly expanding ESG financing provided support for investing in energy and industrial innovations, constructing renewable energy	Heightened international measures against climate change gave rise to major changes in the positions held to date by the government and industry, and movements involved in the gradual phasing out of fossil fuels made rapid progress. It was decided to incrementally phase out coal-fired power generation completely. Coal-fired power operators switched to biomass or ammonia single-fuel-firing power generation. In addition, the move to discontinue gas-fired power generation heightened and a transition to biomass power generation was born (**thermal power generation**). Amid increasing participation in the RE100 global initiative that advocates a complete transition to renewable energy, large-scale introduction of solar power and construction of offshore wind power generation facilities increased dramatically. In particular, the participation of new actors such as the automobile and IT industries in the renewable energy field increased. Issues concerning the environment and consensus building with residents in local communities arose (**renewable energy**). At the same time, the government ranked nuclear power as a green and stable decarbonizing power supply and promoted the gradual restarting of nuclear power plants that satisfy safety standards. However, distrust in nuclear power administrators/operators was as intense as ever (**nuclear power**). In the steel industry, investments in electric-furnace systems having a small amount of carbon emissions rose and the share of this type of production increased. The government also provided technology development assistance for technologies such as hydrogen reduction using blast furnaces but the recovery of costs became an item of concern. In the petrochemical industry, construction of a carbon capture infrastructure proceeded together with a switch in portfolio (**industry**). Amid these developments, the use of EVs

	facilities, and switching over to EVs (**behavior modification**).	spread rapidly and the supply chain for conventional internal combustion vehicles and the personnel employed for their production switched over to businesses centered about inverters, batteries, etc. (**EVs**). Concerns among regular citizens about the climate and environment heightened thereby boosting the power of liberal parties and contributing to a generational change in the ruling party, all of which accelerated the formulation of policies emphasizing renewable energy and new forms of electric power. People adopted new lifestyles linked to industries supported by ESG financing (**behavior modification**).
2030 – 50	International countermeasures to climate change and frameworks for decarbonization became increasingly strict. In Japan, some power generation systems that employ carbon capture were preserved while making use of the existing thermal power generation infrastructure. Low-efficiency coal-fired power plants were retired while high-efficiency coal-fired power plants that employ carbon capture continued operation. A carbon-capture/transport network including cooperation with ASEAN and an international distribution framework for ammonia were established (**thermal power generation**). As public opinion regarding climate measures intensified, the government promoted the development of a large-scale renewable energy infrastructure, a smart power grid, and solar power generation as part of natural disaster countermeasures. The government also supported greater industry competitiveness in wind power generation and regional consensus building and devoted much effort to regional revitalization and job creation (**renewable energy**). Although the development of small modular reactors (SMRs) for nuclear power generation advanced, its share gradually contracted due to the drop in costs of renewable energy and the role played by CSS-equipped coal-fired and gas-fired power generation as stable power supplies (**nuclear power**). In the steel industry, production by electric furnaces increased its share while business by blast furnaces was seen to shift overseas. In the petrochemical industry, a shift toward high-performance materials was seen in Japan, but a movement arose to make basic products at overseas production hubs (**industry**).	International countermeasures to climate change and frameworks for decarbonization became increasingly strict. In addition, concerns increased greatly about ways of achieving a society and economy in harmony with nature. Main coal-fired/gas-fired power operators in Japan changed their line of business to ammonia single-fuel, biomass, or wind power generation. However, uncertainties in establishing ammonia supply networks and sufficient carbon storage facilities meant that some furnaces were simply decommissioned. Additionally, consensus building with labor unions and the community regarding local employment in thermal power generation became an issue. The government enacted policies attaching importance to the creation of green jobs related to renewable energy and the environment (**thermal power generation**). The government promoted the development of smart power grids in regional areas. In addition, the amount of power generated by wind-power facilities linked to regional agricultural promotion and the creation of green jobs increased dramatically (**renewable energy**). Given concerns about nuclear security, massive earthquakes, and the processing of spent nuclear fuel, and taking into account drops in the cost of renewable energy and improvements in power generation stability, the amount of nuclear power generated gradually decreased becoming zero once again (**nuclear power**). In the steel industry, production by electric furnaces increased its share, but traditional blast furnace manufacturers strived to switch to electric furnaces within Japan or planned to pursue steel manufacturing by blast furnaces overseas. In the petrochemical

	The penetration of EVs within Japan rose while relevant industries such as the gasoline station business were forced to switch business format. In addition, car-sharing and ride-sharing services expanded so that EVs took on the property of an infrastructure involving local energy and resilience. Batteries went on to become a key market (**EVs**). Harmony with the environment became an important element of people's lives, but the speed of traditional political decision-making and of economic structural changes was slow. As a result, lifestyles were preserved in various forms based on economic and social models inherited from the previous system (**behavior modification**).	industry, a switch was made to high-performance materials with basic products produced overseas (**industry**). The penetration of EVs within Japan progressed. Amid the heightened development of compact cities, the move from privately owned automobiles to car-sharing schemes gained momentum. Charging facilities were established and EVs were connected to the power trading market (**EVs**). Harmony with the environment became an important element in people's lives, which had a big influence on decarbonization, introduction of renewable energy, and spread of EVs. Urban development centered about pedestrians, creation of green jobs, and changing lifestyles including flexible work styles based on digital technology were all linked to the idea of a complete transition to renewable energy providing a great boost to that transition (**behavior modification**).

In this way, the integrated scenario clearly showed the evolution of these two cases over two key periods.

1st stage of transition: In the period 2020 – 30, the 1st stage of this transition is formed consisting of a series of basic moves toward carbon neutrality, and preparatory conditions for each of the characteristics of power, industry, and behavior modification are formed toward two different visions of the future. Specifically, in the case of "diverse energy," progress is made in ammonia-mixed-combustion and technology development and inter-government negotiations for CO_2 capture, while in the case of "renewable energy," participation in renewable energy increases dramatically by actors who had been on the periphery of the old energy system and heightened concern among the general public about climate and the environment drives policy changes in the government.

2nd stage of transition: In the period 2030 – 50, the 2nd stage of this transition toward carbon neutrality is formed and contrasting conditions arise due to accelerated progress in the transition in every field. In the case of "diverse energy," CCS-equipped fossil-fuel-fired plants are preserved and an international distribution infrastructure for coal and ammonia is formed. In the case of "renewable energy," changes in urban life itself form a basis for a major transition toward the creation of green jobs related to climate and the environment.

These two cases were investigated from preconditions related to power configurations for achieving carbon neutrality—neither was set as conditions for solving diverse social problems. As a consequence, indications of new issues or instabilities occurring in each field can be found in the 1st stage and 2nd stage of this transition in either of these two cases. Here, however, pathways for a transition to the future can be shown from a series of social and technical facts involving power, industry, and behavior modification, which should provide clues to making even better decisions.

In addition, we were able to obtain insights with respect to each domain through the formulation of these scenarios. A scenario focuses on and describes the actions that can be taken toward carbon neutrality by a variety of actors in the social, private, and public sectors, and based on these descriptions, we derived issues that tend to be overlooked or items that should be given attention as "insights."

To give some examples, Tables 3-7, 3-8, and 3-9 list the insights we derived for the domains of coal/gas-fired power, wind power, and hydrogen/ammonia, respectively.

Table 3-7 Scenario descriptions and insights for the domain of coal/gas-fired power

	Scenario Description (excerpt)	**Insight**
Diverse energy	The government supported the securing and commercialization of storage locations for captured CO_2 up to 2030 and pursued a public consensus-building program in relation to CO_2 storage. It released information on the investigation and selection of storage locations within Japan but was nevertheless unable to dispel concerns about safety or impact on the fishing industry among the people or fishery cooperatives in the communities targeted for storage. As a result, consensus building did not go well.	While CSS is essential to a transitional period, the inability to obtain broad social acceptance cannot be ignored. Achieving CCS in Japan will require that the government and business operators fairly and appropriately disclose and describe the advantages and disadvantages of CSS—its necessity, technical possibilities, effects on climate and the environment, etc.—build a consensus, and pursue collaborative construction with local citizens and international communities.
100% renewable energy	In 2025, the Japanese government declared the fading out of all fossil-fuel thermal power generation and the adoption of an energy mix of renewable energy and biomass power generation. In response, power generation operators that had been promoting CO_2-capture high-efficiency gas-fired power generation joined with the Japan Business Federation (Keidanren) to fiercely oppose the government in this policy. After consultations, the Japanese	If aiming for a society supporting 100% renewable energy, thermal power generation should be reduced in a stepwise manner and eventually discontinued. The government needs to draw up a pathway to fadeout in thermal power generation in collaboration with concerned stakeholders including business operators, local governments, and workers and link an energy transition to regional prosperity through the creation of green jobs and the promotion of new

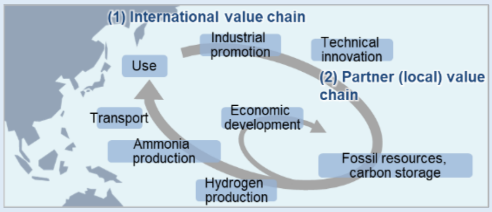
	government decided to compromise by changing to a gradual fadeout and setting a maximum number of years for operation of newly constructed fossil-fuel thermal power plants.	industries.

Table 3-8 Scenario descriptions and insights for the domain of wind power

	Scenario Description (excerpt)	**Insight**
Diverse energy	In response to severe competition with regional energy operators, major power generation operators, and overseas companies due to the promotion of renewable energy, the government enacted policies for enhancing competitiveness in domestic industries (granting subsidies to offshore wind power businesses, promoting human resource development, etc.).	In Japan, the demand for offshore wind power generation has risen rapidly, and while large-scale construction projects have begun, personnel with extensive experience in the field of wind power have been in short supply. This is because expert knowledge in the wind power generation business has been dependent on overseas companies thereby hindering the promotion of wind power in Japan. This obstacle can be mitigated if the government promotes integrated initiatives beyond the boundaries of ministries and agencies while supporting cross-sectoral decision-making and the development and recruiting of expert personnel to support rapid expansion of wind power.
100% renewable energy	For business operators, competition with regional energy operators, major power generation operators, and overseas companies due to the large-scale promotion of renewable energy and competition for competent personnel became increasingly severe. It therefore became a matter of urgency for the government to promote policies for enhancing competitiveness in domestic industries (granting subsidies to offshore wind power businesses, promoting human resource development, etc.).	

Table 3-9 Scenario descriptions and insights for the domain of hydrogen/ammonia

	Scenario Description (excerpt)	**Insight**
Diverse energy	Japan was the first in the world to embark on the creation of an international infrastructure for ammonia (NH_3). The Japanese government concluded strategic agreements with various Asian countries and promoted the development of carbon storage hubs and local production of NH_3. Major factors behind these actions were the worldwide awareness of the CO_2 reduction effect of ammonia single-fuel-firing, the establishment of CO_2 storage technology and preparation of related facilities, and investments in switching over from coal-fired power plants, all of which overlapped with good timing.	To provide mixed firing or single firing of hydrogen/ammonia, the construction of a system for supplying this fuel in large amounts (supply chain) will be essential. Amid accelerated competition centered about Europe, the United States, and China, Japan must contribute to the decarbonization of partner countries to establish a win-win situation. Countries in the Asian region in which thermal power generation is still needed are promising as partner countries.
100%	Although Japan embarked on the creation of an international infrastructure, a state in	

renewable energy	which demand could not be sufficiently satisfied continued. As a result, domestic thermal power plants had to be decommissioned without a plan for switching to NH_3 single-fuel-firing. The demand for NH_3 consequently became smaller than expected and the setting up of a carbon storage hub in Indonesia was delayed.	

While these insights involved transitions in separate domains, it was also possible to obtain key points in an integrated transition that extends beyond the boundaries of individual domains. These relate to multilayered international cooperation, job creation, changes in people's values, and reform of decision-making mechanisms, all necessary for achieving carbon neutrality. Some of these key points are listed in Table 3-10.

Table 3-10 Key points in an integrated transition

1. Multilayered international cooperation on energy resources, innovation, power distribution grids, etc. To achieve carbon neutrality in Japan, the procurement of new resources involving hydrogen and ammonia, the recruiting of expert personnel in the field of renewable energy, and studies on the possibility of interconnecting an international power distribution grid will become important, as will the multilayered construction of a platform for international collaborative initiatives.
2. Consensus building on transitional measures for future decarbonization To achieve CO_2 capture and storage, social acceptance within Japan will, of course, be necessary, but forming agreements with countries and regions for CO_2 storage will also be needed.
3. Fair transitions and creation of green jobs There are fields such as coal/gas-fired power generation, supply chains for internal combustion vehicles, local gasoline stations, etc. that will have to undergo rapid and fundamental changes in an energy-system transition. Focusing on these changes, it will be important to draw up a scenario for regional prosperity through the creation of green jobs while clarifying the effects of these changes on local collectives, civic life, etc.
4. Investment in innovative decarbonization methods in the manufacturing industry Reform in manufacturing processes and supply chains will be necessary in industrial fields including steel. Long-term investment in innovative decarbonizing manufacturing methods will be needed while keeping an eye on a wide range of options involving technologies and systems.
5. Changes in everyone's value system regarding one's city, work, and everyday life

Changes in the energy system will give rise to changes in society—the context for those changes—and especially to transitions in everyone's value system and lifestyle. In particular, there is the possibility that choices in urban mobility, consumption, and energy supply will become targets of serious concern among citizens. It is therefore necessary to aim for long-term energy-system reform while obtaining a good understanding of these concerns.
6. New approaches to decision-making involving the environment and energy Governmental policies regarding the environment and energy in Japan have traditionally been formulated separately, but forming a framework for viewing these policies in an integrated manner will be effective in achieving a long-term energy transition that includes climate change. To this end, it is important to aim for a mechanism that allows for the participation of new actors such as local governments, citizens, NGOs, and financial institutions in decision-making.

In this way, achieving carbon neutrality will require that individual issues in each domain be solved and that fair changes be promoted while grasping the above issues as an integrated process and eliminating barriers to a transition.

Transition scenarios play the role of clarifying the pathway to long-term social changes that need to take place while presenting the issues that actors in each field must solve and the solutions that need attention.

3.4 Chapter 3 Summary

Up to here, we have taken up the subject of transition scenarios as undertaken by Hitachi-UTokyo Laboratory. We described, in particular, the need for transition scenarios and the methodologies used to create them, provided an overview of these scenarios based on the two cases of diverse energy and 100% renewable energy, and presented insights derived from the scenarios.

These scenarios and insights clearly describe the way in which a transition should be made to carbon neutrality in Japan based on different domains and time periods. They also described in a qualitative manner the relationship between two possible future visions with respect to energy, industry, and citizens, and provided insights and strategic suggestions while clarifying main actors and important junctures in each period.

Here, we would like to highlight the following points.

- To achieve carbon neutrality, there is a need to construct a platform for multilayered international cooperation to procure new resources including hydrogen and ammonia, recruit expert personnel in renewable energy, and explore the possibility of interconnecting an international power distribution grid.
- To achieve CO_2 capture and storage, social acceptance within Japan will, of course, be necessary, but forming agreements with countries and regions as locations for CO_2 storage will also be needed.
- For fields like coal/gas-fired power generation, supply chains for internal combustion vehicles, and local gasoline stations that will be pressured to undergo rapid and fundamental changes, it will be necessary to draw up scenarios for regional prosperity through the creation of green jobs while clarifying the effects of those changes on local collectives, civic life, etc.
- To achieve reform in manufacturing processes and supply chains in industrial fields including steel, it will be necessary to make long-term investments in innovative decarbonizing manufacturing methods while keeping an eye on a wide range of options involving technologies and systems.
- It will be necessary to aim for long-term energy-system reform while grasping changes in everyone's value system and lifestyle including choices in urban mobility, consumption, and energy supply.
- A mechanism must be formed for obtaining an integrated understanding of environmental and energy policies that have traditionally been formulated separately. It will therefore be necessary to aim for a mechanism that allows for the participation of new actors such as local governments, citizens, NGOs, and financial institutions in decision-making.

In this way, transition scenarios can act as reference material for achieving a common understanding of the future, which can then be used to formulate a pathway to decarbonization with a wide range of stakeholders.

We note here that the scenarios presented in this document have been compiled as an initial version after review by members of the Hitachi-UTokyo Laboratory with the idea that they would later be supplemented by cases and domains beyond those described above and that the descriptions for each domain would become more accurate. The content of the descriptions provided here should therefore be subjected to future revisions toward more accurate and useful scenarios by adding data and conducting more studies.

At Hitachi-UTokyo Laboratory, we plan to deepen the content of this Proposal in a number of ways such as by analyzing transitions with a focus on various regions in Japan, researching advanced cases and best practices from around the world, enhancing coordination with quantitative research, and studying new cases.

The following chapters will examine future issues uncovered from a quantitative viewpoint and methods for resolving those issues assuming the transition scenarios presented in this chapter.

Chapter 4 Energy systems and macroscopic visions of society

In Chapter 3, we qualitatively analyzed "diverse energy sources" and "100% renewable energy." In this chapter, we quantitatively present the supply and demand structures of the energy system and the necessary countermeasures for the transition to carbon neutrality (CN) in 2050. In addition to the supply and demand of energy, we conducted multiple simulation analyses based on the estimation conditions of the impact of technological innovation, and from the results of these analyses, we depicted the future visions for power and industry.

4.1 Four social visions through renewable energy deployment and electrification

From the results of Chapter 3 and the recent use of hydrogen/ammonia power generation, CCS, and nuclear energy (SMR), we consolidated the results of quantitative evaluation of potential future energy scenarios using simulators and classified the possible social visions that could be achieved by carbon neutrality in 2050 into four (Figure 4-1). The four social visions are classified on the basis of the percentage of variable renewable energy supply (VRE) and the progress of electrification (scale of power demand).

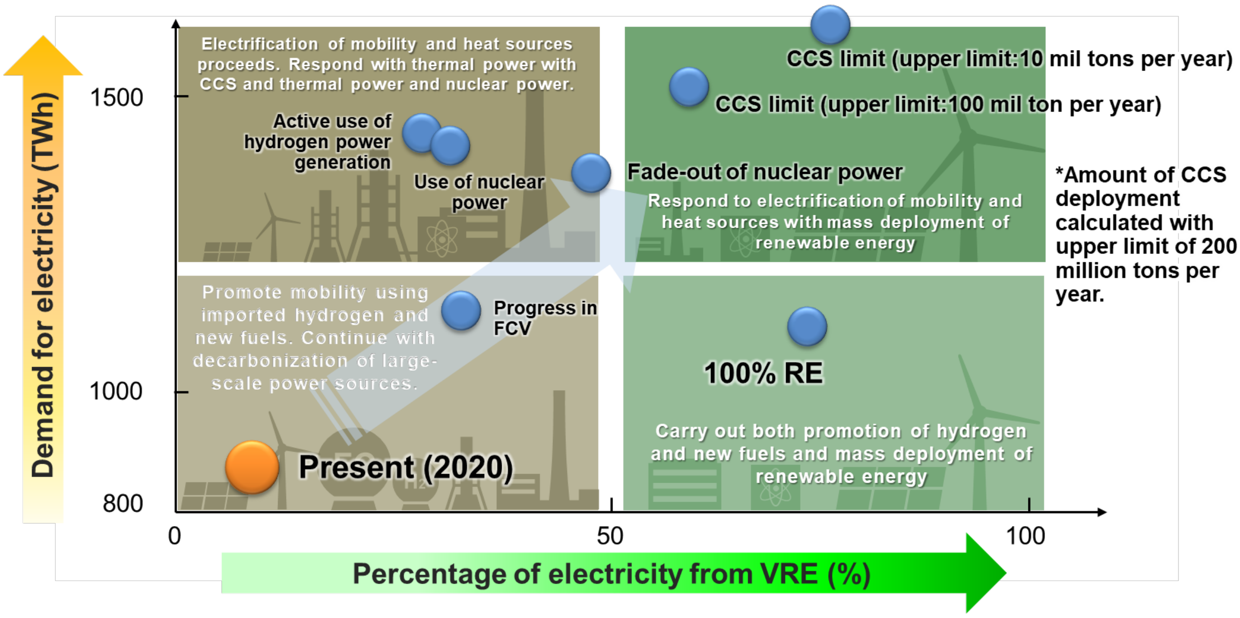


Figure 4–1 Four social visions based on renewable energy deployment and electrification

4.2 Transition issues derived from quantitative evaluation of energy supply and demand structures

For this analysis, we calculated the results using an energy and economic simulation model based on the technology selection model[9] developed by the Fujii-Komiyama Laboratory at the University of Tokyo. This model, which assumes the flow of the energy supply and demand structure and consists of objective functions for minimizing the total cost of energy consumption, power supply, CO_2 emissions, etc. based on the linear planning method, has excellent capability for temporal resolution of energy supply and demand. In this model, the efficiency and tracking speed of various power generation facilities, consumer equipment, inter-area transmission limits, time-varying power generation facilities, energy conversion and storage, cost models for energy-consuming equipment, total energy consumption, and total transport demand are inputted as specifications. It then calculates the total cost minimization at high time resolution (time resolution for the power generation sector is 10 minutes) using CO_2 emissions as constraints, enabling the calculation of the power supply configuration and demand distribution in accordance with the constraints. The cost model, which was set by referring to reference 8 and its cited research, was used to identify social issues in energy systems by numerically showing changes in power configuration and energy consumption across multiple time-sections. This model covers only the energy supply and demand balance over time and cannot evaluate the frequency stability of the system. The installed capacity and investment required to ensure stability are described in section 4.3.

4.2.1 Realization and transition to carbon neutrality through utilization of diverse energy sources

Figure 4–2 shows an example of cost minimization calculation for the energy supply and demand in the transition to carbon neutrality in 2050 using a variety of energy sources (calculation conditions are listed in the appendix). Figure 4-2 suggests that "promoting electrification is economical for realizing carbon neutrality," and that "it is economical not only to use renewable energy, hydrogen, and ammonia power, but also to use thermal and nuclear power with CCS." It also shows the need to actively discussing the use of thermal and nuclear energy from the

[9] Kawakami Y, Komiyama R, Fujii Y, IFAC-Papers OnLine 51(28)598-603 (2018), Kawakami, Komiyama, Fujii, IEEJ Transactions on Power and Energy, 138(5) 382-391 (2018) [In Japanese] https://www.sciencedirect.com/science/article/pii/S2405896318334906

viewpoint of a stable supply of energy (Stable supply is discussed in Chapter 6).

Figure 4-3 shows the transition to carbon neutrality in 2050 for energy supply and capacity in accordance with power supply using various energy sources. In order to achieve 46% emissions reduction in 2030, 160GW/ 253GW solar equipment is required in 2030/2035. "Are these numbers physically achievable?" "What policy should be considered to promote the installation of solar equipment?" "Can we introduce alternative means for emissions reduction?" There is a need to discuss these and other questions.

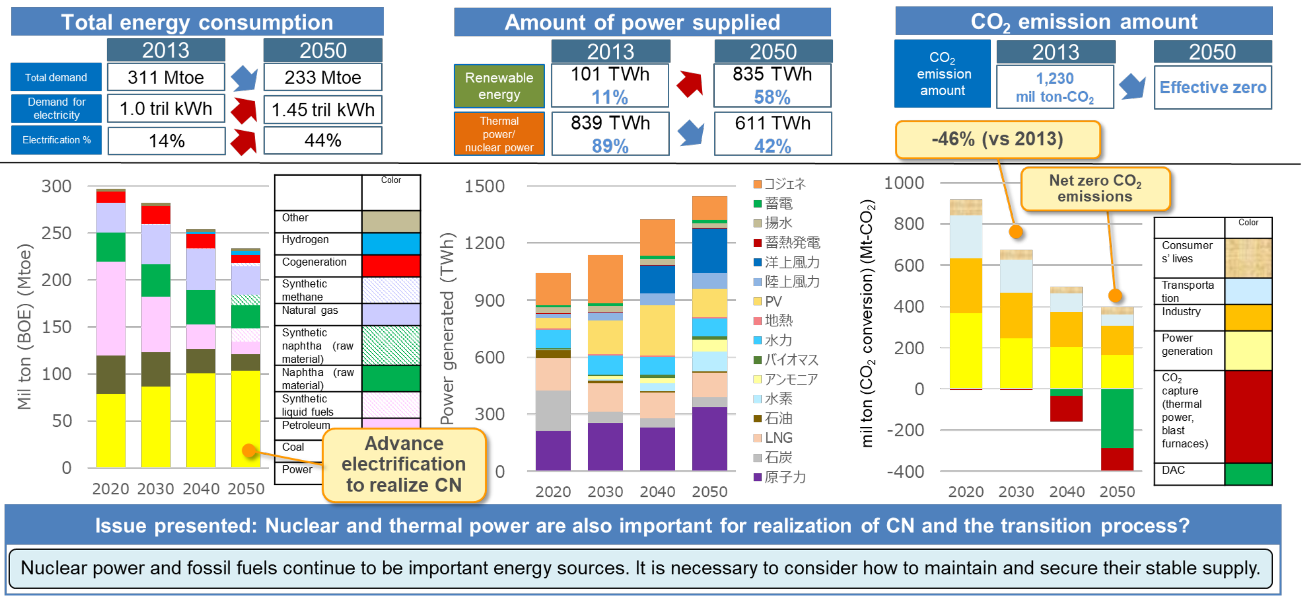


Figure 4-2 Cost optimization calculation for the realization and transition to carbon neutrality utilizing various energy sources

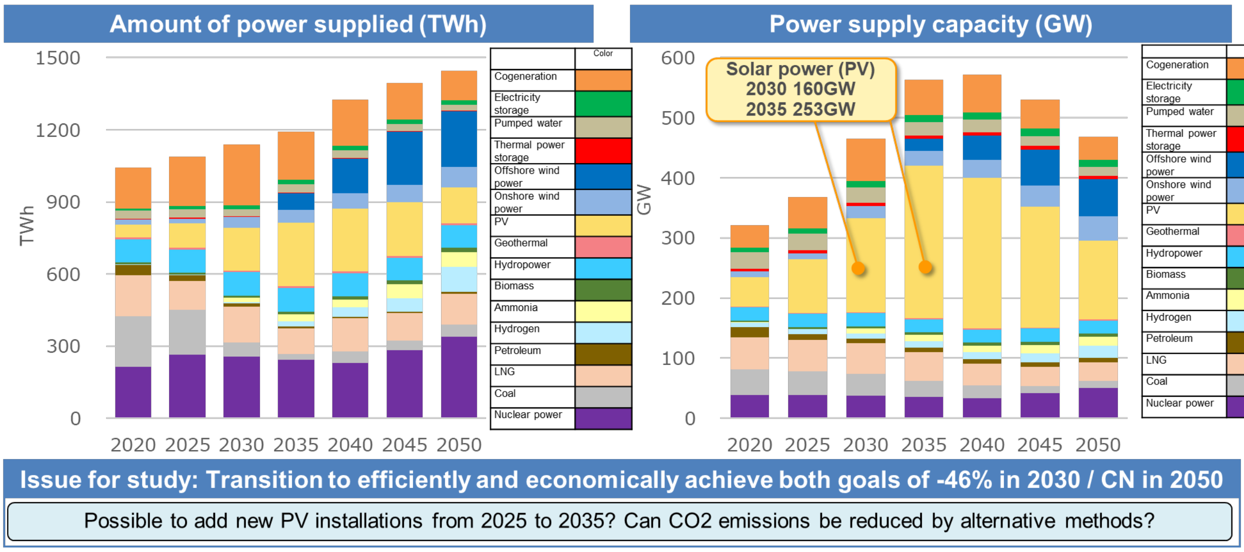


Figure 4-3 Results of estimation of the realization and transition to carbon neutrality utilizing various energy sources (5-year increments)

4.2.2 Realization and transition to carbon neutrality with different constraints on energy use

Figure 4–4 shows the results of estimation of the realization and transition to carbon neutrality for the three cases of "100% renewable energy," "CCS limitation (100 million tons/year)," and "nuclear power utilization." The figure suggests that in order to achieve carbon neutrality in 2050 with "100% renewable energy," the introduction of 355 GW/638 GW of solar equipment by 2040/2050 and 84 GW of electric storage systems by 2050 would be necessary. If we pursue 100% renewable energy, we need to validate the location/land for installing the equipment and the cost of investment (cost-effectiveness).

Figure 4-5 shows the investment cash flow (single year) and trends in CO_2 emission and recovery volumes for each case. For all the cases, investment in DAC will be required after 2040, and for the 100% renewable energy case, there will be "zero emissions from the power sector" and "more emissions from industry, transportation, and consumer life than in other cases." This is because the 100% renewable energy case will have a larger investment in the power sector, such as renewable energy and power grids, and electricity charges will be higher than fuel consumption, resulting in stagnation of the progress of electrification. The volume of renewable energy deployment should also take economic performance into consideration so that the price level enables selection of electricity at the energy demand side.

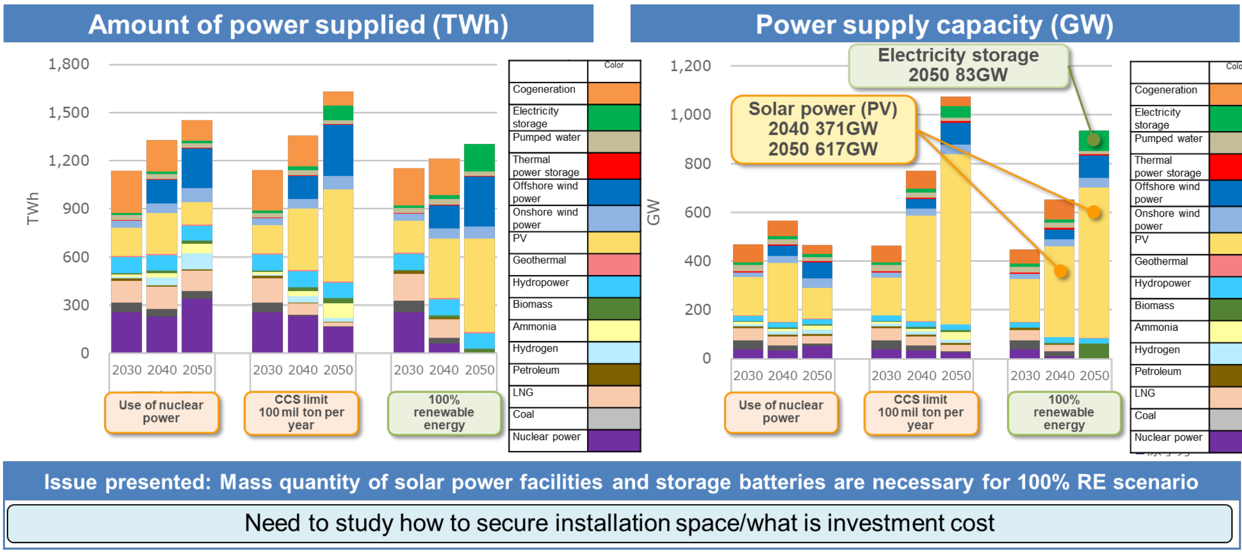


Figure 4-4 Comparison of cases for the realization and transition to carbon neutrality

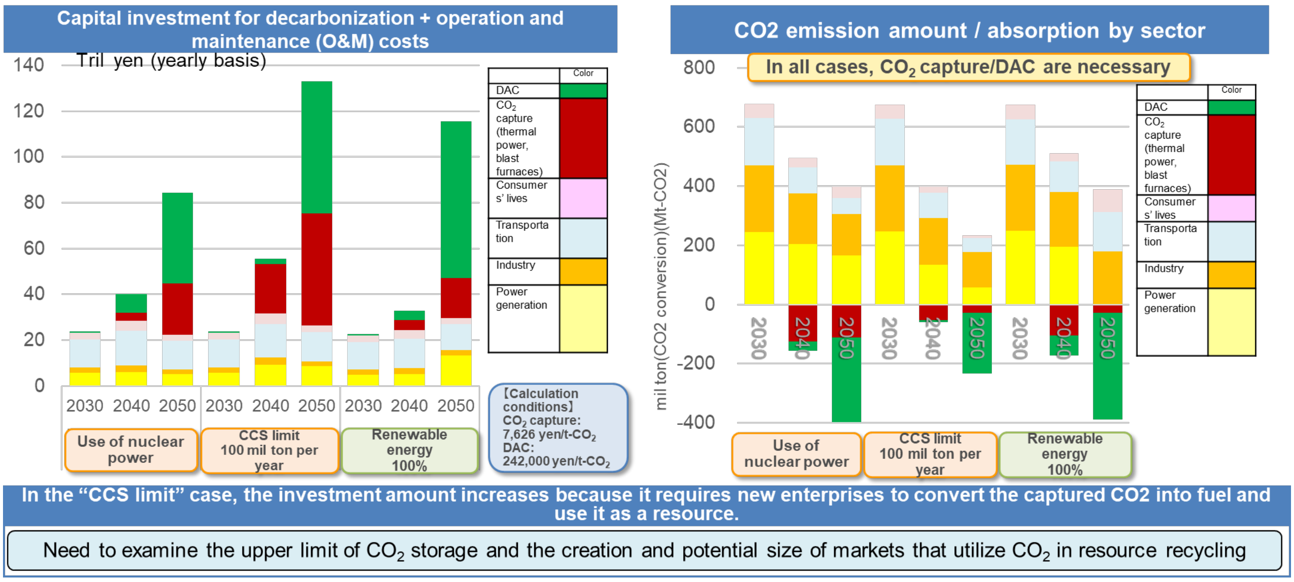


Figure 4-5 Investment cash flow (single year) and CO_2 emissions and absorption for the realization and transition to carbon neutrality

4.3 Challenges and countermeasures for power grids toward the realization of carbon neutrality in 2050

In order to realize carbon neutrality in 2050, as shown in section 4.2, it is necessary not only to invest in power supply and demand facilities, but also to identify issues and implement countermeasures for power grids that connect supply and demand.

Figure 4-6 summarizes the issues and countermeasures for the power grid during the deployment of renewable energy. The challenge is to develop and disseminate technologies that are considered effective upon the increase of the renewable energy ratio, such as technologies for high-speed frequency response and advanced operation of storage systems and pumped storage power generation. In this section, we will quantitatively examine the power grid issues foreseen in Japan, and the necessary countermeasures to address those issues.

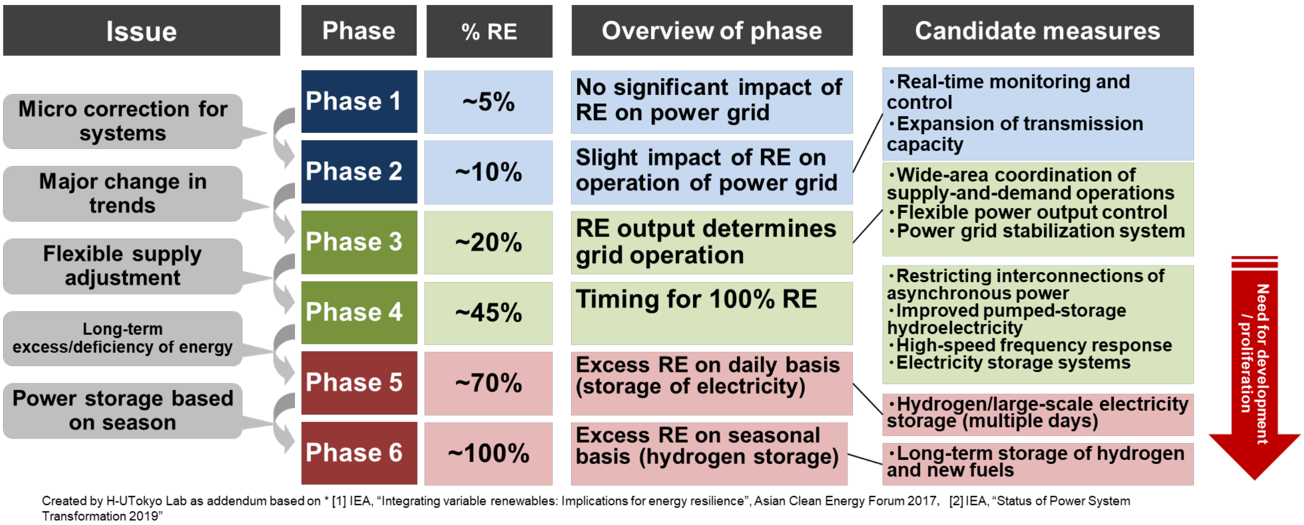


Figure 4-6 Issues and countermeasures for the power grid during the deployment of renewable energy

4.3.1 Power grid issues expected in Japan and their countermeasures

In Japan, there is a lack of agreement (spatial mismatch) between the promising areas for renewable energy such as offshore wind power (Hokkaido, Tohoku, etc.) and power demand areas (Kanto, etc.). As countermeasures to prevent the generation of surplus power in promising areas for renewable energy, new industries (such as hydrogen production) must be introduced, and transmission networks that connect to power demand areas must be constructed. Figure 4–7 shows examples of power supply and demand spatial mismatch and its countermeasure.

In addition to the above, Figure 4-8 shows the fluctuations in power supply and demand with weather, season, and time zones (temporal mismatch) and its countermeasure. Figure 4-9 shows the fluctuations in output of renewable energy and the need for simultaneous, same-volume frequency stabilization as a countermeasure.

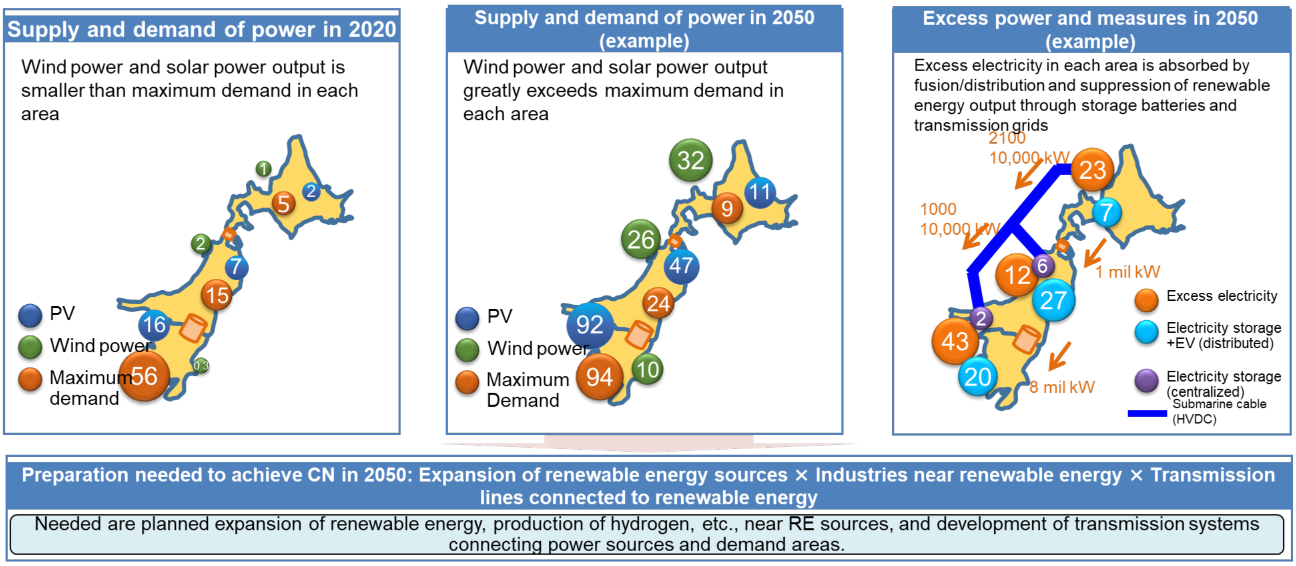


Figure 4-7 Countermeasure 1: Demand generation and development of transmission lines near the renewable energy power sources

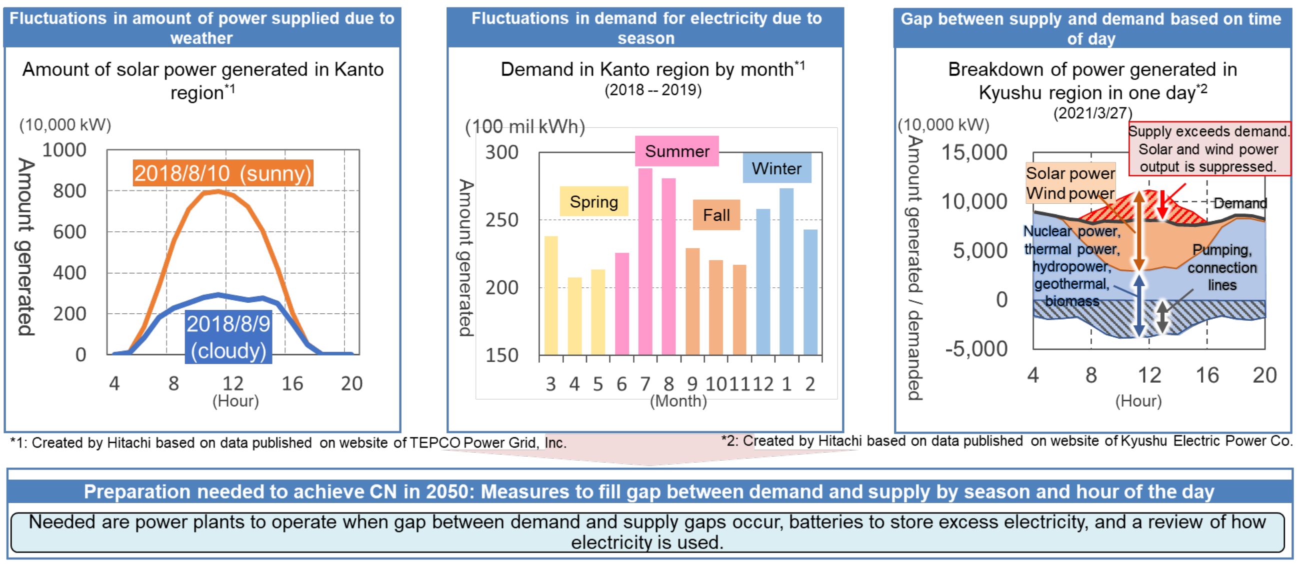


Figure 4-8 Countermeasure 2: Countermeasure against fluctuations in power supply and demand with weather, season, and time zones

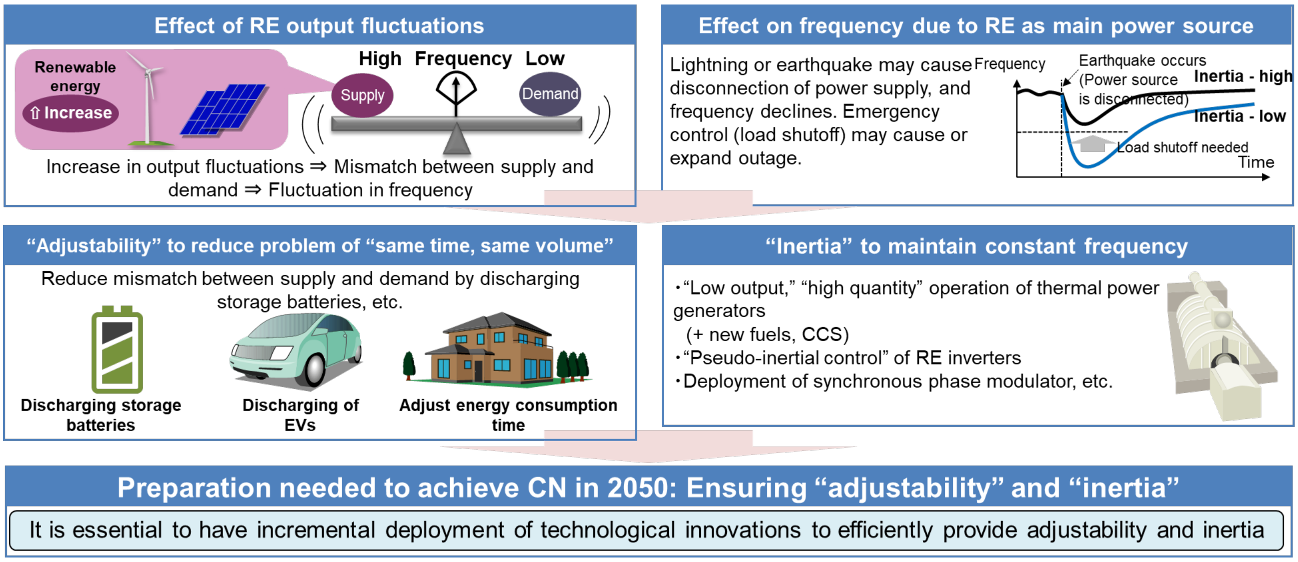


Figure 4-9 Countermeasure 3: Response to renewable energy output fluctuations (simultaneous, same-volume frequency stabilization)

4.3.2 Calculations pertaining to power grid countermeasures

Hitachi-UTokyo Laboratory has built an analysis model for the power grid from publicly available information to examine the phenomena and processes surrounding the power grid, including renewable energy. Analysis was carried out for Hokkaido and Tohoku, which have potential for offshore wind power generation, and Kanto, where energy demand is high, to investigate grid countermeasures for the "East Japan Simulator." Figure 4–10 shows an overview of the analysis system.

Figure 4–11 shows the simulation study conditions used in the analysis system and the results. In the simulation, we estimated and compared the capacity of the power transmission and storage systems connecting Hokkaido, Tohoku, and Kanto for the three cases of "100% renewable energy," "CCS limitation," and "nuclear power utilization." The results suggest that a certain level of transmission capacity and storage system capacity is required for all the three cases. Since it takes time and money to build social infrastructures, it is necessary to start early on with the building of facilities required for all the three cases.

The analysis in Figure 4-11 was premised on establishing new facilities for all the storage capacity requirements. It shows that it is possible to reduce social costs by utilizing the adjustment capacity of distributed resources (heat pump water heaters, EVs, etc.) that are widely used in the local community. This possibility is discussed in Chapter 5.

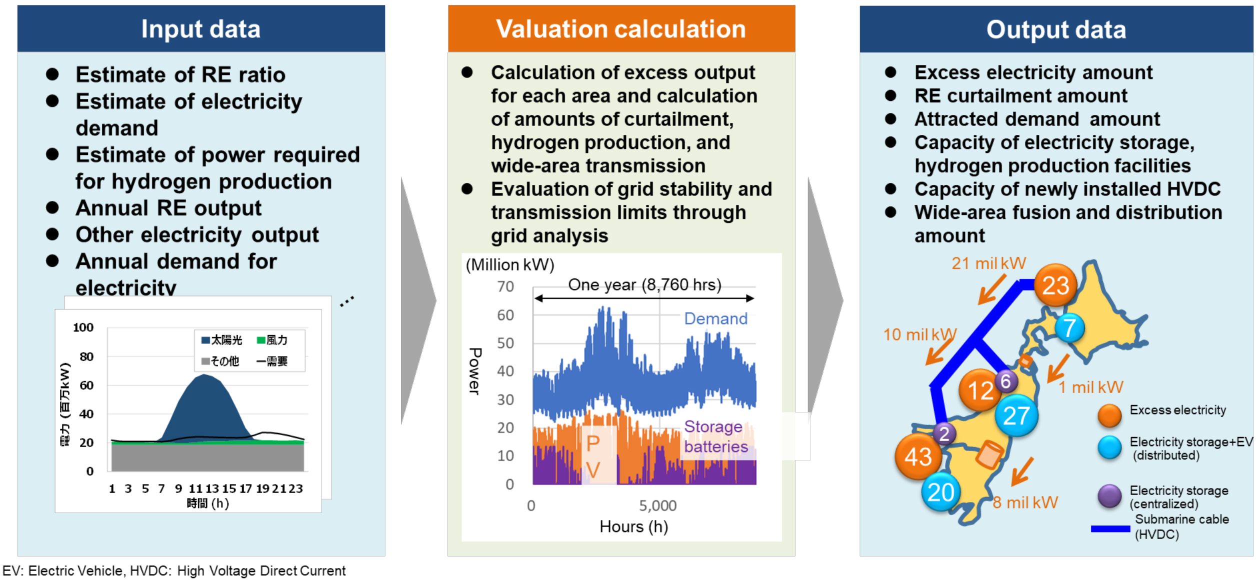
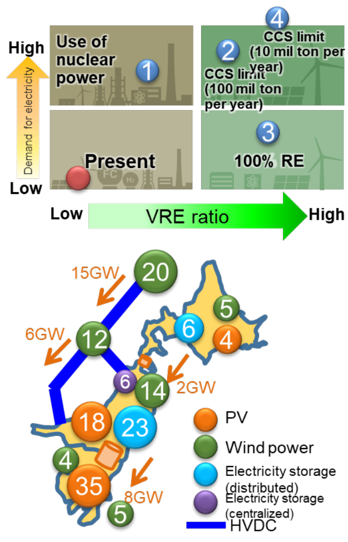


Figure 4-10 Overview of the analysis system (East Japan Simulator) for the power grid issues



Simulation results			①Use of nuclear power	②CCS limit (100 mil ton per year)	③100% RE	④CCS limit (10 mil tons per year)
Data input into simulator	Wind power (GW) (Offshore + onshore)	N. Hokkaido area	20 + 5	29 + 3	29 + 5	29 + 5
		Tohoku area	12 + 15	18 + 8	18 + 14	18 + 14
		Tokyo area	5 + 4	7 + 2	7 + 4	7 + 4
	Solar power(GW)	N. Hokkaido area	4	11	20	36
		Tohoku area	18	47	86	153
		Tokyo area	35	92	168	298
Data output from simulator	HVDC expansion (GW)	(N. Hokkaido-Tohoku)	15	21	20	20
		(Tohoku-Tokyo)	6	10	9	9
	Electricity storage (GWh)	V2G (GWh) (EV conversion)	230 (11.5 mil units)	570 (28.5 mil units)	1,360 (68.0 mil units)	2,910 (145.6 mil units)
		HVDC connections (GWh) (installation space)	60 (1×0.6km²)	80 (1×0.8km²)	90 (1×0.9km²)	90 (1×0.9km²)
		Total electricity storage capacity	290	650	1450	3000
(Ref) Cost calculation based on output data	HVDC expansion (tril yen per year)*1		0.17	0.25	0.24	0.24
	Electricity storage (tril yen per year)	35 yen/Wh	0.5	1.1	2.5	5.3
		15 yen/Wh*2	0.2	0.5	1.1	2.3

Figure 4-11 Simulation study conditions and results[10,11]

[10] *1) Calculations based on the "Feasibility study for the deployment of submarine direct current transmission" by the Agency for Natural Resources and Energy. (https://www.meti.go.jp/shingikai/energy_environment/chokyori_kaitei/pdf/004_03_00.PDF)
[11] 2) W. Cole and A. W. Frazer, "Cost projections for utility-scale battery storage: 2020 update, "NREL/TP-6A20-75385

4.4 Plan and operation of data-driven social infrastructures

In Version 2 of the Proposal, we proposed the data sharing of power systems, and progress has since been achieved in data disclosure regarding the outline of the power grid and other relevant information. Such disclosure of power system data will become a major benefit as the introduction of renewable energy expands because participating power generation companies and transmission and distribution companies can both verify information on the basis of common data. On the other hand, forecast data, including future demand forecasts, will be essential for the formulation of strategies for realizing and transitioning to carbon neutrality in 2050. In this Proposal, the demand-supply simulation model of the Fujii-Komiyama Laboratory at the University of Tokyo was used to calculate the "total energy consumption," "power supply," "CO_2 emissions," and "decarbonization investment cash flow," and the East Japan Simulator of Hitachi-UTokyo Laboratory was used to calculate the power transmission capacity and storage system capacity required in the future. Aside from research investments in the simulation model itself, there is also a need for a mechanism to publicly operate simulators for future predictions and appropriately publish data to enable superior simulator operations and obtain appropriate evidence.

In considering the efficient operation of social infrastructures, it is important to coordinate power supply, supply-demand fluctuations, adjustment capacity, etc., pointing to the need for a mechanism to systematically coordinate each technology and equipment. The coordination mechanism between power systems and social infrastructures (energy assets) in the local community is detailed in Chapter 5.

4.5 Chapter 4 Summary

The following is a summary of the contents of Chapter 4.

- In consideration of the potential of recent technological innovations, as well as the supply and demand of energy, we consolidated the results of quantitative evaluation of potential future energy scenarios using simulators and classified the possible social visions that could be achieved by carbon neutrality in 2050 into four categories.
- The energy supply and demand structure were estimated by cost optimization of total energy consumption,

power supply, CO_2 emissions, and decarbonization investments. In addition to the suggestion that "promoting electrification is economical for realizing carbon neutrality," it was also shown that "it is economical not only to use renewable energy, hydrogen, and ammonia power, but also to use thermal and nuclear power." This shows the need for active discussions on the use of thermal and nuclear energy by government committees and panels.

- Cost optimization calculations were conducted by adding various constraints. However, in all cases, it was necessary to deploy a large number of solar facilities around 2030 in order to physically achieve 46% reduction in 2030. "Is installation physically feasible?" "What policy should be considered to promote the installation?" "Is it possible to reduce emissions by alternative means for emissions reduction?" There is a need to discuss these and other questions.
- Analysis suggested that solar power systems beyond 600 GW capacity and energy storage systems beyond 80 GW capacity should be installed in order to achieve carbon neutrality in 2050 with "100% renewable energy." In the case of 100% renewable energy, we need to validate the location/land for installing the equipment and the cost of investment (cost-effectiveness), other than consider the large investment needed in the power sector for power grids, etc. It should also be noted that electrification will not move forward as electricity charges will become higher than fuel consumption charges.
- We estimated and compared the capacity of the power transmission and storage systems connecting Hokkaido, Tohoku, and Kanto for the three cases of "nuclear power utilization," "CCS limitation," and "100% renewable energy." The results suggested that a certain level of transmission capacity and storage system capacity is required for all the three cases. As such, it is necessary to start early on with the building of facilities required for all the three cases.
- Since the development of social infrastructures will take considerable time and expense, realistic and efficient plans should be made for the formulation of strategies for realizing and transitioning to carbon neutrality in 2050. Quantitative evaluation using simulator is essential for planning, and in this Proposal, we estimated the total energy consumption, power supply, CO_2 emissions, and decarbonization investment cash flow, as well as the power transmission and storage system capacities and total costs required in the future. The possibility of

reducing the cost of storage systems is described in Chapter 5.

- Utilization of various simulators is essential for efficient operation of social infrastructures. Aside from research investments in the simulation model itself, there is also a need for a mechanism to publicly operate simulators for future predictions and appropriately publish data. There is also a need for a mechanism to systematically coordinate technologies, and equipment, including power supply, supply-demand fluctuations, and adjustment capacity.

Chapter 5 Transformation of the regions

In order to achieve carbon neutrality, regional measures must be taken in all directions. In addition, building a new energy system that includes the generation of adjustment capacity from the regions and its delivery to the bulk power system as mentioned in Chapter 4 entails transformation of the decision-making process towards coordination among local actors in the social, private, and public sectors; namely residents, enterprises, national, and local governments. This chapter discusses the regional decision-making discussed in Chapter 3, the approach to building cities from an energy perspective, and the coordination between bulk power systems and value creation in the regions through the use of digital technologies.

5.1 Regional decision-making toward achieving carbon neutrality

Energy use measures, such as the creation of energy conservation and adjustment capacity for the realization of carbon neutrality, have become increasingly important. Likewise, energy-related social trends are rapidly changing, as shown by the global shift toward EVs, the assessment of social impacts of the mass introduction of renewable energy, and the accelerated development toward social implementation of hydrogen and new fuels. In order to realize rich and vibrant regions in the carbon-neutral society, it is necessary to advance various reforms, both large and small, in accordance with the social situation, while suppressing excessive investments in the local communities. Such reforms include infrastructure development that entails significant investments, as well as reforms through coordinated decision-making among the national government, local governments, private companies, and residents, such as sharing among asset owners. These reforms, therefore, require a transition to carbon neutrality through the participation of all members of the local community. Figure 5-1 shows the breakdown of energy consumption in the regions. Since the manufacturing industry consumes a lot of thermal and power energy, it must promote energy conservation, electrification, and process conversion. In the manufacturing and service industries, since CO_2 emissions are evaluated during investment and product selection, CO_2 reduction is somewhat enforced. On the other hand, household energy consumption both for thermal and electric energy, is not small enough to be negligible. Also, since external pressure for reducing CO_2 has little effect in households, it is crucial to deepen individual understanding and awareness and elicit voluntary actions towards carbon neutrality.

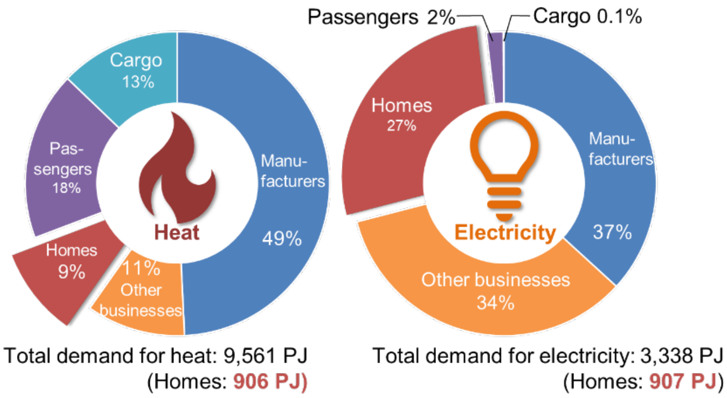


Figure 5-1 Energy consumption breakdown[12]

Individual voluntary actions and choices towards carbon neutrality serve as the starting point for the transition of the entire society that will in turn drive private companies and public entities (Figure 5-2). Similarly, the support of private companies and public entities is also needed for the individual to make those actions and choices, making it necessary to make decisions that are aligned with the interest of individuals, private companies, and public entities. Moreover, major transitions take place through a positive cycle of gradual steps in generating further motivation from individual actions and choices and removing the barriers to actions and choices. For example, for the Superblocks of Barcelona, which is the world's leader in building smart cities, the city's structural changes started with limiting the time for use of cars, followed by installing playground equipment and benches, and eventually involved large-scale construction (Figure 5-3[13,14]).

[12] Calculations based on "Total energy statistics (Energy balance chart)" by the Agency for Natural Resources and Energy, 2019. (Accessed in January 2020).
https://www.enecho.meti.go.jp/statistics/total_energy/results.html#headline2
[13] WORKSIGHT. 2020. "Giving the streets back to Barcelona's residents" (Accessed on December 28, 2021).
https://www.worksight.jp/issues/1644.html
[14] AMP. 2020. "The auto ban movement in Barcelona and the "car-free movement" spreading in cities around the world." (Accessed on December 28, 2021). https://ampmedia.jp/2020/01/27/car-free-movement/

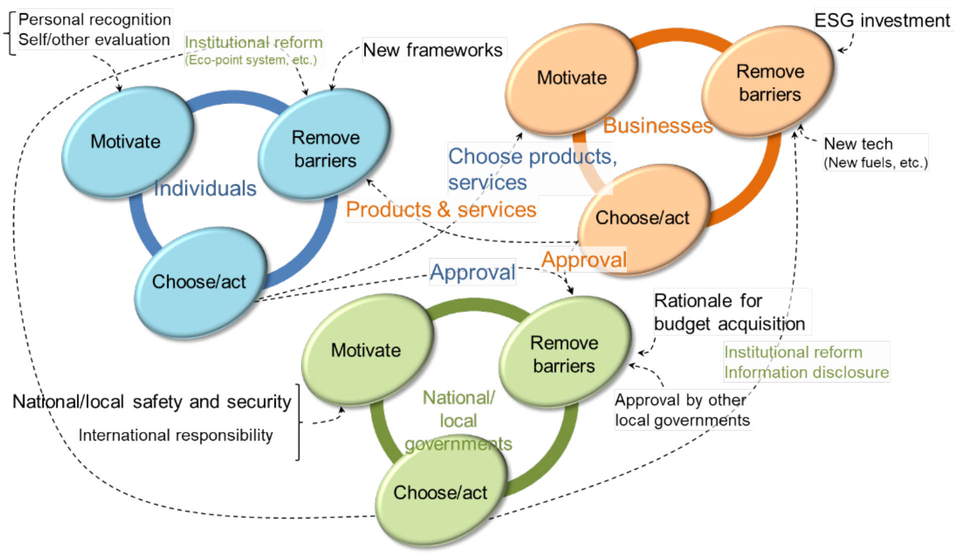


Figure 5-2 Transition of society based on individual actions and choices

Pursuing coordinated regional transition requires deciding the vision for the region and formulating actions and rules for achieving that vision. The vision must be premised on the characteristics of the region, including the region's local industries, topographic features, and population composition. In such decision-making, it is crucial for each actor to proactively participate and be convinced of the vision as the common goal of the region. At this stage, the government's roadmap for regional reform will serve as the springboard for discussions, and the alignment of private companies and residents with the plans formulated by the local government will provide a strong impetus. It will also be helpful to divide the region into several parts and present the current status, target values, and resources along those parts, so that local companies and residents can have a sense of ownership of the plans being formulated. For example, Google's "Environmental Insights Explorer" presents CO_2 emissions from buildings and transportation and the potential of roof top solar power[15]. Each actor should recognize the current situation on the basis of these data and participate in the plan with a sense of ownership.

It is also important to simultaneously show each actor the medium-term expected effects and negative aspects of their behavior, to widely gather the voices of the actors, and to gain wider support and agreement. Possible measures to widely capture the voices of actors include improving the openness and diversity of participants through online

[15] Google. "Environmental Insights Explorer." (Accessed on February 2, 2022). https://insights.sustainability.google/

resident participation and making the decision-making process more transparent. Although some progress has been made in Japan, such as in Chiba Prefecture, it is necessary to accelerate the use of IT for decision-making in the public sector by referring to examples from other countries, such as the open government frameworks in the U.K. and the U.S. (Figure 5-4).

Figure 5-3 Superblocks of Barcelona City[13]

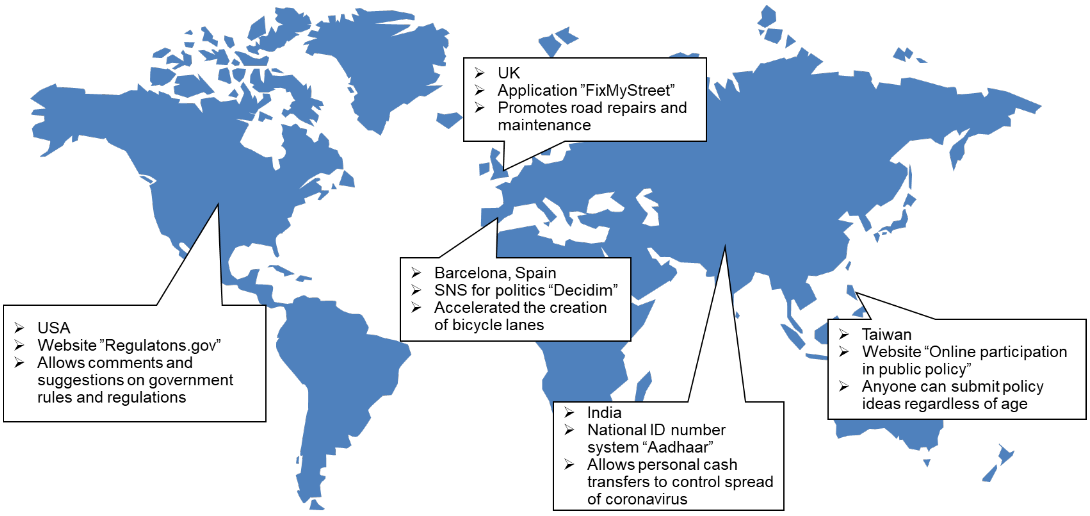


Figure 5-4 Leading cases of "online utilization" in civil dialogs[16,17,18]

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[16] SocietyWorks. "FixMyStreet – Report, view, or discus local problems" (Accessed on February 14, 2022). https://www.fixmystreet.com/#

[17] The United States Government." Regulations.gov – Your voice in federal decision making" (Accessed on February 14, 2022). https://www.regulations.gov/

[18] Nihon Keizai Shimbun, 2022. "The Crisis of Democracy, New opportunities in "Agile Governance": Quick improvement by utilizing IT." (Accessed on February 11, 2022). https://www.nikkei.com/article/DGXZQOUA169LU0W1A211C2000000/

5.2 Urban reform from an energy perspective

Rationally achieving carbon neutrality in Japan requires promoting electrification and the use of renewable energy as the main power source and making use of new fuels[19]. However, since the deployment of renewable energy is subject to land constraints, it requires substantial adjustment capacity, as shown in Chapter 4. Therefore, it is desirable to encourage people to change their behavior by promoting various measures, such as reforms in urban development, and to promote electrification and the use of new fuels via a society-wide energy conservation approach.

Meanwhile, the importance of energy resilience of the regions has dramatically increased due to the recent intensification of natural disasters both in Japan and overseas. For this reason, urban structures must be transformed with flexibility in line with the enhancement of regional resilience.

5.2.1 Energy conservation through urban reforms

As shown in Figure 5-1, there are high demands for heat and power in manufacturing, transportation, households, and businesses in the regions. Because of their wide range of uses, a multi-faceted approach for energy conservation is required. Table 5-1 summarizes the various energy conservation measures related to urban reform. These measures include those that can be carried out by actors individually, those that can be promoted through collaboration among the industries, and those that require the consent and cooperation of many actors. Among these measures, such as the transition to living and working at the same location and to walkable and compact cities, those that change the structure and characteristics of the city will affect many actors as they are promoted also for purposes other than energy conservation.

The following are some specific examples. In regard to walkable cities, as of November 2021, 319 cities in Japan have advocated the concept of "WEDO" (walkable), "eye-level" (first floor of buildings open to the public), "diversity" (diverse uses for diverse people), and "open" (comfortable open spaces). As partners in the implementation of policies, these cities are promoting concrete measures, with 53 cities having established areas for

[19] Ministry of Economy, Trade and Industry, 2021. "Study toward the formulation of a clean energy strategy" (Accessed on January 19, 2022). https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/green_transformation/pdf/001_02_00.pdf

improvement of comfort and livability[20]. In addition, the number of local governments that are planning to create bicycle networks has reached more than 203, showing that the establishment of bicycle-friendly environments is becoming more widely pursued[21]. These two policies, which are aimed at behavior modification leading to carbon-free mobility, are good examples of the role of the support provided by the Ministry of Land, Infrastructure, Transport and Tourism to revitalize the region and reduce bicycle accidents. On the other hand, the traffic congestion on motorways, the lower-than-expected revitalization of the flow of people, and the changes in the landscape are some of the barriers to the transition in the regions. In Japan, where hilly areas account for about 70% of the land and where there is a high elderly population, walkable cities may not be the best option when considering the wide cross-section of residents. For this reason, it is desirable to make decisions based on multiple options, such as the introduction of compact cities and Mobility-as-a-Service (MaaS), which enables sharing of mobility and transportation assets.

This shows that it is important to weigh and select the advantages and disadvantages brought about by the transformation to the actors. Selection, which is needed for the transition, should be done by quantitative evaluation or visualization of measures by using digital technologies that reflect the geographical, population, and age distribution characteristics of the region. These include technologies for human flow detection, human flow simulation, and landscape change simulation. The city of Matsuyama, Ehime Prefecture, is conducting verification of "data-driven urban planning" using digital technologies such as human flow measurement. The city is building consensus on urban development aimed at regional revitalization and establishment of walkable cities that will encourage people to change their behavior[22] (Figure 5-5).

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[20] Ministry of Land, Infrastructure, Transport and Tourism, 2021. "List of cities promoting walkable streets (as of November 30, 2021)." (Accessed on December 30, 2021). https://www1.mlit.go.jp/toshi/content/001420516.pdf

[21] Ministry of Land, Infrastructure, Transport and Tourism. "Roads: Establishing bicycle-friendly environments." (Accessed on December 30, 2021).
https://www.mlit. go.jp/road/road/bicycle/index.html

[22] Hitachi, Ltd., 2019. "Hitachi Review: "People-centric city enabled by digital platforms.” (Accessed on December 28, 2021).
https://www.hitachihyoron.com/jp/archive/2010s/2019/03/pdf/66-71w_HY05A05.pdf

Table 5-1 Energy conservation efforts in the region[23,24,25,26]

Type of energy conservation	Category	Measure
Reduction of thermal demand	Reduction of commutes	Building cities for living and working at the same location
	Reduction of automobile traffic volume throughout the city	Introduction of LRT and transition to walkable and compact cities
	Reduction of cargo energy consumption between cities	Modal shift, joint delivery, and larger transportation vehicles
Reduction of demand for heat and power	Reduction of heat demand in buildings	Improved insulation of houses and buildings, and introduction of solar water heating
	Reduction and effective use of waste heat	Electrification of hot water, cogeneration, waste heat recovery water heating
Reduction of power demand	Optimization of air conditioning and lighting energy	Introduction of BEMS
	Optimization of fluid drive system	Introduction of inverter drive system
Energy conservation-related measures	Energy conservation through captive consumption of renewable energy	Call for installation of PV systems on houses
	Promotion of electrification	Call for adoption of electrification-ready housing, support for HP implementation

23 Ministry of Land, Infrastructure, Transport and Tourism. "Logistics: What is modal shift?" (Accessed on January 2, 2022. https://www.mlit.go.jp/seisakutokatsu/freight/modalshift.html

24 National Institute for Environmental Studies. 2021. "Connect and Spread" Environmental Information Media, Environmental Observatory - Environmental Technology Explanation: Green Logistics" (Accessed on January 3, 2022). https://tenbou.nies.go.jp/science/description/detail.php? ID=24

25 Ministry of Land, Infrastructure, Transport and Tourism. 2020. "Toward urban development compatible with the "new normal" brought about by the coronavirus pandemic. (Accessed on January 3, 2022). https://www.mlit.go.jp/report/press/toshi05_hh_000301.html

26 Ministry of Land, Infrastructure, Transport and Tourism, 2021. "Support for the introduction of LRT." (Accessed on January 3, 2022). https://www.mlit.go.jp/road/sisaku/lrt/lrt_index.html

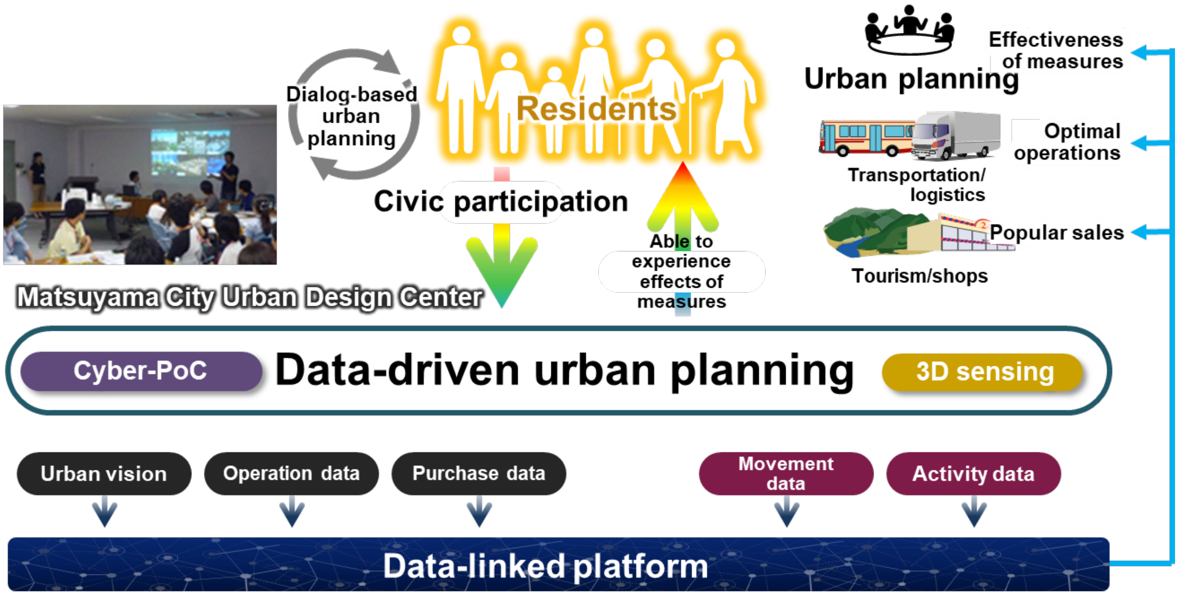

Figure 5-5 Data-driven urban planning[22]

5.2.2 Regional energy resilience

While electrification is being promoted to achieve carbon neutrality, the importance of energy resilience in the regions has heightened due to the continued occurrences of prolonged power outages caused by natural disasters. However, given the weakening of energy bases due to the decline in the number of gas stations and the continuing financial difficulties due to the dwindling working population, it is necessary to ensure energy resilience in line with the changes in the regions.

In Japan, construction sites for onshore wind and mega-solar systems are being depleted, leading to the wider deployment of small-scale (under 2 MW) solar power generators connected to the power distribution system. Therefore, it is crucial to socially implement a system for ensuring resilience by utilizing the solar power generation plants to be installed in the regions, in addition to the conventional approaches of assigning evacuation sites and pre-planning of evacuation strategies.

As an example, Kunitomi-cho in Miyazaki Prefecture is pursuing trials of an energy management system that enhances resilience by linking solar power generation, battery-storage systems, and electric vehicles (EVs) (Figure

5-6). This project is aimed at verifying the use of EVs as public vehicles. During emergencies, temporary regional energy systems can be constructed to link with EVs and solar cells and other assets owned by local residents and local companies, thereby increasing energy resilience while reducing energy investments in the region. This necessitates prior discussions on how to carry out coordination beyond asset owners. In addition, since digital technologies greatly contribute to the improvement of the effectiveness of the measures, such as by predicting how long EVs remain in the region, it is important to also discuss how data can be securely shared and managed.

Figure 5-6 Ongoing demonstration at Kunitomi-cho of an energy management system that uses solar power, battery storage, and EVs[27]

5.3 Coordination with bulk power systems through data-driven intelligent energy consumption

As mentioned in Chapter 4, when a large volume of VRE is deployed to realize carbon neutrality, a large amount of adjustment capacity will be necessary because the power supply and demand balance will fluctuate due to weather conditions. However, a large cost will be needed for installing batteries and other equipment for the power grid in order to secure adjustment capacity. Therefore, it is desirable to have a system to consolidate adjustment capacity from the distributed consumer resources and to curb the social costs of deploying VRE. In this Proposal, we

[27] Nikkei BP Research Institute, 2021. "Forefront of new public-private partnership: "Solar power + EV + Batteries" Verification of resilience plant in Kunitomi-cho (Accessed on January 3, 2022). https://project.nikkeibp.co.jp/atclppp/PPP/news/101202170/

recommend the introduction of a coordination and control platform as a means of consolidating and coordinating these distributed consumer resources.

The coordination and control platform will manage and control the various resources distributed in the local communities using energy data to create values through the use of energy during normal and disaster situations for the demand side and through the stable operation of bulk power systems (Figure 5-7). The platform should be implemented in a phased manner. In the first phase, demand will be coordinated with retail electricity charges that dynamically vary in accordance with the generation and forecast value of VRE, while providing adjustment capacity to the bulk power system and controlling the cost of procurement of electricity on the demand side. In the second phase, the coordination of resources on the demand side will be enhanced, enabling participation in the adjustment capacity market. In the third and final phase, the goal is to actively control regional resources in the event of disasters and improve regional resilience[28].

In the 2030s, electrification centered on automobiles will advance fully, with the number of EVs in the mid-2030s expected to reach 16 million nationwide[29] [30]. A storage capacity of 40 kWh per unit is equivalent to an adjustment capacity potential of 640 GWh. The coordination and control platform must be socially implemented in a phased manner alongside the proliferation of these distributed resources.

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[28] Hitachi-UTokyo Laboratory, 2021. "Toward Realizing Energy Systems to Support Society 5.0 (3rd edition)" http://www.ht-lab.ducr.u-tokyo.ac.jp/wp-content/uploads/2021/03/c5ddff233c8d1e825bb53999344dcc62.pdf

[29] Gendai Mobility Research, 2020. "Decrease in car ownership by more than 20% in nearly half of all municipalities in Japan by 2030." Research Report (Accessed on January 31, 2022). https://www.gendai.co.jp/report/post-1623/

[30] Aim Project Team 2020. "Estimates of what a decarbonized society will look like in 2050" (Accessed on January 6, 2022). https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/034/034_004.pdf

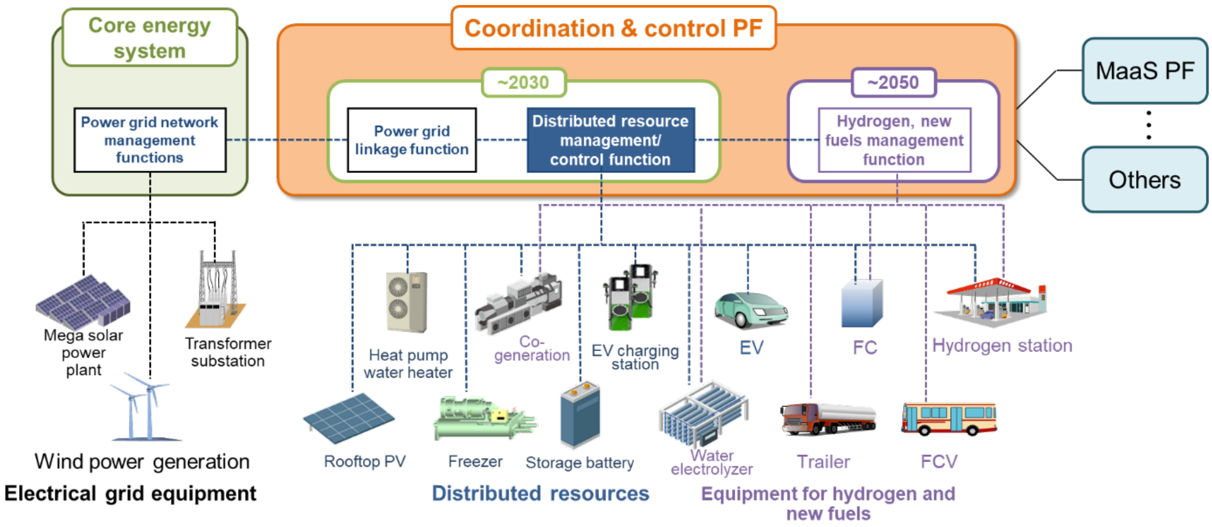

Figure 5-7 Coordination and control platform for integrating distributed resources

The scale of the distributed resource aggregation business utilizing the coordination and control platform must be evaluated in order to socially implement the platform alongside the uptake of EV on the assumption that the private sector will spearhead its implementation. Anticipating its social implementation in 2030, we analyzed the spot market price of the wholesale power market through a simulation of the supply and demand in the power grid. We then analyzed the aggregation on the demand side based on the spot market price. Using the same method, we also estimated the scale of the adjustment capacity from potential distributed resources in 2050.

Figure 5-8 shows the analysis of the spot market price through simulation of the grid supply and demand simulation with the following input conditions: power demand, power configuration, fuel cost, PV and wind power generation, and capacity and loss of interconnection lines[31,32]. The power configuration for 2030 was based on the Sixth Strategic Energy Plan[33]. The results of the analysis showed that supply will exceed demand due to the large volume of solar power generation in 2030, with many instances when the spot market price would reach 0 yen/kWh.

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31 Azuma Hitoshi, Isonaga Akira, Fukutome Suguru, Minotsu Shinichirou, Nonaka Shunsuke, Ogimoto Kazuhiko, Kataoka Kazuhito. 2017. "Demand-supply analysis model with energy and balancing capacity exchange through interconnection," IEEJ Transactions on Power and Energy 137(2), 83-92.

32 Ogimoto Kazuhiko, Iwafune Yumiko, Urabe Chiyori, Azuma Hitoshi, Isonaga Akira. 2021. "Analysis of Spot Energy Market Price using Power Production Simulation Model," Journal of Japan Society of Energy and Resources 42(4), 185-193.

33 Ministry of Economy, Trade and Industry, 2021. "Sixth Strategic Energy Plan (October 2021)." (Accessed on October 30, 2021). https://www.meti.go.jp/press/2021/10/20211022005/20211022005.html

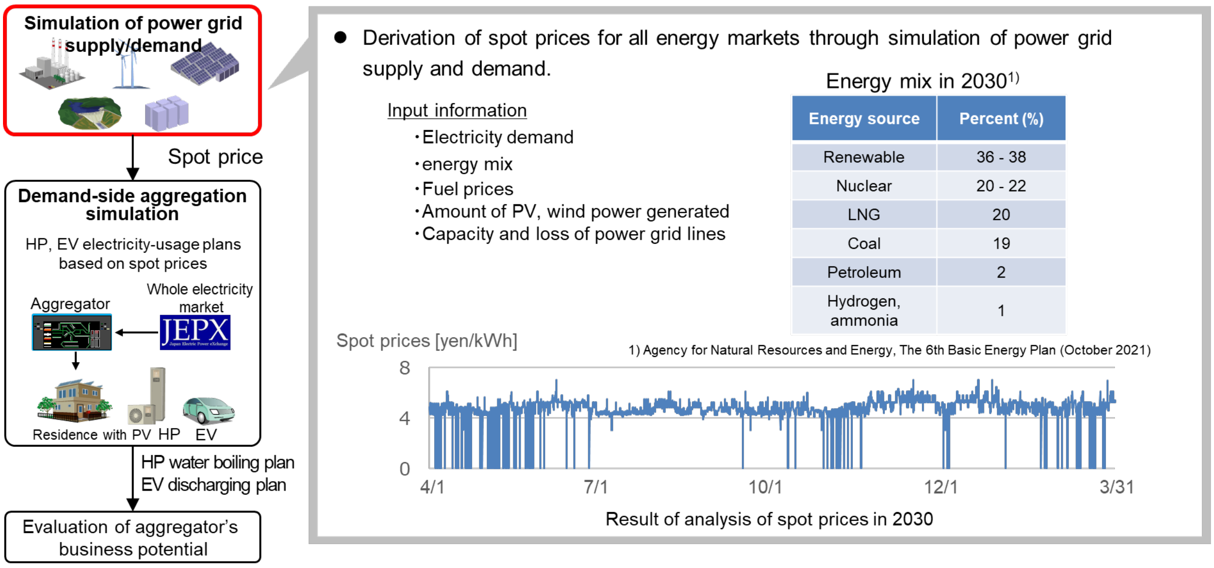


Figure 5-8 Spot market price analysis for 2030 through supply-demand simulation

In the demand side aggregation simulation shown in Figure 5-9, we analyzed the effect of the aggregation of distributed resources on the basis of the resulting spot market price[34]. The aggregation analysis covered households with distributed resources out of around 100,000 detached residential houses in Machida City, Tokyo. Solar power generation (PV), heat pump water heater (HP), and electric vehicles (EV) were deemed as the distributed resources. See Appendix 1 for information on the number of households living in detached residential houses and the derivation of the amount of owned distributed resources.

The analysis was based on two conditions. Case 1 is a case for night-time operation where HP hot water storage and EV charging are carried out mainly from 12:00 to 7:00 am. Case 2 is a case where HP hot water storage and EV charging and discharging are shifted to the optimal time zone based on hot water demand and driving demand. Also, in consideration of the variation in HP hot water demand and EV driving demand, optimization was done by setting a minimum limit on HP water storage and EV storage capacity, and the analysis was performed under conditions where the aggregation does not diminish consumer convenience.

[34] Iwafune Yumiko, Ogimoto Kazuhiko, 2021. "An aggregation evaluation model for residential solar-power generation and consumer equipment," Power & Energy Society of IEEJ.

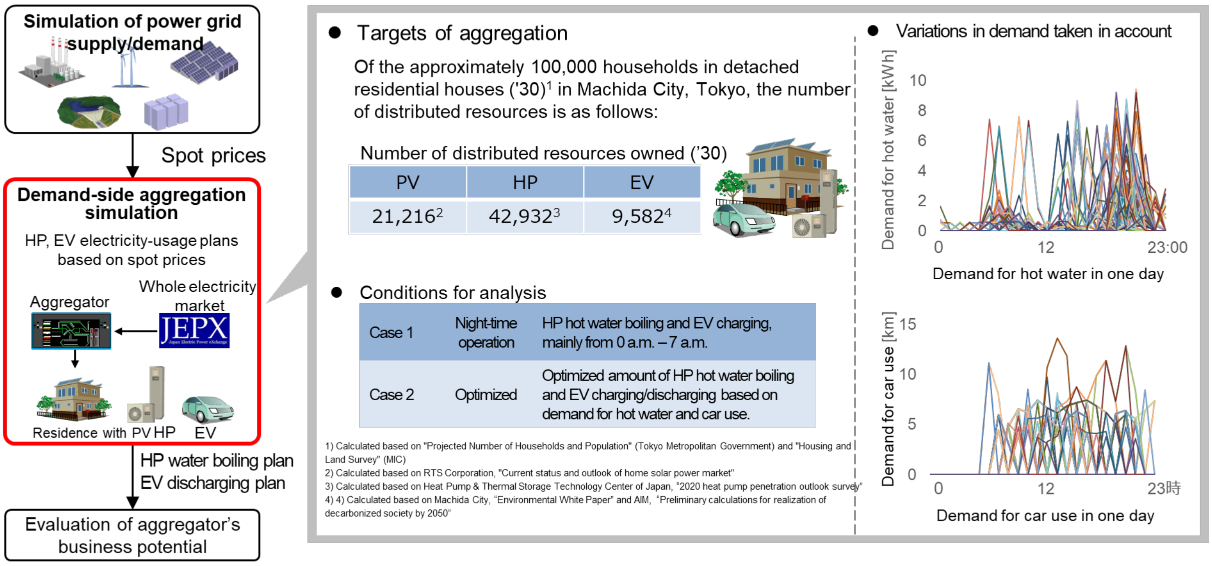


Figure 5-9 Demand side aggregation simulation

Figure 5-10 shows the results of evaluation of aggregator business scale in 2030. The graph on the left side of the figure shows the spot market price for March 6 and the power demand for Machida City as a whole. While EV charging and HP boiling were carried out at night in the night-time operation case (Case 1), the demand for 227 MWh for EV charging and HP boiling was shifted to daytime hours when the spot market price is low in the optimized case (Case 2). This effect is equivalent to 79.5 GWh on a nationwide scale. Substituting this shift in power demand by battery power will lead to a cost of about 4 trillion yen based on a 50 yen/Wh conversion. This shows that aggregation contributes significantly to the reduction of social costs. The 2030 profile also revealed that heat pumps, which are already being widely used, will become the major contributor to the time shift in demand, rather than EV, which has been expected to be provide adjustment capacity from the demand side.

The right side of Figure 5-10 shows the effect of reducing power procurement costs from the aggregator spot market. In the case of night-time operation (Case 1), the cost of procurement is 1.271 billion yen, while in Case 2, the cost is 1.154 billion yen, leading to savings of approximately 120 million yen. Converting this result in terms of the ratio of detached residential houses, the reductions would amount to 14 billion yen throughout the Kanto region and 34 billion yen throughout the country. This shows the potential for an equivalent volume of aggregation business. This analysis does not consider imbalance adjustments or EV charging and discharging outside the home, such as at work, so the business scale will likely be expanded further by taking these into account.

Figure 5-11 shows the results of an estimate of the adjustment capacity that can be created in 2050. The spot market price in 2050 is based on analysis of literature[35]. The distributed resources from detached residential houses in Machida City predicted for 2050 include 31,080 PV units, 78,108 heat pump water heaters, and 38,744 EV units. In contrast to the night-time operation case (Case 1), the optimized case (Case 2) enables generating adjustment capacity of 614 MWh by shifting the EV charging and HP boiling time period. Expanded nationwide, this will be equivalent to an adjustment capacity of approximately 215 GWh. Therefore, the aggregation of distributed resources from detached residential houses in 2050 will make it possible to replace approximately 37% of the battery adjustment capacity (580 GWh) required in the "nuclear power utilization case" mentioned in Chapter 4.

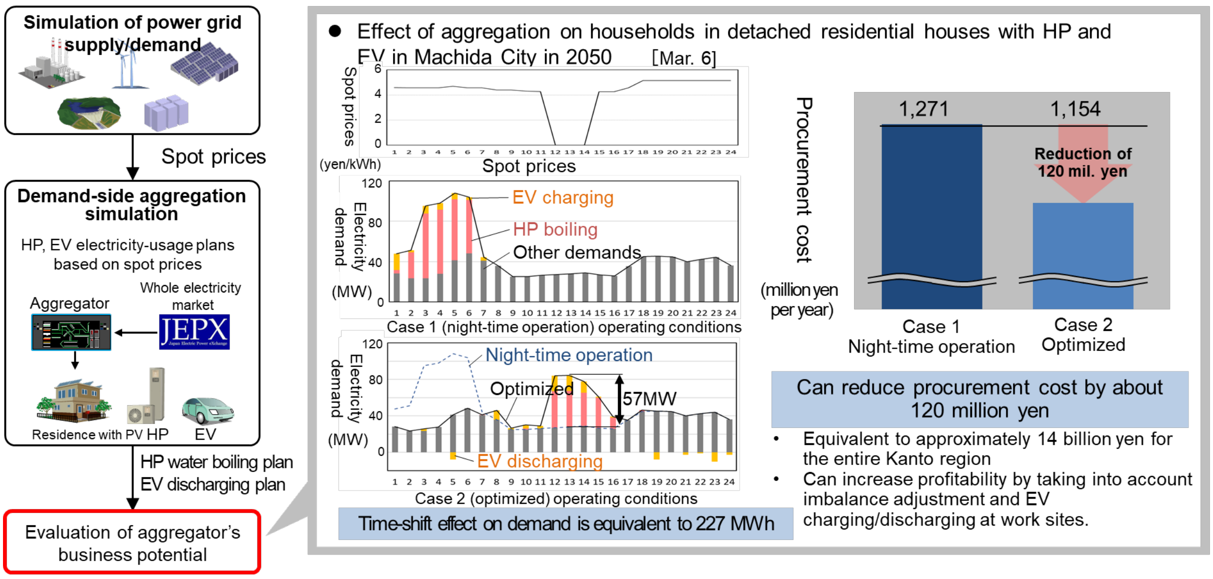


Figure 5-10 Business scale evaluation of aggregators in 2030

35 Ogimoto Kazuhiko, et al., 2022. "Analysis of energy supply and demand in 2050 by soft-linking, Part 2. (3) Power System Model," 38th Conference on Energy System, Economy and Environment, 25-3.

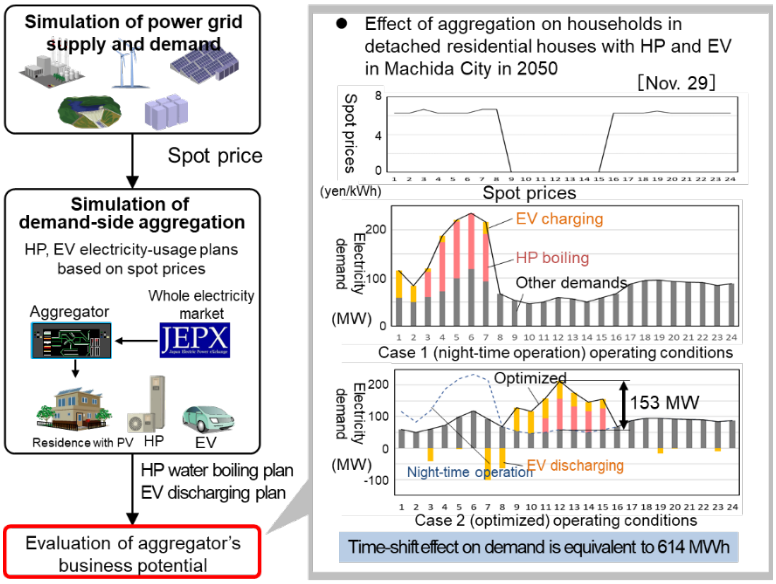


Figure 5-11 Estimation of adjustment capacity in 2050

This aggregation encourages rational economic choices among consumers and does not incur additional costs for infrastructures to implement supply-demand adjustments and other costs. Therefore, it is possible to create adjustment capacity in a win-win scenario between power supply and demand. Social implementation of the coordination and control platform and the necessary device-side interface (IF) should be urgently carried out in order to maximize the effect of introducing the aggregation in time for the rapid increase in electrification in the 2030s.

The above estimate is premised on the ideal situation of aggregating all the distributed resources of detached residential houses through the coordination and control platform. Achieving this aggregation requires setting up platform linkage interfaces for many distributed resources and building consensus for aggregation with resource owners. Measures to encourage the introduction of heat pumps, information to promote demand optimization, including dynamic pricing, and the implementation of the pricing system are actively being discussed[36][37]. In addition to these issues, there is a need to break down barriers for manufacturers and resource owners, such as avoiding duplicate development among equipment manufacturers through compliance with international standards for the

[36] Ministry of Economy, Trade and Industry, 2021. "Future of the Energy Conservation Act (December 24, 2021)." (Accessed on January 6, 2022). https://www.meti.go.jp/shingikai/enecho/shoene_shinene/sho_energy/pdf/036_01_00.pdf
[37] Ministry of Economy, Trade and Industry, 2021. "Realizing carbon neutrality in 2050 and energy conservation policies." (Accessed on January 6, 2022). https://www.nedo.go.jp/content/100940154.pdf

above IF and maintaining the home environment through wireless IF. It is also necessary to establish a forum for comprehensive discussions that include manufacturers and users on the proper management and sharing of information on devices equipped with the IF.

To realize prosperous and vibrant local communities in the carbon-neutral society of 2050, Hitachi-UTokyo Laboratory, through its various recommendations, will lead the launching new markets for regional energy services as described above and facilitate the social implementation of the platform required to build the markets. It will also present the necessary conditions for accelerating cooperation between regions and between the regions and the core energy system, including innovations that should be created amid the competition among service providers and the standards and data management infrastructure that need to be prepared.

5.4 Chapter 5 Summary

The following is a summary of the contents of Chapter 5.

- The transition of the regions entails responding to the constantly changing energy situation. Coordinated decisions must be made among the national government, local governments, enterprises, and residents. Specifically, the vision for the region, including its variability and resilience, and the timing of the transition must be shared as the goals for the region. In addition, measures must be pursued progressively while predicting and validating the merits and demerits for the actors.
- Realizing prosperous and vibrant local communities in the carbon-neutral society necessitates pursuing reforms that are aligned with the social situation, including those that require coordinated decision-making among the national government, local governments, enterprises, and residents, while suppressing excessive investments in the community. The government must formulate a roadmap to show the direction of the transition in the regions, and the regions must develop plans that are suited to their specific situations. Also, each actor in the region must participate in the decision-making by taking ownership of the above plan and understanding the advantages and disadvantages of the measures in advance. These are areas where digital technologies are potentially useful.

- Rationally realizing carbon neutrality in Japan requires promoting energy-saving measures under a new framework, in addition to shifting to renewable energy as the main power source, promoting electrification, and utilizing new fuels. The options for the regions include construction of means and spaces for mobility, adoption of housing designed with new specifications, and joint utilization of assets. Making decisions by leveraging digital technology will accelerate the transition for decisions that involve many actors, such as urban development.
- Energy bases in the regions are weakening with the decrease in the number of gas stations and other facilities, and regional revenue sources are being depleted due to the decline in the working population. Therefore, to ensure energy supply in the event of power outages due to natural disasters while electrification is progressing, we need to discuss how to utilize the solar and EV assets of local residents and companies.
- Along with the upcoming progress of the deployment of EVs, it is necessary to gradually implement a coordination and control platform that will enable the aggregation of heat pumps and EV chargers. In this Proposal, we recommended a cooperative service that will reduce the cost of regional energy procurement by shifting the energy consumption time through the coordination and control platform. We also evaluated the scale of the business, using a residential area in the Tokyo area as an example. Results revealed that in 2030, rather than EVs, heat pumps, which are already becoming widely used, will play a central role in contributing to the shift in demand. Results also showed that deploying the above services nationwide will enable a business scale of 34 billion yen and the generation of 80 GWh of adjustment capacity, which is equivalent to 4 trillion yen in battery-storage cost (50 yen/Wh). Accelerating the social implementation of the coordination and control platform will require discussions on how to properly manage and share information on devices that can be linked to the platform.
- Hitachi-UTokyo Laboratory through its various recommendations, will lead the launching of new markets for regional energy services as described above and facilitate the social implementation of the platform required to build the markets. It will also present the necessary conditions for accelerating cooperation between regions and between the regions and the bulk power system, including innovations that should be created amid the

competition among service providers.

Chapter 6 Realization of carbon neutrality and future-oriented systems and policies

As an approach to an energy system aimed at the achievement of carbon neutrality, we discussed the need to promote electrification and to secure a wide range of energy resources for adhering to the S+3E principle. In addition, the local community should determine the directions for transition based on an appropriate carbon neutrality roadmap and should make decisions by involving the various actors in the region. We reiterated the importance of making decisions to select urban designs that the region should aim for in relation to energy, namely, electrification and conservation of energy in the region. This chapter outlines the systems and policies for social structural changes in Japan over the last 10 years and describes the systems that are considered necessary for carbon neutrality.

6.1 Long-term prospects towards realizing carbon neutrality

In June 2021, the Ministry of Land, Infrastructure, Transport and Tourism announced the final summary of the Long-term Outlook of Japan[38]. According to the summary, Japan, which is faced with the challenges of worsening disasters and a declining and aging population, has called for the formation of local living areas with a population of around 100,000, under the premise of achieving carbon neutrality. Anticipating the establishment of networks among these local living areas, Japan aims to realize a society that can offer true affluence under a safe and secure atmosphere, where resilience is assured. This society is founded on industrial transformation that will enable Japan to stay globally competitive. Figure 6-1 shows the conceptual diagram of the long-term national outlook encompassing the energy sector and premised on realizing carbon neutrality. The stable supply of energy based on S+3E is an essential prerequisite underpinning the local communities and networks that make up the local living areas. In Japan, where resources are scarce, global cooperation is also crucial for nation-building. The country will aim to achieve growth and development of industries, transportation, and services as a disaster-resistant nation. Growth and development will be premised on coordination of energy supply and utilization (demand) to maintain energy in accordance with S+3E. Further, global relationships that take economic security into consideration will be established. Once these

[38]Ministry of Land, Infrastructure, Transport and Tourism. “Long-term Outlook of Japan." (Accessed on March 14, 2022) https://www.mlit.go.jp/policy/shingikai/kokudo03_sg_000243.html

foundations are built, true affluence of the local living areas will be achieved. In accordance with the conceptual diagram in Figure 6-1, below we discuss the current systems and policies in the energy and industrial sectors and in local communities (local living areas), as well as the systems and policies necessary for the transition to carbon neutrality.

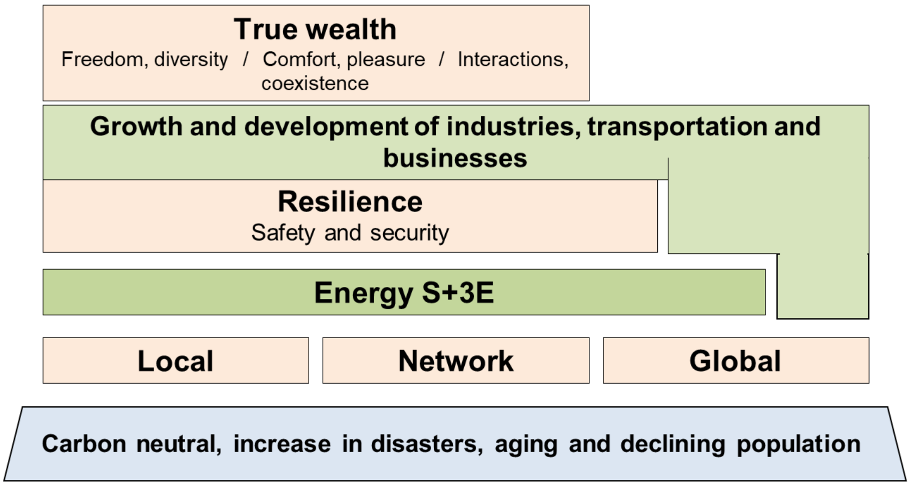


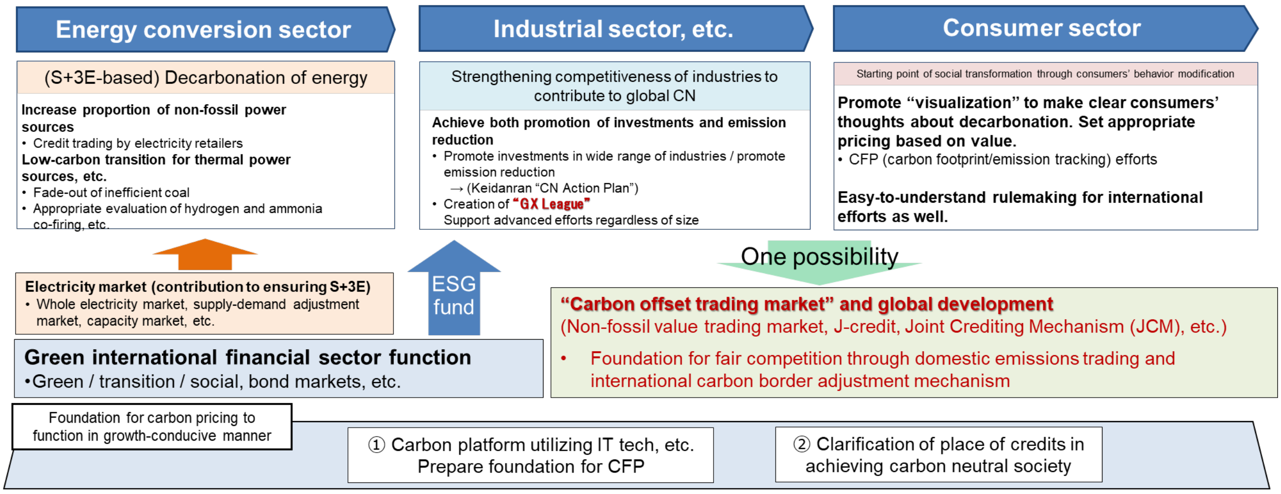
Figure 6-1 Outlook of Japan encompassing the energy sector

6.2 Systems and policies for energy based on S+3E

6.2.1 Current state of systems and policies for energy S+3E

The composition of energy sources has changed significantly as a result of the sharp increase in LNG thermal power generation as an alternative to nuclear power generation, which was halted following the Great East Japan Earthquake. Meanwhile, thanks to FIT and other measures to introduce renewable energy sources, by 2020, wind and solar power generation accounted for about 20% of the power supply. Japan has presented measures to improve the ratio of non-fossil power generation and green innovation strategies aimed at technological innovation for the transformation of the energy business[39]. These policies and strategies are centered on institutional design aimed at liberalizing power on the basis of market principles, including separation between power generation and transmission.

[39] "Green Growth Strategy Through Achieving Carbon Neutrality in 2050." (Accessed on January 22, 2022) https://www.meti.go.jp/press/2021/06/20210618005/20210618005.html



Sources: Material created by H-UTokyo Lab based on materials from Ministry of Economy, Trade and Industry's "Study Group on Economic Methods for Achieving CN Worldwide"

Figure 6-2 Trends related to energy

In addition to the various measures taken by the supply side to stabilize energy supply and demand, coordination of energy demand in response to fluctuations in renewable energy is imperative. In the industrial sector, energy consumption has been on a downtrend as a result of efforts to optimize the use of energy following the surge in energy prices in the early 2000s, the financial crisis in 2009, and the Great East Japan Earthquake in 2011. Partial amendments were also made to the Energy Conservation Act, including the promotion of the introduction of high-efficiency industrial equipment and components[40].

There are also moves to support investment and implementation plans for energy efficiency and energy conservation through the "CN Top League" program[41]. In the civil and service sectors, efforts have been made with regard to heating and cooling, which have high demand ratio. In particular, the Top Runner certification system for equipment[42]and the Building Energy Conservation Act, which covers energy-saving conversion for high insulation performance and installation of solar cells on buildings[43], were fully enforced. These developments point to a positive

40 "Energy Conservation Portal Site" (Accessed on January 22, 2022). https://www.enecho.meti.go.jp/category/saving_and_new/saving/index.html

41 "Study group on economic methods and approaches for achieving worldwide carbon neutrality" (Accessed on January 22, 2022). https://www.meti.go.jp/shingikai/energy_environment/carbon_neutral_jitsugen/index.html

42 Agency for Natural Resources and Energy, "Judgment standards for manufacturers, etc. of energy-consuming equipment" (Accessed on January 22, 2022). https://www.enecho.meti.go.jp/category/saving_and_new/saving/enterprise/equipment/

43 Ministry of Land, Infrastructure, Transport and Tourism, "Building Energy Conservation Act Page" (Accessed on January 22, 2022). https://www.mlit.go.jp/jutakukentiku/jutakukentiku_house_tk4_000103.html

outlook towards standardization of energy-efficient construction of buildings.

6.2.2 Challenges and measures for securing stable energy supply

The “Sixth Strategic Energy Plan,” which was decided by the Cabinet on October 22, 2021, presented the directions for policies toward the realization of "Carbon neutrality in 2050" and "Reduction of GHG emissions by 46% in 2030”[44] on the premise of "S+3E" shown in Figure 6-3. The Sixth Strategic Energy Plan also aims to develop a "framework for ensuring supply capability."

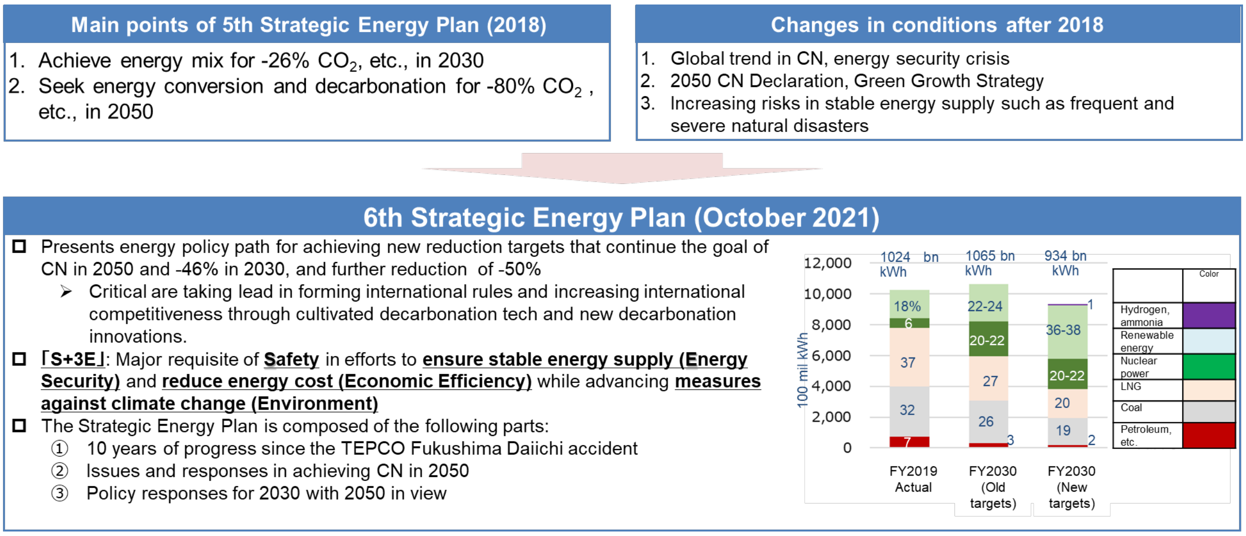


Figure 6-3 Outline of the Sixth Strategic Energy Plan

"Energy system reform" was completed in April 2020, and the measures shown in Figure 6-3 were implemented. One of the objectives of the energy system reform was to "ensure stable supply.” However, the assignment of responsibility for ensuring stable supply is not clearly stated in the current Electricity Business Act.

The Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) has been tasked to promote efforts to ensure supply capability. The Sixth Strategic Energy Plan, however, has put a spotlight on the immense importance of the role of "promoting efforts to ensure supply capability" for the entire country. For this reason, in December 2021, a policy to clearly state "promotion of efforts to ensure supply capability" in the objectives

[44] Agency for Natural Resources and Energy, "Strategic Energy Plan" (Accessed on January 22, 2022). https://www.enecho.meti.go.jp/category/others/basic_plan/

of OCCTO under the Electric Business Act was proposed through a government committee.

Although the deployment of renewable energy, such as wind and solar energy, is being promoted towards the realization of carbon neutrality, there is also a need for power sources that can provide stable supply until its realization, such as hydrogen and ammonia power, to provide new sources of supply-demand adjustment capacity. Further, fuel market conditions will also have a significant impact, including the possibility that prices of LNG and other products will rise sharply during the period of transition to carbon neutrality. Under these circumstances, it is necessary to ensure stable supply of power and supply capability that are unaffected by fuel market conditions.

Although the reform of the energy system has allowed many electric power retailers to join the market, the effect on stable supply became inevitable due to the surge in electricity wholesale prices amidst the tight energy supply in recent years. Efforts to reduce barriers to entry for businesses must be continued to encourage business development through the creation of new innovations based on power supply-demand coordination, such as the power demand aggregation mentioned in Chapter 5. On the other hand, it is now time to organize the responsibilities for adhering to the S+3E principle in power supply, along with the creation of a system that anticipates possible business risks based on S+3E and the formulation of the rules necessary to maintain a stable power supply. Other than implementing measures in addition to the current systems, we should also strive to understand the issues that may arise in the future, such as the planning of the power supply, the burden of costs for stable supply, and the creation of adjustment capacity for renewable energy. Discussions on these issues, including fundamental institutional reforms, should be made.

It has been recognized anew that a global perspective is essential to achieve new development of energy systems. A surge in fuel prices is likely to occur due to the effect of geopolitical and climatic factors, such as Russia's invasion of Ukraine in February 2022 and the shortage of wind power in Europe in 2021. In particular, since LNG has a shorter storage period of about half a year compared with coal, the challenge of whether it can meet the spot demand that cannot be covered by planned imports has been pointed out. It is time for the country to accept the inevitable realities surrounding energy sources, energy supply and demand stabilization, and energy conservation in order to create significant innovations and to ensure as many technological options as possible. Further emphasis is made on the importance of clearly informing the public of the present situation and of ensuring options that can be flexibly made on the basis of objective evidence.

I. 3 purposes of electricity system reform

1. Ensure stable supply
2. Maximally keep down electricity rates
3. Expand consumer choices and business opportunities

II. 3 main pillars of electricity system reform

1. Expand wide-area power grids
2. Full liberalization of power generation and retail sales
3. Further ensuring of neutrality of power transmission and distribution sector through legal separation

Ⅲ. 3 stages of implementation of electricity system reform (Completed in April 2020)

Implementation item	Completed	Main purpose / anticipated effect
1. Establish "mechanism to promote wide-area operations"	April 2015	Use of electricity beyond area of power company through wide-area operation of power grids
2.Overall liberalization of electricity generation and retailing	April 2016	Promote market entry of retailers to homes and keep down electricity rates through competition
3. Separation of transmission and distribution companies (legal separation)	April 2020	Promote fair use of power transmission and distribution networks for new power generation companies

Advantages/disadvantages of vertical integration (before reform) / separation of transmission and distribution (after reform)

	Vertical integration	Separation of transmission and distribution
Ensures grid access for power generation	Possible to plan power generation development and grid maintenance in coordinated manner	Fair access to power grid for new power generators is ensured.
Promotes retail competition	Concerns over preferences to own company when power generation and retail are done by the same company	Major power generators and retailers trade with partners that have best conditions.
Ensure supply/demand adjustment	Easy to procure instantaneous adjustment capability; transaction fees are not needed.	Unclear whether necessary adjustment capability can be procured from other companies; transaction fees required
Responsive to unexpected events	Possible to carry out recovery that coordinates distribution of power with demand when power outage, etc., occurs	Not easy to have coordinated response for power system when unexpected events occur

Challenge in separation of transmission and distribution: Ensuring needed adjustment capability and preparing measures for stable supply is also critical

Direction: Specify role of "wide area mechanism" in ensuring supply capability in Electricity Business Act's "Purpose of the Wide Area Mechanism"

Figure 6-4 Results of the energy system reform and challenges after the reform

6.3 Industrials innovations to realize carbon neutrality

Carbon neutrality entails many transitions not only for energy supply, but also for energy consumption and raw material supply. For example, as shown in Figure 6-5, naphtha, which is the raw material of the four major resins that are vital to our daily lives (polyethylene, polypropylene, polystyrene, and polyvinyl chloride), is currently supplied domestically as a byproduct of gasoline refining and through imports at a ratio of around 50-50. However, a 46% reduction in greenhouse gas in 2030 will lead to a decrease in domestic supply to about 15%, forcing a rethinking of the supply chain. As such, since fossil fuels also serve as carbon sources, it is essential to have a long-term perspective of the fossil fuel supply chain and the value chain for CCUS and other carbon recovery and recycling technologies and for other alternative materials. Advanced analytical technologies related to production and procurement of these sources and materials must be developed.

As mentioned in Chapter 3, for the chemical and steel industries, CO2 capture and CO_2 recycling will be crucial for the realization of the carbon-neutral society. For example, in petrochemical complexes, sites have been internally optimized for the sharing of raw materials such as naphtha, as well as for the supply of heat and power, thus achieving stable production. CO_2 recycling refers to the optimization of the central system of production technologies. Measures should, therefore, be taken to promote investments for consolidating sites and streamlining operations not only to optimize facilities, but also to optimize the raw material supply chain.

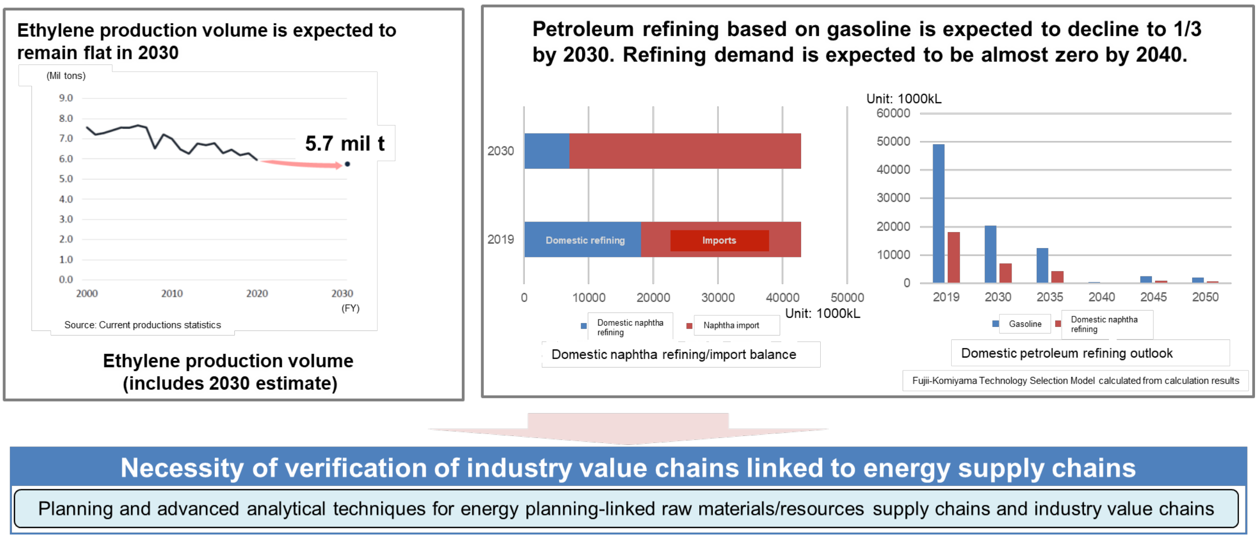


Figure 6-5 Transitional changes (using naphtha supply as an example)

Utilization of data is essential in the transition of the industrial sector towards carbon neutrality. More than simply reducing greenhouse gas emissions, a rethinking of the raw material procurement and supply chain will be needed as well. The causes and effects for such issues are not always defined unambiguously, wherein they usually involve complex and uncertain factors. Likewise, the final benefit may not necessarily be measured in terms of carbon neutrality, but may come in the form of other values for economy, welfare, or services. Solving complex social issues requires objective analytical technologies to examine possible factors related to the issues on the basis of data, maximize the value of carbon neutrality, and minimize the impending crisis. It is important to carry out the analysis of social issues and value chains on the basis of data, as shown in Figure 6-6. There is a need for the construction of a platform for openly managing such data and enabling access to anyone, as well as a framework that enables specific actors to mutually benefit from the data in a highly secure manner.

The transition to carbon neutrality in the industrial sector will lead to the proper evaluation by consumers of each industry's efforts to reduce CO_2 emissions, thereby promoting innovation through competition among industries. As one of the ways to carry out the evaluation, in Version 3 of the Proposal, we forwarded the concept of "CO_2 visualization," in which consumers can monitor CO_2 emissions of final products. This is important as a framework for market formation by consumers and is also necessary for properly evaluating the contribution to carbon neutrality of not only the final products, but also the manufacture of raw materials and components. It is therefore necessary to create a market that cycles investments back into carbon neutrality initiatives. In addition, the carbon neutrality transition process for manufacturing of raw materials, such as steel and chemicals, should not be simply limited to fixed investments in CN technology innovations leveraging supply chain and value chain analysis based on data collaboration as mentioned above. It is also necessary to build an investment cycle that evaluates innovation creation and creates appropriate market values.

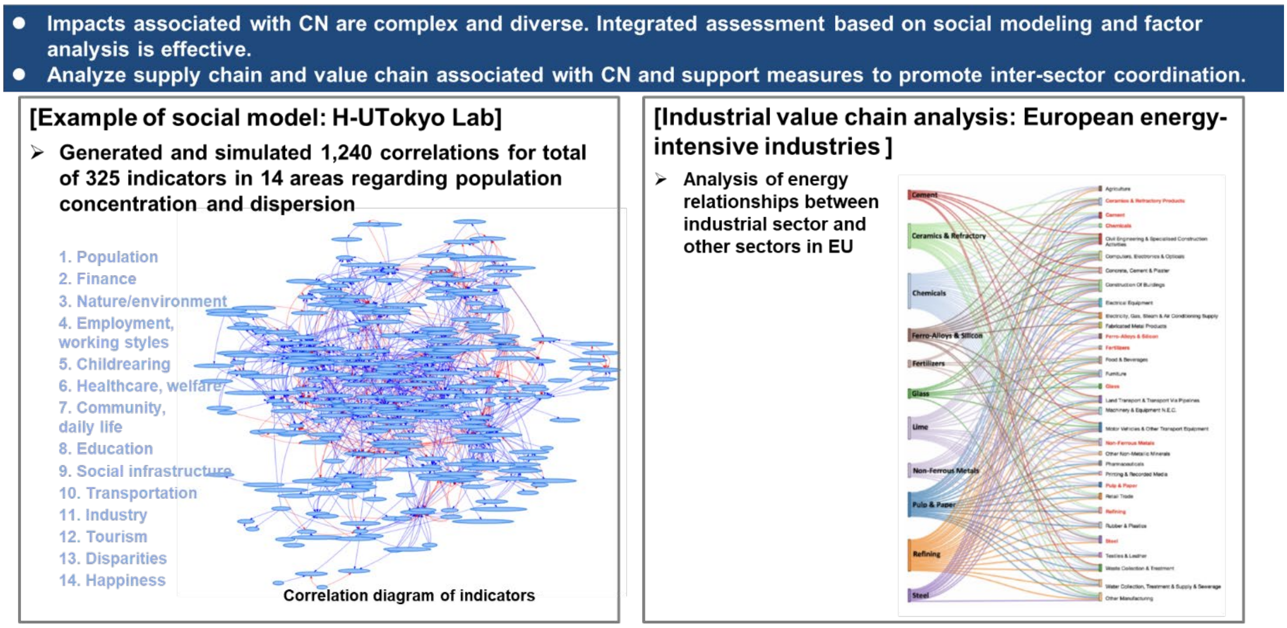


Figure 6-6 Example of analysis of social issues and industrial supply chains using data science

In addition to reducing CO_2 in Japan, CN innovations in industry should be strategically considered for exportation to reduce CO_2 on a global scale, including emerging countries. By developing CN innovations as robust export solutions to foster economic growth and help solve problems in emerging countries, more than simply reducing CO_2, it is possible to create sustainable industries that can compete in the global arena of innovation creation.

6.4 Regional innovations to realize carbon neutrality

Along with the decline in Japan's population since 2015, there is a continuing concentration of the population in urban areas. On the other hand, the population structure in rural areas is characterized by areas with low population density. Due to the need to maintain certain administrative services even in regions with low population density, energy utilization efficiency particularly in the civil sector tends to be lower for sparsely populated regions[45]. Along with the decline in Japan's population since 2015, there is a continuing concentration of the population in urban areas[46]. On the other hand, the population structure in rural areas is characterized by areas with low population density. Due to the need to maintain certain administrative services even in regions with low population density, energy utilization efficiency particularly in the civil sector tends to be lower for sparsely populated regions[47].

The final summary of the "Long-Term Outlook of Japan" asserts that Japan will focus on, maintain, and reinforce local living areas with a population of around 100,000, wherein residents have access to everything they need for everyday life within approximately one hour of travel. Compared with the formation of functions around hub cities with populations of around 300,000 to 500,000 as defined previously, the policy calls for pursuing further decentralization over wider areas. Although the commercial viability of some urban services, such as department stores and core hospitals, may be lower at populations of around 100,000, the digitalization of many services and the progress of ICT in education and telework brought about by the coronavirus pandemic have made it increasingly possible to expand service coverage and improve feasibility of businesses. These opportunities for

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45 Hiroto Asano et al. "Study on the plan for energy-independent settlements in hilly and mountainous areas," Proceedings of Architectural Research Meetings of the Architectural Institute of Japan, Kanto Chapter, 85 (85) 249 - 252, March 2015.
46 National Institute of Population and Social Security Research, "Population and household projections" (Accessed on January 22, 2022). https://www.ipss.go.jp/syoushika/tohkei/Mainmenu.asp
47 Hiroto Asano et al. "Study on the plan for energy-independent settlements in hilly and mountainous areas," Proceedings of Architectural Research Meetings of the Architectural Institute of Japan, Kanto Chapter, 85 (85) 249 - 252, March 2015.

regional digitalization, including energy systems, must be comprehensively implemented to strengthen the energy resilience and security of the local living areas. Likewise, it is necessary to promote measures to fortify the value of energy through S+3E in local living areas by enhancing energy coordination within and among areas, such as through energy supply and demand coordination among regional industries.

In Version 2 of the Proposal, recommendations were made on the disclosure and confidentiality of data in *power* systems and examples of use of data. Since then, initiatives of various agencies and power companies have progressed, and data on the outline of the power grid and other relevant information have been released. These data can now be used in preparing for the expansion of renewable energy and in planning the installation of new wind and solar power generation facilities. On the other hand, while progress has been made through activities of the Grid Data Bank Lab, we are still halfway down the road in the utilization of smart meter data, which constitute a major energy data of the local community, for full-scale services. The utilization of power demand data for services necessitates an acceleration of the establishment of institutional frameworks for data governance. Many data users are foreseen to deploy services in conjunction with other urban data to be used in future smart cities. It is, therefore, necessary to establish data utilization platforms and rules needed for the development and use of data in conjunction with smart city data infrastructure development. Value for both energy providers and service providers can be enhanced by facilitating linkage of power-related data with city data, rather than solely using power-related data for energy management.

6.5 Chapter 6 Summary

The following is a summary of the contents of Chapter 6.

- A stable supply of energy toward the carbon-neutral era requires power sources capable of providing stable supply independent of fuel market conditions. These power sources will play an important role as a stopgap until the establishment of power generation technologies using non-fossil fuels, including hydrogen and ammonia power generation.
- In response to the uncertainties from the difficult geopolitical situation for procurement and the surge in raw

material prices accompanying transition to carbon neutrality, there is a need for frameworks to nurture society as a whole. This entails enabling options for innovation of the material cycle for raw materials and components, beyond simply disposing final products, in order to ensure economic security.

- Solving complex social problems requires objective analytical technologies based on data to analyze possible factors related to the problems, to maximizes the value of carbon neutrality, and minimize the impending crisis. There is a need for the construction of a platform for openly managing such data and enabling access to anyone, as well as a framework that enables specific actors to mutually benefit from the data in a highly secure manner.
- The formation of sustainable regions requires a framework that enables flexible management that is based on the intents and reflects the characteristics of the region. A framework that can be expanded into carbon neutrality should be actualized by taking advantage of systems for flexible operations of current urban plans and for investments that reflect the real situation of the regions.

Chapter 7 Issues and challenges in building a newly conceptualized sustainable society

In the previous chapters, we discussed the scenarios for transition toward achieving carbon neutrality in 2050, the insights gained from the analysis of bulk power systems, the reforms to be taken in the regions, and the systems and policies that support these reforms. However, achieving carbon neutrality in 2050 is only a stepping stone, and its realization must lead to the creation of a sustainable society. This chapter reviews the keywords to consider for the realization of the sustainable society drawn from the issues discussed in the previous chapters. By centering on these keywords, this chapter also sorts out the challenges inherent in the approaches that are considered effective in achieving carbon neutrality. We will then review the areas where innovation should take place and present the ideal vision of a sustainable society.

7.1 Keywords to be considered for the realization of a sustainable society

In the previous chapters, we identified the issues to address and the innovations generated towards realizing carbon neutrality by drawing transition cenarios, analyzing the macroscopic energy systems, and evaluating the value-sharing services in the regions. We also presented the systems and policies to support the innovations. The key ideas of the previous chapters are presented in Figure 7-1. From these key ideas, we have drawn out the keywords for the transition to carbon neutrality; namely, “coordination and coexistence” and national and regional “constraints.” Also, the need for CO2 capture and life cycle assessment leads to the need to review environmental assessment indicators to include not only the energy use phase, but also to include "pollution" from manufacturing to disposal of products and equipment. "Material circulation" is a powerful means to control this "pollution." Building an energy utilization system that reduces the disposal of goods, including CO_2, is necessary for the realization of a sustainable society beyond 2050.

The next sections will explain the social vision for a sustainable society based on the derived keywords.

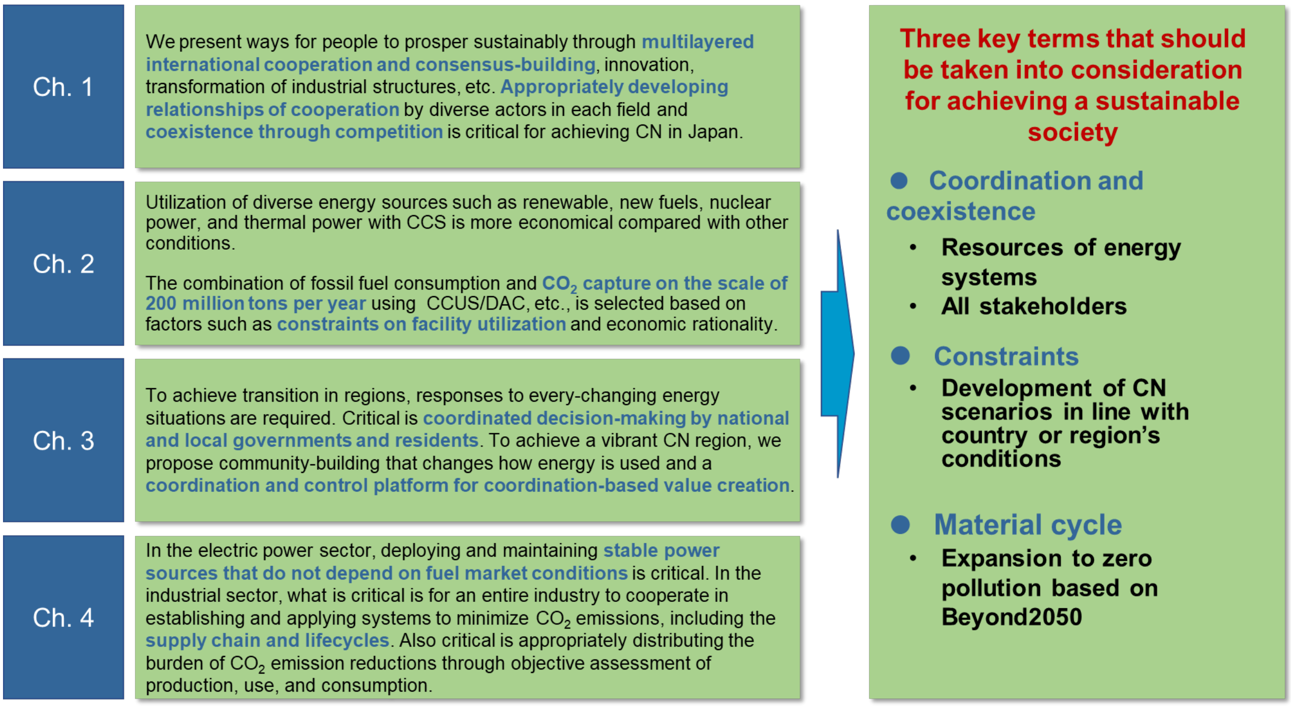

Figure 7-1 Key words for a sustainable society derived from key ideas in the previous chapters

7.2 Coordination and coexistence

7.2.1 Scientific frameworks for a sustainable society

Planetary Boundaries and SDGs are extremely important scientific frameworks for the realization of a sustainable society. The Planetary Boundaries concept defines the areas within which humanity can safely carry out activities to survive. The concept classifies the planet's conditions into three zones. In particular, the climate changes in response to carbon neutrality have reached the zone of uncertainty. In accordance with the concept, once the balance has been broken and the boundary has been crossed, it would be difficult to revert back; hence, returning to the safe zone as soon as possible is crucial. The SDGs are the "development goals for a sustainable society that leaves no one behind" based on the planetary boundaries as the scientific basis. Hitachi-UTokyo Laboratory aims to realize a sustainable society by reaffirming the planetary boundaries from an environmental perspective.

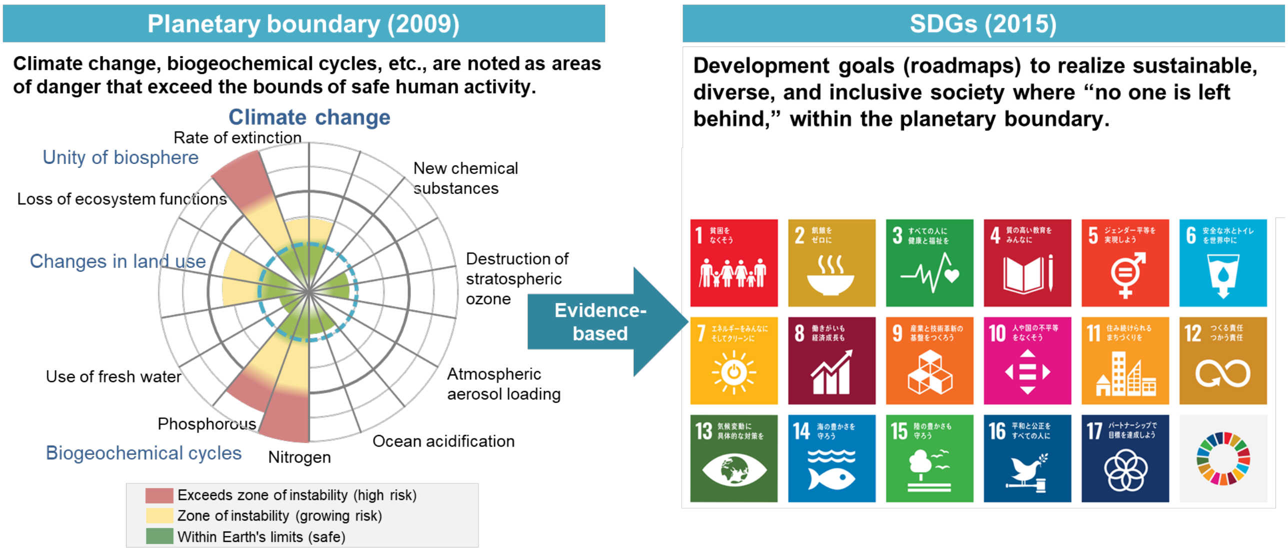

Figure 7-2 Planetary Boundaries and SDGs[48]

7.2.2 Coordination and coexistence in sustainability

The keywords for a sustainable society are "coordination and coexistence." Coordination is a situation in which both sides of two opposing interests work together to solve problems by helping each other. Coexistence, on the other hand, means living in the same place while engaging with other entities and points to a condition in which the parties are not necessarily in a win-win relationship. Figure 7-3 presents coordination and coexistence in the three elements of sustainability; namely, environment, economy and society.

First, let’s focus on coexistence. Coexistence in the environment refers to the formulation of unique goals and transition scenarios based on different national and regional constraints and interests. Coexistence in the economy is exemplified by market competition, where the strong dominates under the principle of competition. Coexistence in society refers to a state where activities are being undertaken to maintain the environment led by some highly environment-conscious residents.

On the other hand, coordination in the environment points to having all stakeholders coordinating to maintain the earth in the context of the planetary boundaries. This is exemplified by harmony with a decarbonized and recycling-

[48] The Planetary Boundaries figure is drawn from the figure prepared by the Ministry of the Environment (http://www.env.go.jp/policy/hakusyo/h29/html/hj17010101.html).

oriented society and with nature. Coordination in the economy points to the construction of systems and mechanisms that will enable both sides to enjoy economic benefits. This refers to contracts, agreements, and the formation of markets operated by common rules. Coordination in society points to the building of frameworks for energy optimization beyond industrial boundaries. This is exemplified by sector coupling and demand response.

Coordination alone will not lead to the establishment of a [sustainable] society and cannot bring about innovations that result from competition. In addition, with coexistence alone, the scope of optimization will be localized for individual activities, and transitions involving major social changes, such as the realization of carbon neutrality and a sustainable society, cannot happen. For this reason, achieving harmony between "coordination" and "coexistence" will determine the realization of a sustainable society.

The underlined portions under coordination are included in the "coordination mechanisms for energy systems" proposed prior to Version 3 of this Proposal. Going forward, Hitachi-UTokyo Laboratory will expand its scope to a recycling-oriented society.

Cooperation: Solving problems through cooperation by parties with conflicting interests by combining strengths and working together
Coexistence: Living in the same place while interacting with others does not always result in a win-win relationship.

	3 items of sustainability	Cooperation	Coexistence
1	Environment	Based on planetary boundary, cooperate with stakeholders and maintain common property that is the Earth/ <Decarbonation, circular, coexistence with nature>	Each country and region faces a different set of conditions. Establish goal/transition scenarios that respond to these conditions <Development and sharing of roadmaps>
2	Economy	Building systems and mechanisms for two parties to enjoy economic benefits by building "give and take" relationship. <Creation of contracts and agreements, creation of markets>	Economic rationality/efficiency are important KPIs, strong actors dominate under the principle of competition. <Winning in market competition>
3	Society	Build framework for energy optimization across industry boundaries. <Sector coupling, demand response>	Promote activities to maintain the Earth's environment, centered on highly conscious citizens. <Innovative citizens>

***Underlined items indicate areas covered by "Energy System Cooperation Mechanisms" being studied to date.**

Figure 7-3 Coordination and coexistence in the three elements of sustainability

7.3 Constraints in Japan and the needed solutions

The second keyword in the realization of a sustainable society is "constraints." Japan is characterized by a narrow landmass, being an island nation with no neighboring countries and surrounded by sea, having limited minerals and renewable energy resources, and having experienced the Great East Japan Earthquake. These are major constraints for Japan.

- Difficulty in securing locations for renewable energy installations due to Japan's narrow landmass

In the 100% renewable energy case mentioned in Chapter 4, more than 600 GW of solar power will be deployed. This volume means securing power generation sites totaling 7400 km^2, an area that cannot be covered even if Tokyo, Osaka, and Kanagawa prefectures will be blanketed with solar panels. In Japan, where 70% of the land are hilly areas, this footprint will have a significant impact on society[49].

In addition, since wind direction in mountainous regions generally changes frequently, even though the average wind speed is high, it is often not suitable for wind power generation. Moreover, since Japan has few shallow beaches, there is little choice but to deploy floating windmills, which are costly to build. For these reasons, the difficulty in securing locations for renewable energy installations is a primary constraint.

- Power systems that are confined within Japan due to the absence of international interconnection lines

Europe, U.S., and China have interconnection lines with neighboring countries that can be used to balance power supply and demand. Although an island nation like Japan, the U.K. is close to its neighbors and interconnection lines with a total capacity of 18 GW are being installed or planned. These interconnection lines provide massive adjustment capacity, which enable reduction in power costs. Japan is not only far from its neighbors, but the geopolitical situation also makes it difficult to build interconnection lines with neighboring countries.

- Continued reliance on imports because of limited resources

Carbon neutrality substantially increases the energy self-sufficiency rate. However, because of Japan's inherently low self-sufficiency rate, the need to import energy sources due to the difficulty of securing locations for renewable

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[49]Japan Institute of Country-ology and Engineering. "Know your country/ Things you probably didn't know about Japan." (Accessed on November 20, 2021) https://www.jice.or.jp/knowledge/japan/commentary06

energy installations mentioned above, and the need for international coordination with a view to overseas transport of CO_2, Japan will have to continue to depend on other countries for importing energy resources and transporting CO_2 for a fee.

- Social acceptance of nuclear power use

Japan's experience of the Great East Japan Earthquake has made it extremely important to obtain social acceptance for the use of nuclear energy. The table in Figure 7-4 shows the results of a public opinion survey by interview.[50] The results point to the importance of building safe and reliable systems, developing advanced nuclear reactors such as SMR, and creating innovations in nuclear waste disposal technologies.

These constraints will lead to an increase in energy costs in the shift towards carbon neutrality, which in turn will result in a decline in the competitiveness of domestic industries. Therefore, we must create innovations that will overcome or mitigate these constraints. Table 7–1 summarizes the effects of the four constraints and their possible solutions. These solutions also show that there should be harmony between the control of costs and advancement of functions through coexistence (competition) and the solution and mitigation through coordination.

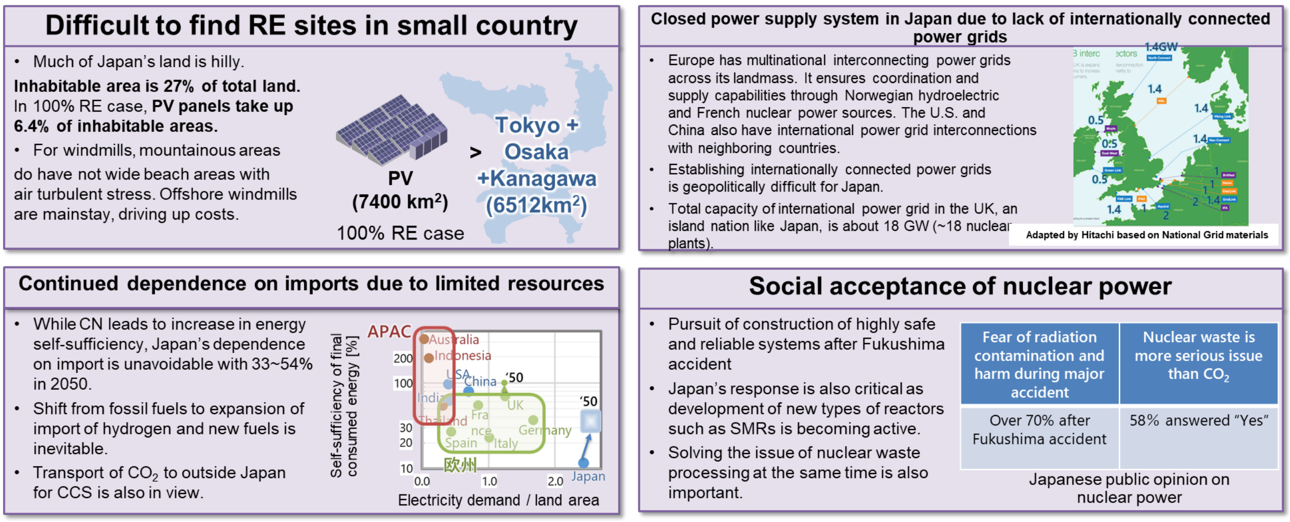


Figure 7-4 Constraints in Japan

[50]Junko Kitada, 2019, "Dynamics of public opinion on nuclear power generation - Conflict between risk, values, and efficiency," Osaka University Press.

Table 7-1 Effects on energy cost and solutions to the constraints

Constraints	Effect on energy costs	Solutions
Narrow landmass	Difficulty in building renewable energy installations at low costs	Establishment of offshore wind power generation technologies
Absence of international interconnection lines	Need for a large amount of adjustment capacity to maintain the domestic supply-demand balance	Output adjustment of nuclear power generation facilities and use of demand response
Limited domestic resources	Importation of fossil fuels, hydrogen and new fuels; overseas transport of CO_2	Generation of adjustment capacity through EV utilization to reduce fuel used for adjustment capacity
Social acceptance of nuclear power use	High level of public interest in radiation contamination damage and nuclear waste since the Great East Japan Earthquake	Construction of highly safe and reliable systems; innovations in fuel burning technology

7.4 Innovations based on material circulation and Japan's unique challenges

As mentioned in Chapters 3 and 4, carbon neutrality cannot be achieved by simply deploying a large amount of renewable energy. The reason for this is that in addition to securing locations for renewable energy installations, coordination with regional industries, and the cost of securing adjustment capacity through the introduction of renewable energy as mentioned above, attention should also be given to the treatment of CO_2 and waste during the manufacture of renewable energy equipment.

Figure 7-5 shows the CO_2 emissions of the power generation sector in the "100% renewable energy" case in Chapter 4. The "100% renewable energy" case is a vision for society where fossil fuel-fired power generation and nuclear power generation plants will be gradually closed, and power supply will be replaced by renewable energy and power supply from new fuels. If the energy demand from 2050 onwards would be supplied from solar power (581 TWh/year) and wind power (386 TWh) as the main power sources, using the existing methods for producing renewable energy equipment would result to indirect emissions of 56 Mt/year of CO_2 from equipment production and disposal. This means that even with the deployment of the large-scale renewable energy mentioned above, it is impossible to achieve true zero-carbon power.

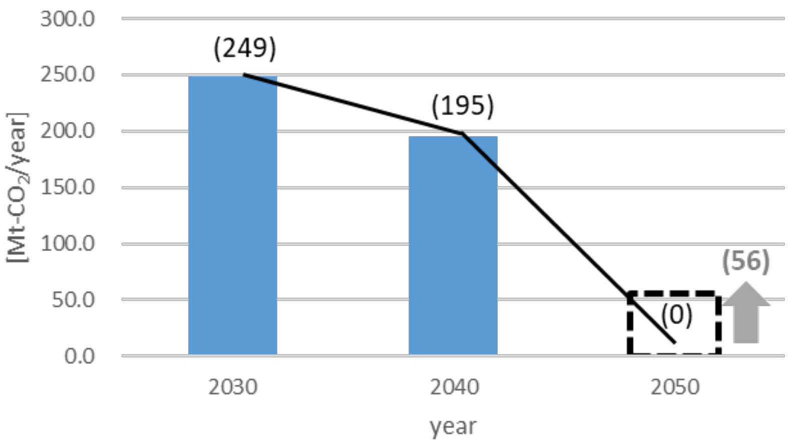


Figure 7-5 Power generation sector CO_2 emissions in the 100% renewable energy case[51]

Also, waste generated when equipment reaches its end of life is also a major issue. Table 7-2 summarizes the impacts of solar and wind power generation and disposal of EV batteries, which are considered effective for carbon neutrality.

The deployment of solar and wind power in the 100% renewable energy case assuming equipment lifespan of 25 years for solar and 20 years for wind power would mean the disposal of 2 million tons of solar panels, 56 thousand tons of wind power blades, and 490 thousand tons of main body and basic equipment parts per year. Also, the use of 40 million EVs nationwide assuming a vehicle battery life of 10 years would mean the disposal of 1.2 million tons of waste batteries per year. Solar panels have a complex multi-layered structure of protective glass, cells, adhesives, and backsheets, while windmill blades are made of reinforced fiber plastic, which is a lattice of fibers and plastics. These complex configurations make it difficult to recycle them.

There are also concerns about the trade value of EV batteries because they are expensive to recycle, and the main battery materials, namely, lithium and cobalt, are produced by only a few countries. Batteries are essential for making renewable energy the main power supply in the transition to carbon neutrality, and large quantities of batteries will be deployed in society. Europe has taken the lead in creating rules for battery reuse and recycling, and Japan has also

[51] Estimate by Hitachi-UTokyo Laboratory based on indirect CO_2 emissions from solar and wind power generation systems as described in the Central Research Institute of Electric Power Industry Report, “Comprehensive evaluation report on life cycle CO_2 emissions from power generation technologies in Japan (Y06)”

participated in these discussions. Along with the creation of industrial rules, discussions should be pursued on the construction of a circular economic system in Japan as a multi-sectoral initiative.

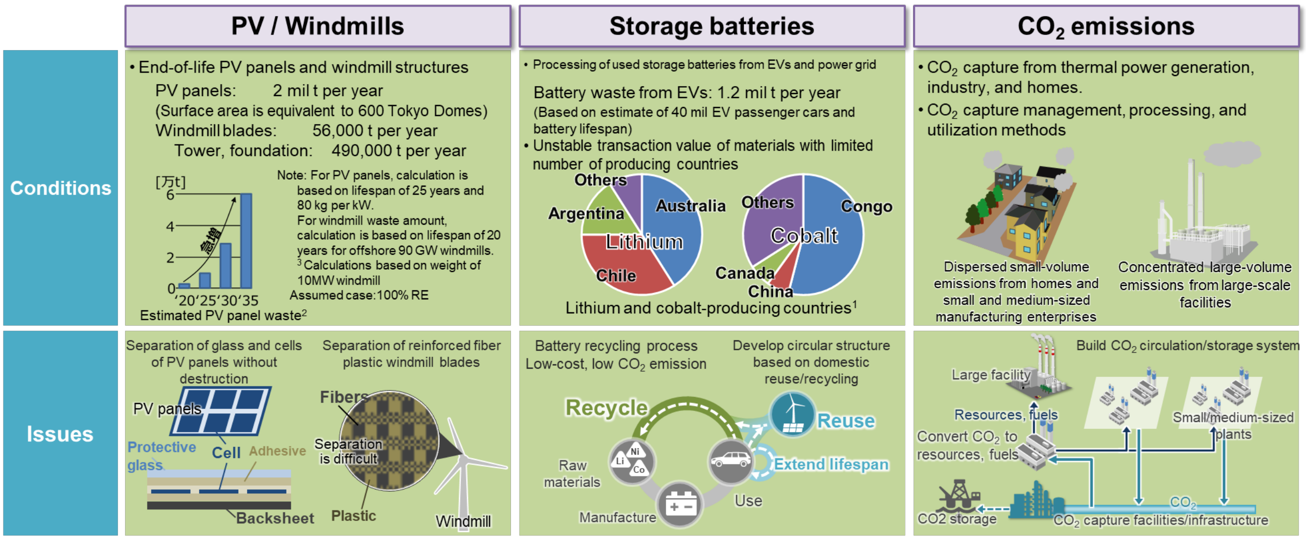
Japan's energy system has been based on the S+3E concept. However, realizing a sustainable society necessitates a review of the environmental assessment scale as described above to incorporate environmental impacts encompassing scopes 1, 2, and 3, such as life cycle CO_2, waste, and auxiliary works. There is need to reevaluate the social vision and the means deemed effective for carbon neutrality. At the same time, there is a also a need to foster the following innovations: (1) recycling-oriented innovations supporting reuse and recycling, such as technologies for separating fibers and plastics inside wind blades and solar panel cells, low-cost and low-CO_2-emission battery recycling processes, and recycling structures that promote battery reuse; (2) material-saving and energy-saving innovations for industrial processes with minimal material and energy requirements and for encouraging behavior modification; and (3) and collaborative innovations that encourage energy consumers to collaborate towards the spatial and temporal distribution of energy resources. By fostering these innovations, we should break away from the linear economy of repeatedly consuming energy and emitting CO_2 in each process, such as in the unplanned production of large quantities of goods, the discovery of materials, the processing of products, and the disposal after their use. The butterfly diagram shown in Figure 7-6 should be implemented in various places.

Implementing the above measures by particular actors or within particular domains could result in a decline of energy efficiency and economic performance for the whole of society and a shift of the economic burden to certain actors. A reuse and recycling system must, therefore, be established across the entire society to avoid this situation, and rules must be developed to support the system. Moreover, the circulation structure for reuse and recycling should not be confined within domestic markets. Instead, we should pursue international coordination built on win-win relationships, such as by balancing recycling and local industry development, thereby simultaneously reducing social costs and promoting material circulation.

It is extremely important that CO_2 generated from electric power, industries, and homes be managed with high transparency and that emissions responsibilities be clearly identified. For recovery of CO_2, multiple industrial measures should be formulated for its conversion as resource and fuel through storage, capture, and methanation.

Recovery by leveraging biological cycles such as through reforestation should be reexamined to make it appropriate to regional characteristics. The promotion of these measures and the development and social implementation of the necessary infrastructures will only be possible through coordination and coexistence across sectors.

Table 7-2 Status and issues in renewable energy, EV batteries, and CO_2 emissions[52,53,54]



[52]Agency for Natural Resources and Energy, 2018. "Rare metals hold the key to widespread use of EV." (Accessed on November 20, 2021) https://www.enecho.meti.go.jp/about/special/johoteikyo/ev_metal.html

[53] Ministry of the Environment, "Results of study toward promotion of reuse, recycling, and proper disposal of solar power generation equipment." (Accessed on November 20, 2021) https://www.env.go.jp/recycle/recycling/renewable/h2810/h28-01.pdf

[54] Ministry of Land, Infrastructure, Transport and Tourism. "Optimum scale of base ports supporting upsizing of windmills and power plants." (Accessed on November 30, 2021) https://www.mlit.go.jp/kowan/content/001418320.pdf

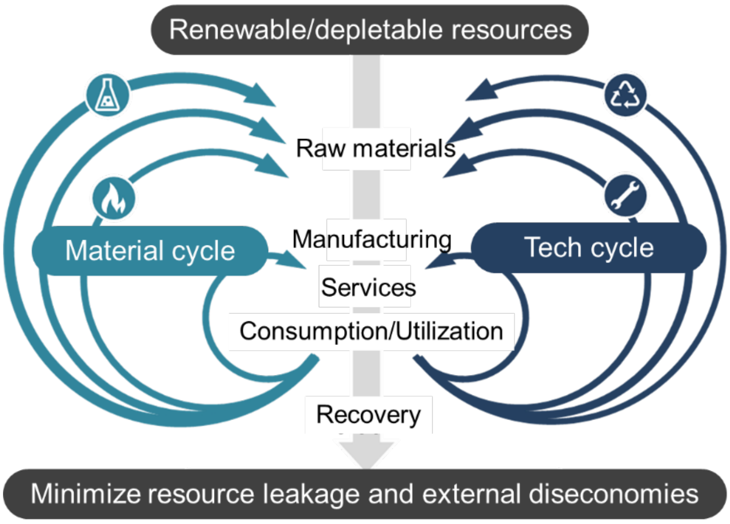


Figure 7-6 Butterfly diagram for preventing waste from being produced beforehand[55]

7.5 Vision and concept toward building a sustainable society

The movement toward carbon neutrality, which entails enormous social changes, is taking place simultaneously around the world at a rapid speed. This has resulted in significant changes in the premises for decision-making, such as the sudden fluctuations in resource prices. These social changes are likely to continue in the future. There is a need to bring about innovations that will overcome country- and region-specific constraints on the premise of a flexible response to these changes and coordination and coexistence in the context of planetary boundaries. These innovations will in turn require the building of a mechanism for coordination between the energy system and the material cycle.

Going forward, Hitachi-UTokyo Laboratory will propose the paths to transition and the ways for coordination and coexistence needed to shape a sustainable society. These include the construction of a circular economy involving multiple sectors, the implementation of recycling systems, the selection of products and services that minimize energy consumption, and the promotion of relevant behavior modifications.

In parallel, we will propose the path for development of human resources capable of overseeing the discussions on innovations required for data-driven enhancement of energy consumption and reduction of waste across an extremely broad range of technical fields. These human resources should likewise be capable of showing the directions on how

[55] Revised by Hitachi-UTokyo Laboratory from the model proposed by the Ellen MacArthur Foundation

society should proceed with these innovations.

To express these commitments, we revise the concept diagram for the energy project as follows.

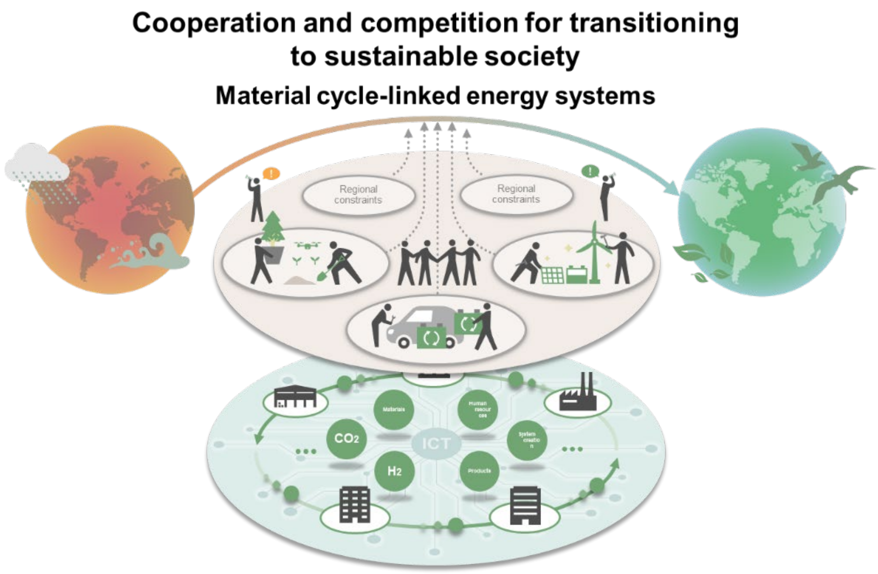


Figure 7-7 New concept diagram of the Hitachi-UTokyo Laboratory energy project

7.6 Chapter 7 Summary

The following is a summary of the contents of Chapter 7.

- Measures that are considered effective in realizing carbon neutrality may in fact have negative effects from the perspective of planetary boundaries. For example, wind and solar power, the main renewable energy sources, produce a large amount of poorly degradable waste materials at the end of equipment life. This is also true for batteries used in conjunction with the deployment of renewable energy. These waste materials could exacerbate chemical contamination and loss of biodiversity.
- To achieve carbon neutrality in a sustainable manner, the entire society should aim to reduce life cycle CO_2 emissions (LC-CO_2) and waste across social domains and actors. We must also restructure the S+3E concept with new criteria incorporating these initiatives.
- We have shown how the social visions presented in Chapter 4 would change when the estimated amount of waste generated by renewable energy and batteries and the axis for their evaluation are focused on LC-CO_2. It

is difficult to achieve a sustainable society in the current linear economy, where energy is used and CO_2 is emitted in each phase of manufacturing, utilization, and disposal. We should avoid the decline in energy utilization efficiency and economic performance of society as a whole as a result of emission reduction measures that are confined to specific domains and actors. To this end, we should endeavor to create a society that links energy and material circulation through data, on the premise that all actors composing society coordinate and coexist appropriately in accordance with the planetary boundaries.

- With the above insights, we revised the vision and concept diagram of this Proposal. Going forward, Hitachi-UTokyo Laboratory will discover social visions that lead to reduction of LC-CO_2 and waste from a broad social perspective through conversations with various actors. We will propose the paths to transition and the ways for coordination and coexistence needed to shape a sustainable society, including the construction of a circular economy involving multiple sectors, the implementation of recycling systems, the selection of products and services that minimize energy consumption, and the promotion of relevant behavior modifications. Likewise, we will propose ways for developing human resources who will oversee the discussions across the various areas for fostering the necessary innovations and who will lead the transition of society.

Chapter 8 Proposal

To realize a sustainable society within planetary boundaries, the necessity for major changes in not only in the energy field but all domains of society and the private and public sectors is being discussed around the world. On the other hand, natural environments, energy systems, social systems, and citizens' values, all of which differ between countries and regions, are considered to present major challenges in promoting transformations. The Hitachi-UTokyo Laboratory has presented transition scenarios that give insights and identify issues that are now occurring or will occur in not only the energy sector but also in Japan's society and private and public sectors, to raise discussion points that Japan should consider (Chapter 3). Based on these discussion points, we have fleshed out strategies needed to realize carbon neutrality (CN) by evaluating analysis of energy systems, macro vision of society, and transformations of local communities (Chapters 4 and 5). We have also presented systems and policies needed to overcome challenges to realizing CN (Chapter 6). In addition, we have presented energy-related issues in realizing a sustainable society, with CN in 2050 as a checkpoint. We argue that building a sustainable society cannot be done simply by introducing renewable energy. New coordination and competition to transition to the new "sustainable society" are needed to bring about radical transformation of society (Chapter 7). Here, "coordination" refers to the state where actors with conflicting interests join forces together to help one another to solve problems. "Competition" refers to the state where actors providing products and services compete with one another to bring about innovation.

We summarize our recommendations below.

- **The Hitachi-UTokyo Laboratory has created transition scenarios to realize CN by 2050, based on analysis of diverse actors in society and in the public and private sectors. Here, we conducted analysis of the diverse actors that play roles in each sector, based on interviews with experts and knowledge acquired from existing statistics and reports. Our analysis sought to assess the changing relationships and roles of NGOs and universities in the social sector; electricity, gas, transport, steel, petrochemicals, finance, and other businesses in the private sector; and the Japanese government and international organizations in the public sector; while considering their self-interests. We also created domain scenarios based on two cases involving Japan's energy source configuration in the future ("100% renewable energy" and "diverse energy resources"). The domain scenarios describe the pathways of change, including behaviors of energy providers, industries, and citizens, that are estimated for realizing CN. These scenarios present ways for realizing sustained prosperity by people around the world through national boundary-transcending collaborations to realize CN, consensus-building on measures such as CCS, fair decision-making through**

the participation of citizens, businesses, and governments, and furthermore, long-term investment in decarbonation innovations, transformations of industrial structures, and creation of green jobs. (Chapter 3)

Using micro knowledge as clues, the Hitachi-UTokyo Laboratory has described scenarios on modifications in the behaviors of energy providers, industries, and citizens and presented pathways for achieving CN by diverse actors that make up society. For example, we presented how, in the thermal power generation domain, because no social consensus has been formed in many countries, including Japan, to make CCS a reality, governments and energy providers must fairly and appropriately disclose its benefits and disadvantages, such as the necessity of CCS, technical feasibility, and impact on the climate and environment, and form broad consensus in the public and international society. In the petrochemicals domain, tens of thousands of gas stations in Japan are facing business transformation amid the movement to CN due to EV adoption and a declining population. We presented the possibility that the gas stations can play new roles as energy supply centers during disasters and, in collaboration with local governments and citizens, as local infrastructure with enhanced functions for residents, such as mobile shops and medical care facilities.

The points of discussion for realizing CN, derived from the formulation of scenarios described above, are wide-ranging. In particular, the following points are considered to be important for realizing CN: (1) international cooperation for CN, which Japan alone cannot achieve by itself, (2) consensus-building on transition measures toward achieving decarbonization, (3) impartial transitions and creation of green jobs, (4) long-term investments in decarbonation innovation in the industrial sector, (5) understanding the value framework of citizens in cities, and (6) participation in decision-making that transcends frameworks such as the private sector, public sector, and society. In this way, to realize CN in Japan, it is critical to bring about transition to a sustainable society across areas that were formerly considered separate.

- **In formulating transition scenarios for energy systems, we returned climate change to within planetary boundaries, quantitatively analyzed and evaluated the energy system configuration and necessary measures to remain within the boundaries, and depicted a vision of future power and industry domains. Due to the progress of technological innovation and differences in cost conditions, we organized and categorized the 2050 CN vision along two axes: deployment of renewable energy and electrification of transport and industrial sectors. We presented the resulting four completely different visions of society. The results of cost minimization calculations for energy systems corresponding to each vision of society**

suggest that using diverse energy sources such as renewable energy, new fuels, nuclear power, and thermal power with CCS is more economical compared with the other visions. The results also show that even in the case of using 100% renewable energy as the power supply, due to economic rationality factors such as constraints in installation of facilities and the costs of electrifying non-electrified areas, a combination of fossil fuel consumption and capturing 200 million tons of CO_2 per year using CCUS/DAC, etc., is selected. The Hitachi-UTokyo Laboratory will conduct in-depth analysis of visions of future society by collecting further information and emphasizing data in order to rebuild energy systems while keeping down social costs, coordinating with actors on the energy supply side and demand side, CO_2 capture operators, and government and financial sectors. We will also repeatedly conduct simulations based on technological development trends and social conditions to bring about advancement of the use of diverse technologies and decarbonation innovations through competition between energy providers (electricity providers, fuel providers) and industries and between CO_2 capture technologies. Besides identifying issues, we will also present areas where innovations should occur.

(Chapter 4)

The results of the quantitative evaluation we carried out this time showed that offshore wind is a feasible option as a decarbonized energy source in each case. The results also indicated for electricity distribution facilities, it is necessary to install new 15-21 GW high-voltage DC transmission plants along the "Hokkaido – Tokyo/Tohoku route" by 2050. Furthermore, the results revealed that to absorb surplus electricity from renewable energy sources and output fluctuations, large-scale electricity adjustment totaling 300 – 3,000 GWh must be distributed in line with the distribution of renewable energy sources (storage batteries, V2G, hydrogen production, etc.)

Meanwhile, uncertainties still remain in the four presented visions of society, such as technological innovations. The Hitachi-UTokyo Laboratory is therefore conducting quantitative evaluation based on multiple hypotheses. We will reflect the results of discussions on technological innovations and market creation in the CO_2 business, which has a scale of 200 million yen per year, using CCUS/DAC, and energy demand models for new industries, such as data centers, into simulations, and will study the future vision and process for realizing energy systems that are highly likely to emerge in the future. We are carrying out these processes so stakeholders can make appropriate decisions on transitions to multiple futures that may occur.

- **To realize transitions in local communities, what are needed are regulations, subsidies, and responses to**

daily-changing energy conditions, such as fluctuations in energy prices. Decision-making where the national government, local governments, companies, and citizens are coordinated is thus critical. Specifically, it is important to advance measures in stages while sharing the ideal state of the local community, including resilience, and the timing of transitions as the local community's goals. At the same time we must predict and verify advantages and disadvantages to actors involved. For this proposal, we have presented actual examples of data-based decision-making, urban design, and strengthening resilience. We have also proposed a coordinated service that reduces the cost of producing energy in local communities by shifting consumers' energy consumption time. This service can both realize energy cost reduction for consumers and provide bulk power systems with the capability to adjust. To realize prosperous and vibrant CN local communities by 2050, the Hitachi-UTokyo Laboratory will drive the social implementation of platforms required to establish new markets and build them for local energy services as described above through proposals at each location. At the same time, we will present the ideal state of innovation and rule formation that create competition between service providers as well as conditions required to accelerate coordination between local communities and between local communities and bulk energy systems.

(Chapter 5)

Energy-related social trends are changing rapidly. These include the increase in importance of measures on the energy use side, such as energy conservation, adjustment of energy to realize CN, and the worldwide shift toward EV adoption. To realize prosperous and vibrant local communities in a CN society, there is a need to achieve transformations, both large and small, adapted to social conditions, while curbing excessive investments in local communities. The transformations include those requiring decision-making coordinated among the national government, local governments, companies, and citizens, such as decision-making on infrastructure maintenance that comes from large-scale investment and the use of shared assets. As an example of value creation resulting from coordination based on citizens' participation using data and digital technologies and community-building that changes how energy is used, the Hitachi-UTokyo Laboratory has proposed a service for reducing local energy procurement costs by shifting the time of consumers' energy consumption. In this edition of the proposal, we evaluated a test case that used a residential area in Tokyo. The results reveal that in 2030, instead of EVs, heat pumps already growing in adoption will play the main role in contributing to demand shift. Expanding this project nationwide can yield a business with a size of 34.0 billion yen and create power adjustment of 80 GWh, which is equivalent to 4 trillion yen when converted to storage battery costs (50 yen/Wh).

Going forward, to accelerate the realization of such energy services, we will evolve data-based technical proposals and propose measures to accelerate healthy competition between services and coordination between local communities and with core systems.

- **To realize energy transition, it is necessary to review electricity system reforms that have been implemented in line with CN social realization scenarios, and prepare systems and frameworks that support the transition in non-electricity systems and industries and local communities. In the electricity domain, securing power sources that do not depend on the conditions of fuel markets during the CN transition process is an issue. In response, we have proposed the development of a system for stable supply of electricity. The system identifies the location of responsibility, including the introduction and maintenance of stable energy supplies. In the industrial domain, the uneven distribution of burden on specific industries for reducing CO_2 emissions under the current system, and as a result, the decline of Japanese industries' international competitiveness and the country's strength, are issues. To help the manufacturing industry as a whole to coordinate and minimize CO_2 emissions, including in supply chains and lifecycles, we have proposed the visualization of efforts made by individual actors to reduce CO_2 and promoted cost subsidies and equalization of burden so the burden of reducing CO_2 is not concentrated on specific actors. We have also proposed forming a domestic market based on competition to stimulate innovations, and have proposed contributing to CO_2 reduction in the world as a whole by developing CO_2 reduction businesses in developing countries. To flesh out decentralization guidelines for local communities as described in the Second Edition, the Hitachi-UTokyo Laboratory will propose concrete data systems that promote coordination with distributed energy resources; national infrastructure, societal, and urban plans; and management systems.**

(Chapter 6)

To realize a CN society and build a sustainable society from 2050, transitions that add the perspective of economic security to CO_2 emissions and energy costs are necessary. To realize this, in the electricity domain it is essential to secure energy sources that bring about both stable energy supply during the transition process to CN and introduction of innovation, and to formulate and execute an energy system roadmap for this transition. In the industrial domain, because the transition involves transformations of raw materials for manufacturing, such as steel and petrochemicals, data-based strategies and measures that take into account supply chains and LCA are needed. CN transition in industrial manufacturing should proceed through competition between suppliers. This will be expedited by a system that appropriately discloses the process of CO_2 reduction from procurement to final product, leading to coordination of economic burden as a result of CO_2 emission reduction between consumers and manufacturers. Meanwhile, building CO_2 capture systems such as CCS (CCUS/DAC) and its subsequent processing systems is important from the perspective of securing new fuels and promoting heat source substitution in industries that are difficult to electrify, as well as ensuring adjustable capability when deploying VRE. The challenge of CO_2 capture requires the development of systems and policies that promote appropriate response measures, such as solutions within a domain and between domains, and taking advantage of the characteristics of a particular region.

The Hitachi-UTokyo Laboratory seeks to further evolve the decentralization described in the 2nd edition of the Proposal and propose systems that balance both CN and prosperous lives by comprehensively using energy data of diverse local communities, based on the integration of cyber systems and real-world systems in Society 5.0. We will also extract requirements for fleshing out decentralization of energy, such as the potential of local communities for industry, e.g. local industries, and for renewable energy.

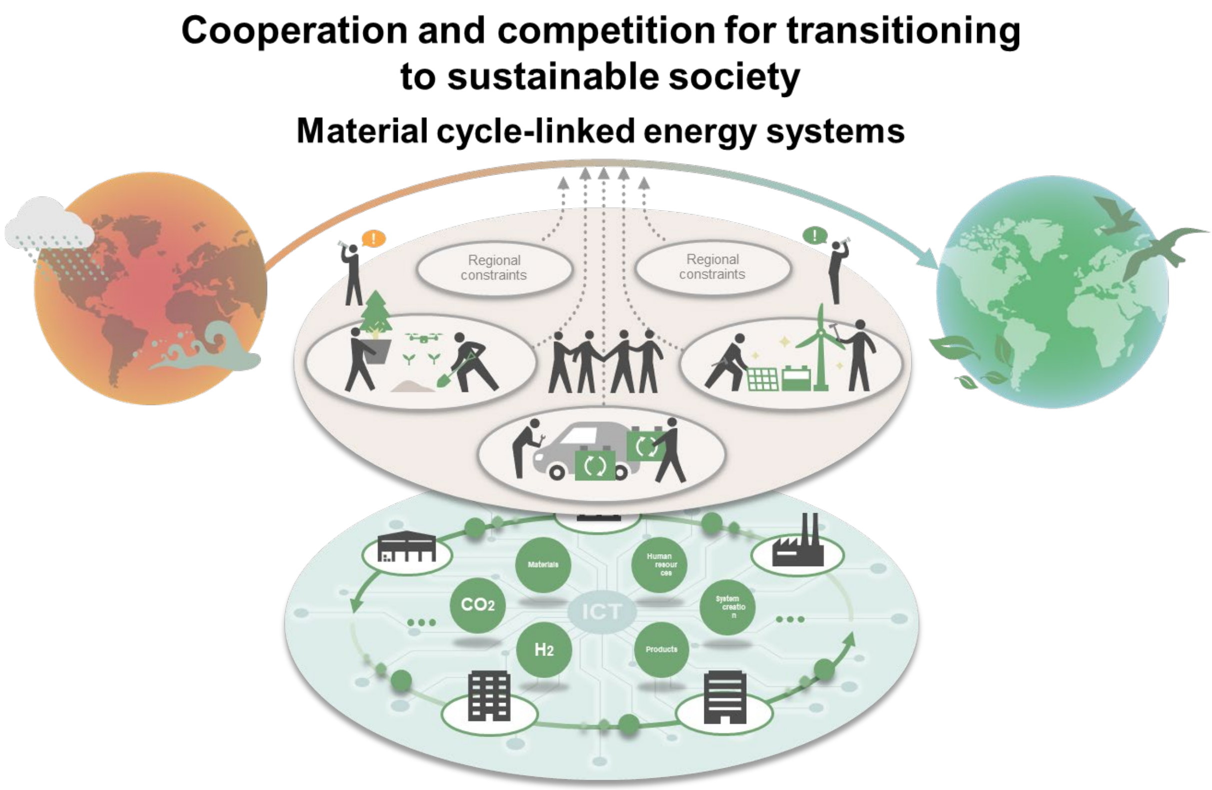
- **Measures considered effective for CN may, on the other hand, have a negative impact from a planetary boundary perspective. For example, wind power and PV, which are representative renewable energy sources, produce persistent waste at the end of their equipment's life. This is also the case for batteries used with the deployment of renewable energy. Their waste may cause progressive chemical pollution and loss of biodiversity. To realize CN in a sustainable manner, in addition to measures being advanced independently by each product and service provider, we should aim for the realization of a society that, transcending domains and actors, efficiently advances reduction of lifecycle CO_2 (LC-CO_2) emissions and waste in society as a whole. We must rebuild S+3E on a new scale that incorporates these goals. In this chapter, based on the assumption that technological improvements will be made by extending existing technology, we have presented the expected amount of waste generated from renewable energy sources and storage batteries, changes in the vision of society shown in Chapter 4 when LC-CO_2 is made an evaluation axis, and the limits of a linear economy, which consumes energy and emits CO_2 in each phase of production, use, and waste. From the premise that actors that form society coordinate and compete based on planetary boundaries, we realized that a society in which energy and material circulation are more efficiently linked should be realized, and reviewed this vision and its concept diagram. The Hitachi-UTokyo Laboratory will propose the ideal state of coordination and competition needed to form a**

sustainable society, including building a circular economy involving multiple sectors, implementing recycling systems, selecting products and services to reduce energy consumption, and inducing behavioral modifications. We will also propose transition pathways.

(Chapter 7)

CO_2 emissions occur during the stages of production, use, and disposal. Social choices should be made by incorporating social burdens related to lifecycle CO_2 emissions and waste products in evaluation standards. Also, because we should avoid reduction in energy use efficiency and economic efficiency in society as a whole due to measures to reduce the emissions of certain actors who engage in excessive competition, it is necessary to discuss measures for reducing CO_2 emissions and waste in society as a whole.

In the Hitachi-UTokyo Laboratory, from conversations with diverse actors, we will discover the ideal state of competition between actors that lead to reduction of LC-CO_2 from a society-wide perspective. In parallel, based on data we will propose innovations needed to bring about improvements in energy consumption and reduction of waste, innovations for human resource development, and pathways to achieve them.



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WG0: overall vision; WG1: core systems and systems and policies; WG2: local communities; WG3: scenario formulation sections.

In each working group, the name of the leader is underlined.

Appendix 1. Derivation of number of households living in detached residential houses and number of distributed resources owned in Machida City, Tokyo

Table A1-1 shows the results of deriving the number of households living in detached residential houses and quantity of distributed resources (HP, PV, EV) in Machida City, Tokyo. Below, we discuss the processes for deriving the values for 2030 and 2050 shown in the table.

Table A1-1 Number of households living in detached residential houses and quantity of distributed resources owned in Machida City, Tokyo

	2030	2050
1. Households living in detached residential houses	96,596	86,330
2. Heat pump water heaters (HP)	42,932	78,108
3. Solar power generation (PV)	21,216	31,080
4. Electric vehicles (EV)	9,582	38,744

1. Number of households living in detached residential houses

Table A1-2 provides a summary of derivation of the number of households in detached residential houses in Machida City, Tokyo. First, we determined the number of households in Machida. A study estimated about 200,000 households in Machida City, Tokyo in 2030.[1] It also projected figures to 2040, but did not specify the number of households in Machida in 2050. Based on the rate of change in number of households from 2015 to 2040 shown in the paper, we estimated the number of households to be 178,000 in 2050.

Next, we determined the number of households living in detached houses out of all households in Machida. The percentage of detached residential houses in the Kanto region was 48.5%.[2] Assuming the same percentage of detached residential houses in Machida, we calculated the number of households living in detached residential houses in the city to be approximately 97,000 in 2030 and 86,000 in 2050.

Table A1-2 Derivation of number of households living in detached residential houses in Machida City, Tokyo

	2030	2050
Number of households in Machida (A)	199,168	178,000
Of these, number living in detached residential houses (=A×48.5%)	96,596	86,330

[1] Tokyo. 2019. "Estimate of Population No. 71 Projected Number of Households in Tokyo." Accessed Jan. 6. https://www.toukei.metro.tokyo.lg.jp/syosoku/sy19rf0000.pdf

[2] Japan Posting Network Association - Kanto Block. 2015. "Number of Households in Machida City." Accessed Jan. 6. http://www.pos-kanto.jp/

2. Heat pump water heaters (HP)

We summarize the process of deriving the number of heat pump water heaters in Table A1-3. The estimate of the spread of heat pump water heaters is calculated separately for Japan's cold climatic zone and warm climatic zone. Machida is categorized as belonging to the warm climatic zone.[3] The same study estimated the number of households living in detached residential houses to be 22.5 million in 2030 and 21.0 million in 2050. Assuming that the number of heat pump water heaters in detached residential houses in the warm climatic zone grows under the medium-growth assumption case until 2030, and increases rapidly afterwards, shifting to the high-growth assumption case in 2050, we determined the number of HP units to be about 10 million in 2030 and 19 million in 2050. Assuming uniform penetration of heat pump water heaters nationwide and in Machida, we determined the number in Machida to be 42,932 in 2030 and 78,108 in 2050.

Table A1-3 Derivation of number of heat pump water heaters

	2030	2050
Detached residential houses in warm climatic zone (nationwide) (A)	22,500,000	21,000,000
Number of heat pump water heaters (nationwide) (B)	10,000,000	19,000,000
Number of households living in detached residential houses (Machida) (C)	96,596	86,330
Number of heat pump water heaters (Machida) (=B/A×C)	42,932	78,108

3. Solar power generation (PV)

Table A1-4 provides a summary of deriving the number of solar power generation panels. The amount of solar power generation deployed for use in detached residential houses is estimated to be 30.2 GW in 2030 under the current-growth assumption case[4] and 45 GW in 2050 under an acceptance-oriented scenario.[5]

These calculations are based on households living in detached residential houses nationwide. For the number of households living in detached residential houses nationwide, we totaled the number of such households in the warm climatic zone and in the cold climatic zone given in Reference 3 to arrive at 27.50 million households in 2030 and 25.00 million households in 2050.

In the same manner as deriving the number of heat pump water heaters, we assumed the penetration rate of solar power generation deployed in detached residential houses to be the same nationwide and in Machida. The amount of

[3] Heat Pump & Thermal Storage Technology Center of Japan. 2020. "2020 heat pump penetration outlook survey" (in Japanese) Accessed Jan. 6. https://www.hptcj.or.jp/Portals/0/data0/press_topics/2020NewsRelease/news_release_siryo.pdf

[4] RTS Corporation. 2020. "Notice of publication of 'Current status and outlook of home solar power market (2020 ed.): Toward future business development'" (in Japanese). Accessed Jan. 6. https://www.rts-pv.com/news/202003_7166/

[5] Central Research Institute of Electric Power Industry. 2020. "Study of mass deployment scenarios for wind and solar power generation to achieve net zero" (in Japanese). Accessed Jan. 6. https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/034/034_007.pdf

solar power generation deployed for use in detached residential houses in Machida is thus estimated to be 106.1 MW in 2030 and 155.4 MW in 2050. Furthermore, assuming an average output of 5 kW per solar panel, the number of PV panels in Machida City is determined to be 21,216 units in 2030 and 31,080 units in 2050.

Table A1-4 Derivation of solar power generation amount and number of PV panels

	2030	2050
Number of households living in detached residential houses (nationwide) (A)	27,500,000	25,000,000
Amount of solar power generation deployed for use in detached residential houses (nationwide) (B)	30.2 GW	45 GW
Number of households living in detached residential houses (Machida) (C)	96,596	86,330
Amount of solar power generation deployed for use in detached residential houses (Machida) (D=B/A×C)	106.1 MW	155.4 MW
Number of PV panels deployed for use in detached residential houses (Machida) (=D/5 kW)	21,216	31,080

4. Electric vehicles (EV)

Table A1-5 provides a summary of deriving the number of electric vehicles. Under the scenario where 100% of new cars in 2050 are EVs, the percentage of EVs among all vehicles is estimated to be 16% in 2030 and 79% in 2050.[6] On the other hand, the number of cars owned per household in Machida City is decreasing year by year, and is estimated to be 0.62 in 2030 and 0.57 in 2050.[7] From these premises, we determined the number of EVs in Machida to be 9,582 in 2030 and 38,744 in 2050.

Table A1-5 Derivation of number of electric vehicles

	2030	2050
Percentage of EVs (nationwide) (A)	16%	79%
Number of cars per household (Machida) (B)	0.62	0.57
Number of households living in detached residential houses (Machida) (C)	96,596	86,330
Number of EVs (Machida) (=A×B×C)	9,582	38,744

6 AIM Project Team. 2020. "Preliminary calculations for realization of decarbonized Society by 2050" (in Japanese). Accessed Jan. 6. https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/034/034_004.pdf

7 Machida City. 2019. "Machida City environmental white paper 2019 (data collection) Chapter 1 Machida City's environmental measurements and statistical data" (in Japanese). Accessed Jan. 6. https://www.city.machida.tokyo.jp/kurashi/kankyo/kankyo/keikaku/keikau/dainijikankyomaster/kankyouhakusho/kankyohakusyo2019.html

Appendix 2. Evaluation of business scale of aggregators in 2030

In Chapter 5, we evaluated the business scale of aggregators in 2030. Results of analysis of EV charging and discharging were presented as the optimized case of application (Case 2). In this section, we compare the effects of EV charging and discharging.

Table A2-1 Conditions for analysis

Case1	Night-time operation	HP hot water boiling and EV charging, mainly from 0 a.m. – 7 a.m.
Case 2-1	Optimized (EV charging)	Optimized amount of HP hot water boiling and EV charging based on demand for hot water and car use.
Case 2-2	Optimized (EV discharging)	Optimized amount of HP hot water boiling and EV discharging based on demand for hot water and car use.

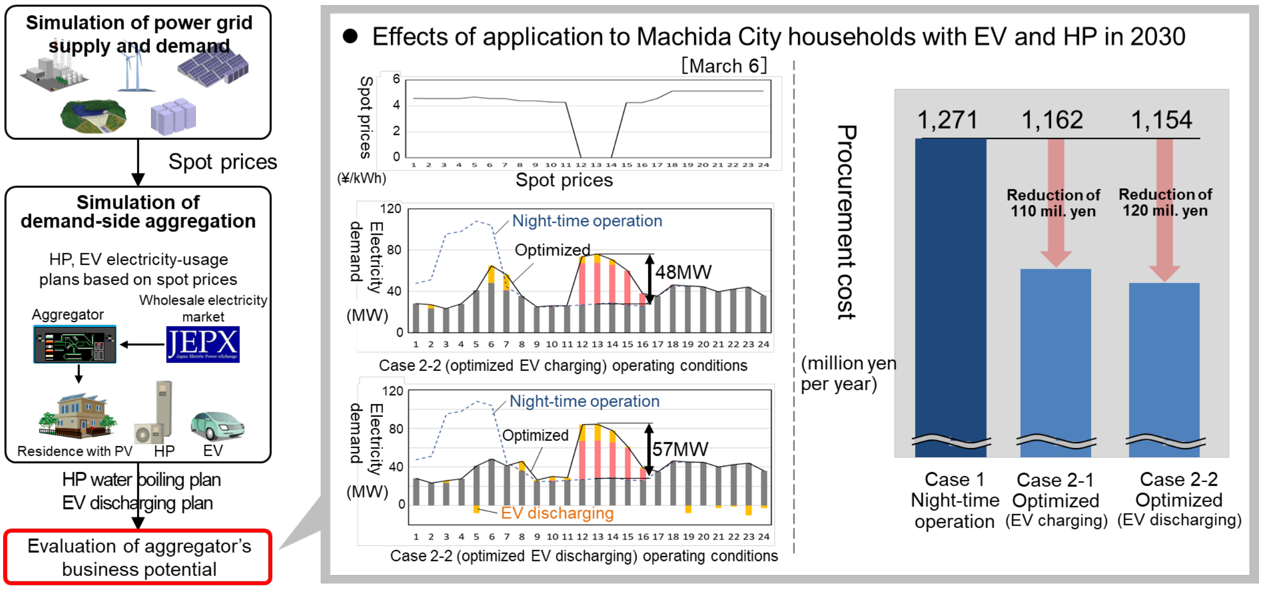

Figure A2-1 Demand-side aggregation simulation

The left side of Figure A2-1 shows the spot market prices and the overall demand in Machida City on March 6. In contrast to Case 1, in which EV charging and HP water boiling take place during the night, in Case 2-1 (optimized EV charging) and Case 2-2 (optimized EV discharging), EV charging and HP water boiling are shifted to daytime hours, when spot market prices are lower. The resulting time shift effects on demand are 192 MWh and 227 MWh, respectively. Converted to a nationwide scale, the effects are 67.2 GWh and 79.5 GWh, respectively.

The right side of the figure shows the effect of reduction in aggregator's procurement costs. In Case 1, the procurement costs are 1,271 million yen. In contrast, in Case 2-1 (optimized EV charging), the procurement costs are 1,162 million yen, a reduction of about 110 million yen. In Case 2-2 (optimized EV discharging), the procurement costs are 1,154 million yen, a reduction of about 120 million yen. Extending the reduction effect to TEPCO's service area results in reduction of about 12.8 billion yen and 14.0 billion yen, respectively.

In the optimized cases, HP water boiling and EV charging (discharging) are carried out during times when procurement costs are minimized based on spot market prices. They thus take place during daytime hours, when spot market prices are low. Meanwhile, EV discharging can reduce procurement costs by taking place during hours when spot market prices are high. However, in the simulation of power grid supply and demand in 2030, time periods with high spot market prices do not occur. As a result, the effect of EV charging becomes small. This explains why no great difference is shown in the reduction of procurement costs between Case 2-1 (optimized EV charging) and Case 2-2 (optimized EV discharging). If PV installation further increases in the future, the PV generation amount is expected to decrease, and spot market prices are expected to increase during evening hours, when the demand for electricity surges. As a result, the effect of EV discharging is expected to increase.

Appendix 3. Energy technology selection model (model for minimizing dynamic cost)

In Chapter 4, we used the technology selection model developed by the Fujii-Komiyama Laboratory at the University of Tokyo to present quantitatively the supply and demand structure of energy systems and necessary measures for the transition to CN by 2030 and 2050. The features of this model are as follows:

・Possible to calculate optimized cost in an energy supply and demand structure for energy use in entire Japan under CO_2 emission constraints

Evaluation of the entire system is carried out based on the energy system shown in Figure A3-1.

(Primary energy, conversion sector, and final consumption sector [industry, household, business, passenger, freight]).

Detailed analysis is also carried out for the energy components

(Resolution of time → unit of 1 hour. Analysis based on 8,760 hours per year → Detailed consideration of fluctuations in renewable energy output)

・ Analysis is carried out based on accumulation of individual technologies on the energy supply side (primary/secondary energy) and demand side (steel, cement, chemicals, civil, transport, etc.). This allows consistent analysis of the energy supply and demand structure in the achievement of CN and in its transition.

・The model takes into account diverse technological elements, including innovative technologies: vehicles (EV, FCV), energy storage (Li-ion batteries, NAS batteries, thermal energy storage systems), CCUS (direct capture of CO_2 in the atmosphere, methanation, FT synthesis), energy carriers (hydrogen, ammonia, methanol, synthetic gas, synthetic petroleum), power generation technologies (hydrogen power generation, ammonia power generation, offshore wind power generation, fuel cell batteries, thermal storage power generation), energy conservation technologies (heat pumps), etc.

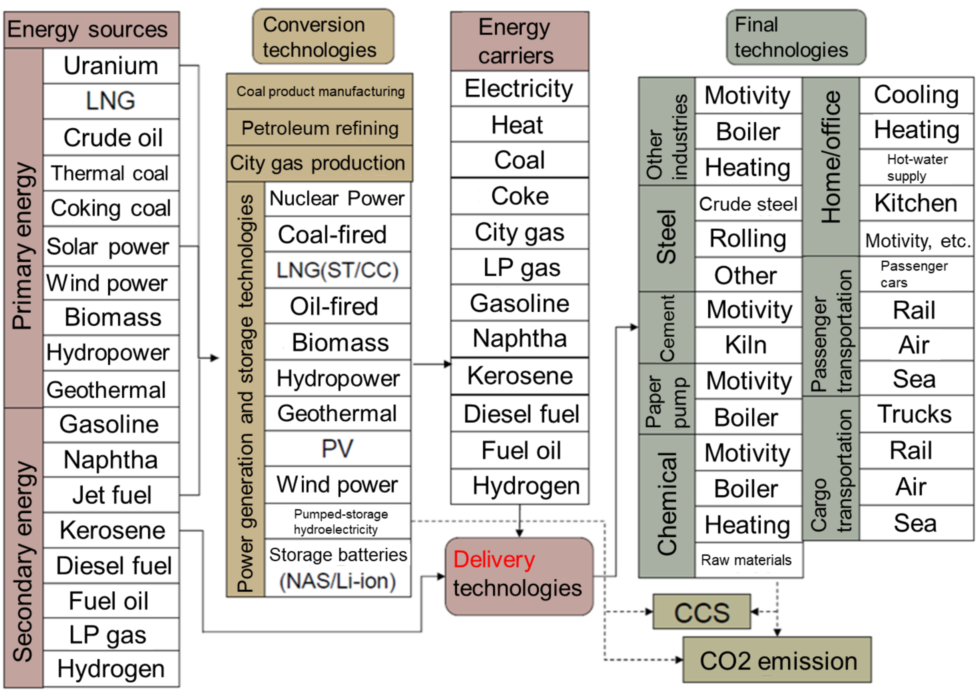

Figure A3-1 Reference energy system

The main conditions (base conditions) of the simulation carried out in Section 4.2 are shown in Figure A3-2. The conditions for each energy scenario are shown in Table A4-1.

- **Assumes all major decarbonation technologies (renewable energy, nuclear power, hydrogen, CO_2 capture) are deployed**
- **For CN in 2050 and transition scenarios, cost is optimized and simulation is performed.**

CO_2 emissions (Reduction target)
2030: -46% compared with 2013
2050: Net zero (-100%)

Conditions for deploying power generation facilities and tech (2050)

Solar power generation (PV): New installation of facilities without limit on generation capacity.
Japan Photovoltaic Energy Association's (JPEA)'s target value is 300 GW in 2050(*1)

Wind power generation: New installation of facilities with target of 40 GW onshore and 90 GW offshore
Japan Wind Energy Association (JWEA)'s target value in proposal to government (*2)

Nuclear power generation: Construction of new plants up to 50 GW
・Restart of existing power plants / extension of operational life (from 40 to 60 years)
(Excludes plants scheduled for decommission)
・Completion and start of operation of three new reactors whose construction has been suspended
・Construction of small modular reactors (SMR)

Hydrogen power generation: Import 20 million tons / import price of 20 yen/Nm^3
Target value given in ""Green Growth Strategy through Achieving Carbon Neutrality in 2050"(*3)

Conditions for deploying **CO_2 capture tech** Deployment of CO_2 capture technologies that achieve emission reduction targets
- Carbon Capture, Utilization & Storage (CCS)
- Direct Air Capture (DAC)

(*1) Japan Photovoltaic Energy Association (8 March 2021 materials) (in Japanese) https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/026_05_00.pdf
(*2) Japan Wind Power Association (24 March 2021 materials) (in Japanese) 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" (in Japanese)
https://www.meti.go.jp/policy/energy_environment/global_warming/ggs/pdf/green_honbun.pdf

Figure A3-2 Main simulation conditions (base conditions)

Table A3-1 Conditions for each energy scenario

	(1) 100% renewable energy	(2) Nuclear power fade-out	(3)Thermal power with CCS limit	(4) Use nuclear power	(5) Active use of hydrogen power generation	(6) Progress in FCV
Nuclear power – operational life	Suspended	40	60	←	←	←
Nuclear power – max capacity (GW)	0	4	24	50 (SMR)	24	←
Thermal power with CCS max limit (ton)	200 mil	←	100 mil	200 mil	←	←
Hydrogen import – max limit (ton)	20 mil	←	←	←	40 mil	No upper limit
Hydrogen unit price (yen per Nm^3)	20	←	←	←	10	20
FCV price (compared to present)	0.68	←	←	←	←	0.20
EV price (compared to present)	0.68	←	←	←	←	←
Solar power (PV) - max limit (GW)	None	←	←	←	←	←
Onshore wind power - max limit (GW)	40	←	←	←	←	←
Offshore wind power - max limit (GW)	90	←	←	←	←	←
PV construction cost (10,000 yen per kW)	15	←	←	←	←	←
Onshore wind power construction cost (10,000 yen per kW)	21	←	←	←	←	←
Offshore wind power construction cost (10,000 yen per kW)	51	←	←	←	←	←
CCS cost (yen per ton CO_2)	745	←	←	←	←	←
DAC cost (yen per ton CO_2)	10,340	←	←	←	←	←
Lithium battery storage cost (yen per Wh)	10	←	←	←	←	←

***1) Annual cost: Sum of energy costs (=fuel costs) and capital investment costs from primary energy to final energy consumption in 2050.**
***2) Equipment cost of hydrogen importers is not considered.**
CCS: Carbon dioxide Capture and Storage, DAC: Direct Air Capture, EV: Electric Vehicle, FCV: Fuel Cell Vehicle, SMR: Small Modular Reactor

Appendix 4. Overview of domain scenarios

Table A4-1 provides an overview of domain scenarios for the case of "diverse energy." Table A4-2 summarizes domain scenarios for the case of "100% renewable energy."

Table A4-1 Overview of domain scenarios for the case of "diverse energy"

	Domain	2015-20	2020-30	2030-50	Main points
By source of electricity	Coal-fired with CO_2 capture	Based on the "5th Strategic Energy Plan," inefficient coal-fired thermal generation is faded out and high-efficiency coal-fired thermal generation is promoted.	Fade-out of coal-fired power generation and conversion to high-efficiency coal-fired power production steadily advance. The government promotes in parallel domestic consensus on CO_2 storage and international collaboration for offshore storage.	Fade-out of coal-fired power generation and conversion to high-efficiency coal-fired power generation with CO_2 capture is completed. The government achieves international collaboration for offshore storage.	1. As part of Japan's 3E+S response, it is necessary to consider scenarios for maintaining coal-fired thermal power generation as a stable source of energy supply during disasters. 2. For CO_2 storage, besides creating a process for building domestic public consensus, it is also necessary to consider international collaboration as an alternative scenario.
	Gas-fired with CO_2 capture	The "Energy Conservation Act" is revised to promote fading out of inefficient thermal power generation and replacement with new gas-fired power generation.	Gas-fired power production businesses use government funds to develop and commercialize CO_2 capture systems.	Gas-fired power production continues by building CO_2 capture and transportation network using LNG infrastructure and through realization of CO_2 storage in government-led collaboration with ASEAN countries.	1. Domestic public acceptance of CCS and international collaboration/APAC collaboration for CCS are established through government efforts. 2. The government and citizens, both concerned about regional decline (depopulation, decline in economic strength, unemployment and job retention) due to fade-out of gas-fired power generation, build consensus.
	Solar	Since the Paris Agreement, large-scale projects have started based on the "fit" system. Measures against environmental impact are promoted.	The number of organizations and associations making full transition to renewable energy is growing. Automotive, IT, petrochemical, etc., businesses participate in new renewable energy-based electricity business. The government designates promotion zones and manages environmental impacts.	Spread of solar power generation proceeds through large-scale renewable energy infrastructure, smart power transmission and distribution networks, and strengthening against natural disasters. IT and energy-linked businesses become widespread. Solar energy reaches 30% of total power generation by 2050.	2020-30: It is important to establish infrastructure for systems to improve functions related to power generation/control and to reduce costs. This is done through the participation of various new actors with diverse capitalization. 2030-50: The characteristics of solar power generation are useful for anti-disaster measures. From the standpoint of disaster prevention, its installation needs to be expanded in comprehensive land use, e.g., installation of solar power generation facilities on publicly owned land.
	Wind power	Ambitious wind power projects are designed thanks to "Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities." Consensus building with local residents begins	Participation of domestic and foreign companies in wind power generation business accelerates. There is difficulty in building consensus with local industries and residents on installation of wind turbines.	Industrial competitiveness grows due to intensifying market competition. There are examples of wind power generation projects that contribute to improving regional QoL and QoW.	1. Offshore and onshore wind power generation businesses need to contribute to the revitalization of local economies and build consensus with local industries and residents. 2. The acceleration of deploying wind power encourages the entry of capable foreign companies. Policies to increase the competitiveness of domestic offshore wind power industry are necessary.
	Hydroelectric, geothermal	Although the total amount of hydroelectric and geothermal power generated is not great, they are attracting attention as local and autonomous renewable energy sources.	The Japanese government enacts policies to promote the introduction of small and medium-sized hydropower plants.	In addition to reducing CO_2 emissions, small and medium-sized hydropower plants demonstrate value in raising local residents' awareness and improving local economies. Related industries also emerge.	2020-30: Solving issues related to the introduction of small and medium-sized hydropower plants (water rights, profitability, reduction of maintenance and management load) and raising awareness in the private sector about reducing environmental burdens. 2030-50: Reduction of business risk of small and medium hydropower plants.
	Biomass mono-firing with CO_2 capture	The "5th Strategic Energy Plan" stimulates growth of biomass power generation.	The business of biomass power generation expands through community-based CO_2 capture-free power generation. This is stimulated by government policy, where the growth of production amount in 2050 is limited to 1.7x of the 2015 level.	Due to international recognition of the need for CO_2 capture also in forest biomass power generation, the government shifts policy to biomass power generation with CO_2 capture.	1. In the reference value case, the spread of biomass power generation is curbed. 2. If biomass power generation is certified as not carbon neutral in the future, CO_2 capture may become mandatory. Biomass power production businesses may not be viable due to CAPEX/OPEX.
	Nuclear power	After the Fukushima Daiichi Nuclear Power Plant accident, continued evacuation and damage to reputation become	Nuclear power is positioned as a stable, clean power source. Nuclear power generation increases due to the restart	The cost of renewable energy falls and market share increases. Furthermore, coal- and gas-fired power generation	2020-30: Even if nuclear power is considered effective as a clean energy source for achieving decarbonization, its promotion requires careful discretion based on public discussions, including with residents in reconstruction areas and in areas

		entrenched. From 2015, the plant gradually resumes operation.	of power plants that meet safety standards by 2030. However, distrust of nuclear energy agency and businesses is high, and new construction and renovations of nuclear power plants do not occur.	with CCS continues. Development of SMRs and related technologies progresses, but they do not reach operational status in Japan. The amount of energy produced by nuclear power gradually shrinks. Nuclear power plants age, and technological development and operations become problematic.	involved in spent fuel disposal. 2030-50: Establishing SMRs promoted by the government requires consensus-building with residents from standpoints that include not only decarbonization but also nuclear security in surrounding areas, spent fuel disposal, and formulation of regulations such as evacuation plans.
	Mono-firing of hydrogen and ammonia	The amount of ammonia being traded is slow. Most production is local. Its use as fuel in Japan is extremely small.	(1) Opposition to ammonia co-firing power generation erupts, and the government strengthens safety measures. (2) Japan begins government-led effort to establish international (Asian) supply chain for ammonia. Shift of ammonia production factories to overseas accelerate.	The foundation for the international distribution of ammonia is established. The conversion of ammonia-coal co-firing to mono-firing of ammonia proceeds.	2020-30: Establishment of international supply infrastructure for NH_3 and H_2 and CCS infrastructure begins. 2030-50: Development of systems for mass production of NH_3/H_2.
By industry	Steel	High-grade steel is Japan's strength. Compared with European and North American steelmakers, Japan's blast furnace cement proportion (blast furnace cement sold/all cement sold) is overwhelmingly higher.	The decarbonization movement and policy support stimulate shift to electric furnaces. Blast furnace manufacturers begin to move toward hydrogen reduction. R&D spending increases.	Electric furnace manufacturers increase domestic market share. Domestic production of steel from iron ore is maintained with specialization in high-grade steel. Factors include propping H_2 prices with hydrogen reduction and subsidies.	1. Blast furnace manufacturers and electric furnace manufacturers are almost in conflict in terms of their situations and strategies. 2. Technologies and infrastructure for steel production by hydrogen reduction are established. Various protection and preferential measures are taken for the steel manufacturing industry as national policy.
	Petrochemicals	The business challenge of the petrochemical industry in Japan is improving profit margins.	Environmental responses become the most important business issue for companies. Government-led carbon capture infrastructure development begins. M Companies also develop and accumulate carbon capture technology and know-how.	The risk of China becomes visible also in the development of carbon capture supply chain. The petrochemical industry achieves low-margin business overseas expansion due to decarbonation. Domestic business is restructured.	2020-30: Carbon storage-related domestic and international frameworks and technological development are established. 2030-50: Employment is maintained or reduced as industrial structure changes. Development of international supply chain for carbon capture and to ensure Japan's security.
	Transport	The automotive industry is the backbone of the Japanese economy in terms of export value, employment, etc.	To support the spread of EVs, battery storage manufacturing capability in Japan is strengthened. Competitiveness is maintained by responding to lifecycle assessments. Government and private sector support the shift to electrification in related industries, including parts and services.	Progress is made in the application of new green fuels to areas where electrification is difficult. Progress is also made in preparing an environment for using EV storage batteries to stabilize the power grid.	1. Strengthening domestic capability for manufacturing storage batteries and reducing emissions throughout their entire lifecycle, including production, use, and disposal, is critical to maintaining competitiveness. 2. Material and human support for actors affected by the shift from internal combustion engine-centric industrial structure becomes critical.
Behavior modification	Behavior modification	The 2015 Paris Agreement and the government's carbon neutrality goals begin to have strong appeal among young people.	Everyday citizens' concerns about climate change and renewable energy grow. The spread of EVs accelerates. Gas and coal-fired thermal power generation continues due to carbon capture technology. Nuclear power generation also continues as a stable source of electricity.	Temperatures continue to rise and carbon emission standards become stricter. Expansion of power grids and development of usable geographic areas promote the shift to renewable energy.	2020-30: The government's policy of restarting nuclear power plants and continuing gas- and coal-fired thermal power generation may create conflicts with citizens who are concerned about the climate and environmental efforts. 2030-50: As a result of stricter international climate measures, there is the possibility that government will promote renewable energy policies.

Table A4-2 Overview of domain scenarios for the case of "100% renewable energy"

	Domain	2015-20	2020-30	2030-50	Main points
By source of electricity	Coal-fired with CO_2 capture	Based on the "5th Strategic Energy Plan," inefficient coal-fired thermal generation is faded out and high-efficiency coal-fired thermal generation is promoted.	Due to international pressure, the government decides to abolish coal-fired power, which had been positioned as stable energy supply during disasters. Coal-fired businesses switch to non-coal-fired power generation or renewable energy.	Due to increased participation of major coal companies in biomass power generation, competition with local power generation businesses intensifies and industry restructuring accelerates. The government implements QoL/QoW measures to address changes in social structure.	1. Measures for regional QoW/QoL are needed as coal-fired thermal power generation is faded out. 2. Due to convergence of major thermal power businesses and regional renewable energy businesses on renewable energy power generation, separations and mergers of energy businesses in Japan as a whole proceed.
	Gas-fired with CO_2 capture	The "Energy Conservation Act" is revised to promote fading out of inefficient thermal power generation and replacement with new gas-fired power generation.	The government's decision to completely abolish gas-fired power generation causes pull-out of funds by investors, forcing companies to change business to biomass power generation, etc.	Due to business withdrawal, gas-fired businesses struggle to form consensuses with labor unions, local governments, and residents. Government responds with green job creation policy.	1. Due to national policy, gas-fired power generation businesses are forced to transform. These changes include ceasing domestic operations and converting to biomass power generation. 2. The government also needs to promote green job creation and other job creation measures.
	Solar	Since the Paris Agreement, large-scale projects have started based on the "fit" system. Measures against environmental impact are promoted.	The number of organizations and associations making full transition to renewable energy is growing. Automotive, IT, petrochemical, etc., businesses participate in new renewable energy-based electricity business. The government designates promotion zones and manages environmental impacts.	Spread of solar power generation proceeds through large-scale renewable energy infrastructure, smart power transmission and distribution networks, and strengthening against natural disasters. IT and energy-linked businesses become widespread. Solar energy reaches 30% of total power generation by 2050.	2020-30: Participation of international actors, with background in EVs and IT, can accelerate improvements in functions and cost reductions related to energy generation and control. 2030-50: The characteristics of solar power generation are useful for countermeasures against natural disasters. Installation on public lands may expand from the perspective of disaster prevention.
	Wind power	Ambitious wind power projects are designed thanks to "Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities." Consensus building with local residents begins.	Wind power generation market reaches height due to abolition of coal-fired power generation plants. The government struggles to reach consensus with local industries and residents.	Wind power businesses expand overseas. Their examples as good regional reconstruction projects increase. On the other hand, the government struggles in developing measures to avoid large-scale power outages caused by natural disasters.	1. The government must consider and implement measures for the daily work and life (QoW/QoL) caused by future energy scenarios. 2. Acceleration of the introduction of wind power spurs market entry by capable foreign companies. Policy to increase competitiveness in domestic wind power-related industries is required.
	Hydroelectric, geothermal	Although the total amount of hydroelectric and geothermal power generated is not great, they are attracting attention as local and autonomous renewable energy sources.	The Japanese government enacts policies to promote the introduction of small and medium-sized hydropower plants.	In addition to reducing CO_2 emissions, small and medium-sized hydropower plants demonstrate value in raising local residents' awareness and improving local economies. However, there is an urgent need to improve the business environment to overcome high carbon taxes.	2020-30: Solving issues related to the introduction of small and medium-sized hydropower plants (water rights, profitability, reduction of maintenance and management load) and raising awareness in the private sector about reducing environmental burdens 2030-50: Pros and cons in promoting decarbonization by introducing a high carbon tax. Reduction of business risk of small and medium hydropower plants.
	Biomass mono-firing with CO_2 capture	The "5th Strategic Energy Plan" stimulates growth of biomass power generation.	Coal-fired power generation market becomes active as target for 2050 becomes 3x or more than 2015 level due to abolition of coal-fired power generation. Finance institutions promote investment, and government also supports new job creation.	New actors such as domestic producers and international procurers and establishment of supply chain becomes in achieving stable and mass procurement of biomass fuels. Collaboration transcending the boundaries of related ministries and agencies is important.	1. Fossil fuel power generation businesses are forced to transform. These changes include ceasing domestic operations and converting to biomass power generation. 2. The transition to renewable energy and biomass power generation may cause issues such as environmental damage and lack of stability in energy procurement.
	Nuclear power	After the Fukushima Daiichi Nuclear Power Plant accident, continued evacuation and damage to reputation become entrenched. From 2015, the plant gradually resumes operation.	Nuclear power is positioned as a stable, clean power source. Nuclear power generation increases due to the restart of power plants that meet safety standards by 2030. However, distrust	Renewable energy overcomes issues as establishment of transmission and distribution infrastructure proceeds. Meanwhile, nuclear energy again is reduced to zero due to	2020-30: Even if nuclear power is considered effective as a clean energy source for achieving decarbonization, its promotion requires careful discretion based on public discussions, including with residents in reconstruction areas and in areas involved in spent fuel disposal. 2030-50: During this period, Japan's existing nuclear power plants age, and accidents and

			of nuclear energy agency and businesses is high, and new construction and renovations of nuclear power plants do not occur.	issues related to nuclear security, large earthquakes, and spent fuel disposal, as well as changes in nuclear energy policies overseas.	crises involving nuclear power plants not only in Japan but also abroad can significantly impact public opinion in Japan.
	Mono-firing of hydrogen and ammonia	The amount of ammonia being traded is slow. Most production is local. Its use as fuel in Japan is extremely small.	(1) Opposition to ammonia co-firing power generation erupts, and the government strengthens safety measures. (2) Japan begins government-led effort to establish international (Asian) supply chain for ammonia. Shift of ammonia production factories to overseas accelerate.	Japan-led Asian supply chain for ammonia faces setback. Closures Coal-fired plans follow in succession.	2020-30: Establishment of international supply infrastructure for NH_3 and H_2 and CCS infrastructure begins. 2030-50: System for mass production of NH_3/H_2
By industry	Steel	High-grade steel is Japan's strength. Compared with European and North American steelmakers, Japan's blast furnace cement proportion (blast furnace cement sold/all cement sold) is overwhelmingly higher.	Shift to electric furnaces continues due to prior decarbonation movement, policy support, and the balance between supply and demand. Blast furnace manufacturers begin to move toward hydrogen reduction. R&D spending increases.	Electric furnace manufacturers become destination for surplus electricity and grow in domestic share. Steel production using iron ore moves overseas.	1. Blast furnace manufacturers and electric furnace manufacturers are almost in conflict in terms of their situations and strategies. 2. There is conflict between CO_2 reduction limited to Japan and whether discussion of total global CO_2 reduction is possible.
	Petrochemicals	The business challenge of the petrochemical industry in Japan is improving profit margins.	Environmental responses become the most important business issue for companies. Government-led carbon capture infrastructure development begins. M companies also develop and accumulate carbon capture technology and know-how.	Carbon capture comes to deadlock. Oil prices skyrocket, and M companies that have endurance in the petrochemicals industry consolidate. Revision of employment measures and education system is needed.	2020-30: Carbon storage-related domestic and international frameworks and technological development are established. 2030-50: Employment is maintained or reduced as industrial structure changes. Development of international supply chain for carbon capture and ensure Japan's security.
	Transport	The automotive industry is the backbone of the Japanese economy in terms of export value, employment, etc.	Variable renewable energy such as solar and wind power are deployed at a rapid pace. The use of storage batteries in cars to stabilize the energy grid becomes more important. Aggregators of distributed power sources and recharging service providers play important roles.	As a result of increase in costs for grid stabilization and electricity prices, individuals shift to walking, bicycling, and other modes of transportation. Combined with a modal shift in long-distance transportation, etc., this leads to the growth of compact cities.	1. Technological development and environmental improvement to utilize storage batteries of EVs, including used batteries, to stabilize the distribution grid becomes important. 2. Against the background of increase in electric prices due to expansion of deployment of variable renewable energy, transformation of individuals' mobility and logistics systems occur.
Behavior modification	Behavior modification	The 2015 Paris Agreement and the government's carbon neutrality goals begin to have strong appeal among young people.	Everyday citizens' concerns about climate change and renewable energy grow. The shift to EVs and the participation of IT companies accelerate people's choosing renewable energy. Distrust of nuclear energy policies grow, and policy changes encourage the development of renewable energy infrastructure.	Large earthquake shuts down all nuclear power generation. Digital power transmission and distribution networks are established through reconstruction projects in affected areas.	2020-30: Against the background of citizens' concerns about the climate and environment, linkages with EVs and the participation of telecommunication companies have the possibility of giving rise to a completely new situation for energy. 2030-50: The situation of climate measures and a major earthquake disaster in Japan can further strengthen the push for renewable energy.