東京大学
THE UNIVERSITY OF TOKYO

HITACHI
Inspire the Next

Proposal

Toward Realizing Energy Systems to Support Society5.0

(Ver.5)

March 24, 2023 Hitachi-UTokyo Laboratory

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Executive Summary

The Energy Project of Hitachi-UTokyo Laboratory has been proposing visions and scenarios for energy systems since 2016. Version 4 of "Toward Realizing Energy Systems to Support Society 5.0" published in 2022 summarized the results of discussing the issues surrounding carbon neutrality by 2050 and social sustainability from 2050 onward and the initiatives for solving those issues, all against the background of Environmental, Social, and Governance (ESG) investing, the beginning of discussions on Japan's Sixth Strategic Energy Plan and Clean Energy Strategy, and social movements such as COP26.

As Version 5 of "Toward Realizing Energy Systems to Support Society 5.0," this document summarizes the results of discussions on three points of change relative to Version 4, namely, "geopolitical changes," "sustaining the global trend toward decarbonization," and "national and regional circumstances related to energy." Version 5 is organized around the following four viewpoints: (1) energy transition scenarios based on overall social trends, (2) energy systems that consider measures to be taken toward carbon neutrality along with quantitative evaluations by simultaneously backcasting from 2050 and forecasting to 2030, (3) issues surrounding power systems as seen from social changes since 2022 and the direction of energy system reforms, and (4) the challenge of using new simulation technologies to find pathways toward carbon neutrality while maintaining Quality of Life (QoL). Specifically, after identifying changes in social trends overall and gaining insights from the energy transition scenarios in (1), this document will present issues and directions of reform with respect to energy systems (2) and power systems (3) and describe the challenges in finding pathways to achieving carbon neutrality while maintaining QoL (4) taking into account the studies in (1) to (3) and individual and regional effects in particular.

In this document, a total of 18 proposals for the short term up to 2030 and the medium-to-long term from 2030 to 2050 are summarized in Chapter 7. This section summarizes the results of studies leading up to those proposals.

Geopolitical crises and transition pathways: Changes in the landscape and regional viewpoints (Chapter 2)

We have so far drawn up transition scenarios assuming the two power supply configurations of "diverse energy" and "100% renewable energy" for achieving carbon neutrality by 2050 as presented in 2021 by the Research Institute of Innovative Technology for the Earth (RITE). These transition scenarios were established for 12 domains in the categories of power, industry, and behavior modification for two stages running from 2020 to 2030 and 2030 to 2050. Here, in Version 5, we endeavored to understand new geopolitical conditions in relation to energy and climate change and reflected those conditions in the scenarios. We also focused on Japan's regional areas that are strongly associated with important initiatives such as the introduction of renewable energy on a large scale and industrial transitions, and we attempted to revise our scenarios and make them more realistic using case studies. Furthermore, for fields that were not sufficiently investigated in last fiscal year's scenarios such as agriculture, the chemical industry, and sustainable aviation fuel (SAF), we added a more detailed analysis. We derived the following points from the results of these studies.

1. Can a governance mechanism be created to accelerate systemic changes in response to the current geopolitical crisis? As previously discussed, the European Union (EU) and the United States are accelerating countermeasures to climate change in the medium-to-long term based on a policy of ending dependence on Russian fossil fuels. At the same time, it has been pointed out that Japan is somewhat behind in accelerating such countermeasures in the national consciousness and in structural transitions. Amid such sudden and dramatic geopolitical changes, governance that can accelerate transitions integrated with all sorts of sectors is becoming increasingly important.

2. Amid climate change and soaring fuel costs, can Japan take the lead in establishing international cooperation toward climate and energy transitions in the Asia-Pacific region? Soaring energy and food prices are also generating a risk of reverting to fossil fuels in opposition to decarbonization. For Japan, securing a supply chain for hydrogen, ammonia, rare metals, and other resources and for carbon storage is essential especially amid geopolitical changes. It is crucial that the Japanese government strengthen its efforts in leading multi-layered international cooperation in relation to climate and energy with Australia, which is strengthening its countermeasures to climate change, and with various Asian countries having high fossil-fuel dependence.

3. Can pathways be found to transitions that empower local actors and that differ for each region based on diverse natural environments? In Japan, a country with abundant natural environments, social issues, lifestyles, and energy potential differ from region to region, which makes for multidimensional pathways to transitions. This state of affairs makes it necessary to support capacity building in regional actors (active entities) such as citizens and local companies and to aim for prosperity centered about a green transition in energy and food. In particular, adjustability on the demand side is important in terms of the efficient use and stable supply of regional energy, and to this end, digital innovation will play a leading role.

4. Based on strategic industrial policies, can the government build a consensus with local citizens and companies while supporting the coordination abilities of local governments? In Japan's diverse regions, the importance of the coordination abilities of local governments in the face of unprecedented challenges is increasing, but at the same time, they are deficient in human capital and know-how and in the ability to create cross-sectional mechanisms. For this reason, the government must overcome a vertical administrative structure and provide support for maximizing regional power based on strategic industrial policies. In addition, the construction of a consensus-building platform by the government and local government based on scientific data and open dialogue together with local citizens and companies should become an important foundation for carrying through long-term transitions across a wide range of fields.

Furthermore, given sudden and dramatic changes in the geopolitical situation, it will be necessary to create a form of governance that can accelerate transitions in climate and energy supported by regional independence while searching out new channels of cooperation within the Asia-Pacific region.

Energy system measures based on the gap between backcasting and forecasting (Chapter 3)

We revised energy scenarios considering soaring fuel costs, simulated progress in technical innovations and energy scenarios differing in cost conditions (100% renewable energy, thermal-power Carbon Capture and Storage (CCS) limitations, use of nuclear power, hydrogen procurement), and studied in detail the use of nuclear power based on a balance among increase in total costs, energy self-sufficiency rate, and stockpiling rate. To achieve a carbon neutral scenario, the following measures should be taken: (1) accelerate the deployment of renewable energy and achieve early implementation of decarbonized power supplies such as nuclear power, (2) avoid the discarding of photovoltaic (PV) equipment in a short period of time after installation and solve issues related to the installation environment, (3) diversify the use of hydrogen and ammonia beyond power generation to synthetic fuels, etc., (4) promote heat utilization through cogeneration, etc., and (5) secure energy resilience and security. Additionally, looking at the period 2040 – 2050, there will be a need for developing, investing, and fostering innovation in (1) the practical use and dissemination of CO_2 capture through Direct Air Capture (DAC) and (2) the manufacturing of fuel from recovered CO_2 and its use in the transport and industrial sectors.

As for issues and countermeasures in the core energy system in the face of a rapid expansion of renewable energy, the following measures should be taken: (1) secure an appropriate number of thermal-power and nuclear-power turbine control platforms to deal with drops in frequency caused by drops in inertia and introduce inertia control for distributed resources, (2) use local resources and adopt measures for avoiding system congestion to deal with frequency fluctuations caused by insufficient coordination abilities, (3) enhance local-storage and electric-vehicle (EV) control in addition to bolstering power transmission to deal with drops in system stability, and (4) enhance inverter control and use integrated control to deal with instability associated with an increase in inverter power supplies.

On studying the bulk system toward carbon neutrality, it will be necessary to share the data and simulation models of many stakeholders including power generation, transmission, and distribution operators and consumers and to develop and use simulation and evaluation technologies. Specifically, the following measures should be taken toward carbon neutrality: (1) visualize multifaceted and quantitative issues through numeric simulation models, and (2) evaluate implemented measures as needed, invest in facilities and innovative technologies, and upgrade systems in response to changing circumstances.

Role of local communities toward an era of renewable energy as the main power source (Chapter 4)

With regard to the potential of demand coordination created through the cooperative operation of equipment having a storage function such as heat pump (HP) water heaters and EVs studied in Version 4, we performed trial calculations targeting HP water heaters and EVs in the household sector (detached residential houses, condominium complexes) plus HP water heaters in the service sector. The results of these calculations revealed that the potential of demand coordination created from local communities in 2030 would be 33.2 TWh/year on a nationwide scale, which would require the widespread adoption of equipment having the necessary functions and their early implementation in society.

While the promotion of electrification is basic to achieving carbon neutrality, it cannot be denied that there are regions and industries for which electrification is difficult. Instead of criticizing or excluding such regions and industries, a means of promoting carbon neutrality on a nationwide basis combined with carbon emissions trading, negative emissions, etc. should be explored. To promote a smooth transition to decarbonization in local communities, support of stepwise changes, inclusive participation, and clarification of roles are all important. In particular, local governments will have a major role to play, and they should conceive and form a community-based value-circulation system as early as possible.

Direction of energy system reform for carbon neutrality (Chapter 5)

Energy system reform in Japan consisting of three stages—expansion of wide-area system operation, full liberalization of the retail market, and neutralization of the power transmission and distribution sector through legal unbundling—came to an end in April 2020. Based on the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) and Japan Electric Power Exchange (JEPX), the ratio of renewable energy has increased greatly by aiming for a nationwide merit-order scheme and forming other systems to expand the adoption of renewable energy including a Feed-in Tariff (FIT) system. On the other hand, the recoverability of expenses (especially fixed expenses) for power generation operators has dropped due to inducements to trade at short-term marginal cost, and the profitability of thermal power generation, in particular, has also dropped due to a decrease in kWh accompanying the increase in the ratio of renewable energy, all leading to an increase in the suspension or scrapping of certain facilities.

The soaring prices of imported resources, which became especially noticeable from autumn 2021, has had serious effects on power procurement bringing the following points to the forefront. (1) Securing kW: Amid volatility in the short-term market, power supply capacity must be secured for the sake of a stable supply of power regardless of whether the market price is low. (2) Upgrading of the power transmission/distribution network: Power transmission/distribution facilities must be upgraded to enable the introduction of renewable energy on a large scale. (3) Securing kWh: Fuel procurement risks must be dealt with.

Based on the above studies, we identified three new issues as seen from the present system.

1. Excessive dependence on short-term market prices: System design has come to be centered on spot prices in the wholesale power trading market, and as a result, providing for a stable supply of power in the medium-to-long term and working toward decarbonization has been insufficient.
2. Lack of inter-market coordination: Markets such as the capacity market and supply-and-demand coordination market have come to be formed from the viewpoint of economic efficiency centered on spot-price signals, but the inconsistency of this scheme with medium-to-long-term policy objectives such as a stable power supply and decarbonization has become apparent.
3. Large-scale introduction of variable renewable energy: The question of how to aim for further introduction of renewable energy must be taken up, which will require more measures such as upgrading of the power transmission/distribution network, enhancing operation systems, and securing coordination abilities.

Based on the above, we propose the following three points as the direction to be taken toward the second reform of the power system.

1. Formulate a medium-to-long-term policy axis: (1) Distinguish between economic efficiency that aims for short-term merit order and medium-to-long-term policy objectives such as a stable power supply and decarbonization, and (2) conduct further studies on market design that up to now has been pursuing efficiency.
2. Reconstruct the role of the market: (1) Correct market distortions, (2) make the power-supply state of operation

transparent and public, and (3) provide comprehensive market monitoring.

3. Reconstruct the consumer sovereignty system: (1) Merge the mechanism based on consumer judgment with the (2) emissions trading system.

Finding pathways toward energy transitions while maintaining QoL (Chapter 6)

With the aim of reflecting policy in the pathways to many social changes and in social behavior modification that will accompany energy transitions, we studied the coupling of two simulation models in which we simulated social changes related to energy transitions through social models to grasp “likely social visions.” We then reflected the “energy supply and demand trends” shown by those social visions in energy supply and demand simulations. The following three energy-field policies derived from this coupled simulation take on importance: (1) expanded introduction of EVs from the first half of the 2030s, (2) accelerated introduction of solar power generation (PV) and wind power generation from the 2030s, and (3) investment by large companies in the environmental field from the 2020s and securing of earnings by small- and medium-sized companies through accelerated measures and environmental contributions from the first half of the 2030s. In addition, the following administrative measures including land development and urban development will be important in 2034 and 2035: (1) drastic measures for improving underpopulated areas, (2) various measures for securing employment, (3) measures for making everyday life and corporate activities more efficient by using features in the information field such as teleworking, and (4) measures for introducing heat pumps and equipment for configuring distributed resources as in the case of factories and measures for inducing the appropriate operation and locating of facilities.

Eighteen Proposals “Toward Realizing Energy Systems to Support Society 5.0” (Chapter 7)

Short Term

Geopolitical crises and transition pathways: Changes in the landscape and regional viewpoints (Chapter 2)

1. Construct governance to accelerate integrated transitions amid sudden and dramatic geopolitical changes
2. Secure a global supply chain for clean transitions
3. Promote international cooperation in climate and energy issues in the Asia-Pacific region
4. Construct a consensus-building platform based on dialogue with science

Energy system measures based on the gap between backcasting and forecasting (Chapter 3)

5. Reevaluate energy scenarios based on the international situation
6. Establish measures based on the gap between energy-system backcasting and forecasting
7. Develop analytical and evaluation techniques enabled by data and simulations

Role of local communities toward an era of renewable energy as the main power source (Chapter 4)

8. Promote local contributions toward carbon neutrality and energy supply and demand based on S+3E
9. Draw up measures to promote smooth transitions in local communities

Direction of energy system reform for carbon neutrality (Chapter 5)

10. Establish a medium-to-long-term axis beyond short-term market principles
11. Reconstruct the role of the market
12. Reconstruct consumer-led system

Finding pathways toward energy transitions while maintaining QoL (Chapter 6)

13. Recognize the necessity of objectively analyzing the social changes accompanying carbon neutrality
14. Formulate energy-field measures coupled with land and urban development
15. Formulate administrative measures including those for land and urban development in conjunction with energy transitions

Medium-to-long Term

Geopolitical crises and transition pathways: Changes in the landscape and regional viewpoints (Chapter 2)

16. Find transition pathways for each region
17. Maximize strategic industrial policies and regional abilities

Technical measures for energy systems (Chapters 3 and 4)

18. Develop techniques for formulating energy-scenario measures toward carbon neutrality

Chapter 1 Introduction

Import fuel prices rose sharply due to the effects of extreme weather events in Europe from the autumn of 2021 and the Russian invasion of Ukraine in February 2022. This, in turn, let to a jump in energy costs and soaring prices for a variety of related commodities. Such changes were not limited to Japan. Rather, they occurred on a worldwide basis accompanied by problems unique to each country resulting in a complicated situation. Nevertheless, the driving force toward carbon neutrality held fast centered about Europe despite these energy-related changes. This rising to the surface of “geopolitical impact,” “adherence to a worldwide trend toward carbon neutrality,” and “circumstances unique to each country and region in relation to carbon neutrality” can be viewed as the “great changes of 2022.”

On the basis of these changes, Hitachi-UTokyo Laboratory decided to study energy transition scenarios and issues and countermeasures surrounding energy systems, and based on those studies, to study systems and policies in relation to power systems. In Version 5, much discussion is given to energy transition scenarios focusing, in particular, on new geopolitical conditions related to energy and climate change and on Japan’s regional areas that are strongly associated with energy. Additionally, with regard to simulations based on a technology selection model that we have studied continuously up to Version 4, a large gap is found to exist between the form of energy in 2030 derived by energy backcasting from 2050 when carbon neutrality is expected to arrive and the form of energy forecasted from the present. In Version 5, we perform a wide-ranging study on new issues related to this gap and measures for eliminating it. As a short-term measure for overcoming this gap in energy scenarios, we took up the potential for demand coordination created by the cooperative operation of equipment having a storage function such as HP water heaters and EVs. We attempted to quantify this potential for demand coordination in detail and studied whether this gap could be overcome if consumers made use of their own energy resources to greatly expand the introduction of renewable energy. Due to the sharp rise in fuel prices, issues surrounding power systems have come into focus, so we also took up the direction of energy system reform.

In this proposal “Toward Realizing Energy Systems to Support Society 5.0,” we studied technical issues and measures surrounding energy systems and the direction of energy system reform based on the formulation of transition scenarios as described above, and we conducted simulations to propose pathways to achieving carbon neutrality while maintaining QoL. Based on the results of these studies, we made 18 specific proposals as summarized in Chapter 7.

Chapter 2 Geopolitical crises and transition pathways: Changes in the landscape and regional viewpoints

2.1 Transition scenarios created by Hitachi-UTokyo Laboratory

2.1.1 Transition scenarios drawing pathways to carbon neutrality

Achieving "carbon neutrality" that essentially makes carbon emissions zero through human socioeconomic activities will be difficult without extremely wide-ranging and long-term reforms involving the government, industry, and civic life[1]. Making a transition from the conventional energy system centered about fossil fuels to a system centered about renewable energy is, of course, urgent, but it will require transitions in supply-chain and manufacturing methods in a variety of industries as well as changes in civic life including means of habitation, mobility, consumption, eating, and labor. At Hitachi-UTokyo Laboratory, our aim is to help meet this challenge by creating "transition scenarios" that can draw up pathways to achieving carbon neutrality in Japan. A transition scenario clarifies hidden issues and key junctions and presents the way that fair and sustainable changes toward carbon neutrality should take place by studying the process of long-term change involving a variety of actors based on multiple pathways[2].

Hitachi-UTokyo Laboratory creates transition scenarios by conducting analyses based on an original technique for drawing up transitions involving a wide range of areas[3]. Such scenarios describe pathways to carbon neutrality in Japan by 2050 by conducting interviews with experts in major fields[4], holding workshops sponsored by Hitachi-UTokyo Laboratory, etc., and using the results of those interviews and gatherings to analyze the main actors (agents) and issues in those fields (Table 2.1).

Here, in particular, we make qualitative descriptions for 12 domains involving power, industry, and behavior modification (Table 2.2) and for two stages running from 2020 to 2030 and 2030 to 2050. Additionally, while referring to study materials related to power configurations for achieving carbon neutrality by 2050 announced in 2021 by the Research Institute of Innovative Technology for the Earth (RITE)[5], we have been drawing up forms of achieving carbon neutrality for the two power configurations of "diverse energy" and "100% renewable energy" via pathways that differ for each of these cases.

1 At present, global-environment scientists are pointing out that the expansion of human socioeconomic activities are greatly changing the conditions that have supported human development for more than 10,000 years up to now and that these activities are actually threatening the survival of mankind. In addition, experts who are researching the limits of the global environment in maintaining the conditions for human survival called "planetary boundaries" point out that the breaking point at which humans can safely and fairly live has already been exceeded. Particularly, with regard to climate change, they point out that a situation in which conditions for human survival will significantly change is already approaching. In Japan, efforts are accelerating toward decarbonization to avoid such a climate crisis at the government, business, and civic level. Johan Rockstrom, et al. 2015. Big World, Small Planet: Abundance within Planetary Boundaries. New Haven: Yale University Press.

2 Transition scenarios at Hitachi-UTokyo Laboratory are influenced by the idea of changes in socio-technical systems in the multi-level-perspective theory of Frank W. Geels. Frank W. Geels. 2002. "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study," Research Policy 31, 1257–1274; and Frank W. Geels, et al. 2020. "Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050)." Technological Forecasting and Social Change, 151, 119258.

3 Saartje Sondeijker has established an original methodological basis for transition scenarios. Saartje Sondeijker. 2009. *Imagining Sustainability: Methodological building blocks for transition scenarios*. Erasmus University Rotterdam.
http://hdl.handle.net/1765/17462. However, Hitachi-UTokyo Laboratory creates transition scenarios by an original process that, while referring to Sondeijker's steps in scenario constructions, obtains strategic suggestions by analyzing actors spanning multiple domains.

4 These expert interviews were held 38 times over the period from November 2020 to December 2022.

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

Table 2.1 Fields related to experts participating in interviews

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

Table 2.2 Domain configuration of transition scenarios

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

2.1.2 Revelations from past activities

At Hitachi-UTokyo Laboratory, we first announced our scenarios in 2022 and reported on revelations obtained from those scenarios at open forums that we held, in proposals, etc.

These scenarios clarified the features in each of the two stages leading toward carbon neutrality by 2050. They also showed how these features diverged for the two cases of “diverse energy” and “100% renewable energy” in each of those two stages (Table 2.3).

Table 2.3 Two transition stages shown in scenarios announced in FY2021

Stage	2020-30: 1st Stage	2030-50: 2nd Stage
Features	Preparatory conditions for transitions take shape from the viewpoints of power, industry, and behavior modification.	Accelerated progress in making the transition broadens the differences between scenarios.
Divergence	**Diverse energy:** Amid international movements toward decarbonization, development of ammonia co-firing and CO_2-capture technologies and inter-governmental negotiations advance. **100% renewable energy:** Participation by new actors toward renewable energy expands rapidly. Heightened concern about the climate and environment by the general public leads to policy shifts in the government.	**Diverse energy:** Fossil-fuel power generation with CCS continues. An international distribution infrastructure for carbon and ammonia takes shape. **100% renewable energy:** Changes in urban life result in a great shift toward the creation of green jobs related to the climate and environment.

In addition, the points listed in Table 2.4 were presented based on the scenarios studied in FY2021.

Table 2.4 Main points in transition scenarios announced in FY2021

#	Point	Details
1	**Multilayered international cooperation on energy resources, innovation, power grids, etc.**	Achieving carbon neutrality in Japan will require the construction of a multilayered international cooperation infrastructure for procuring new resources involving hydrogen, ammonia, etc., recruiting experts in renewable energy, constructing international power grids, etc.
2	**Consensus building on transitional measures for future decarbonization**	Achieving CO_2 capture and storage will, of course, require public acceptance within Japan, but a consensus must also be reached with countries and regions targeted for storage.
3	**Design of fair transitions and creation of green jobs**	Prosperous regional scenarios through creation of green jobs must be designed to deal with changes in coal-fired power generation, supply chains for internal combustion vehicles, local gasoline stations, etc.
4	**Investments in innovative decarbonization techniques in the manufacturing industry**	Long-term investments in innovative decarbonization-type manufacturing methods will be needed based on a wide range of options in steel and other industries.
5	**Changes in people's framework of values for one's city, work, and everyday life.**	Changes in the energy system will arise in the context of social changes marked by transitions in people's framework of values and everyday lifestyles. In particular, options related to mobility, consumption, and energy in one's city are likely to become a major concern among the public.
6	**New ways of decision-making involving the environment and energy**	Integration of the environment and energy in government policies and positioning them in a wide context: promote participation in decision-making by new actors such as local governments, citizens, NGOs, and financial institutions.

2.2 This fiscal year's scenario study items

Based on the above type of analysis, we performed an analysis for FY2022 while adding new viewpoints to the studies that we conducted last fiscal year.

To be specific, we attempted to understand the new geopolitical situation in relation to energy and climate change and reflect that situation in our scenarios. Additionally, by focusing on Japan's regional areas that are strongly associated with important areas such as the introduction of renewable energy on a large scale and industrial transitions, we attempted to revise our scenarios and make them more realistic based on case studies. Furthermore, for fields that were not sufficiently investigated in last fiscal year's scenarios such as agriculture, the chemical industry, and sustainable aviation fuel (SAF), we added a more detailed analysis.

Portions of these analyses were presented at a closed workshop (September 2022) and an open forum (January 2023) held by Hitachi-UTokyo Laboratory.

In this chapter, we discuss our suggestions for transition scenarios toward carbon neutrality by 2050 while focusing on changes in geopolitical conditions that began to take place in February 2022 and on original initiatives in Japan's regional areas.

2.3 International geopolitical landscape of energy

The transition to carbon neutrality in Japan is not something that can be accomplished only by the efforts of domestic actors. Each of these actors—government, industry, and citizens—is positioned in a political and economic landscape that extends beyond national borders. Here, decision-making and behavior are greatly limited by complex fluctuations in that landscape.

Countermeasures to global climate change, which up to the end of 2021 had been seen as gaining momentum in a gradual manner, has been facing sudden and complex changes since Russia's invasion of Ukraine in February 2022 in a manner that could not have been foreseen.

Here, in an effort to understand the impact of these changes on Japan's transition to carbon neutrality, we take up some of those changes.

2.3.1 Surge in fossil fuel prices and the global response

Russia's invasion of Ukraine launched in February 2022 brought great changes to the international landscape in terms of energy and climate change. Countermeasures to climate change that had been accelerating up to the previous year came to take on significant risk amid large fluctuations in energy supplies and price. Nevertheless, in Europe and the United States, large-scale policies came to be released for accelerating energy transitions.

Since the invasion of Ukraine, the prices of crude oil, gas, coal and other forms of energy as well as food including wheat and fertilizer exported from Russia and Ukraine have skyrocketed bringing about a global energy and food crisis.

Against this background, Europe has been moving rapidly to reduce dependence on Russia in the energy field. At a meeting of the European Council held in March 2022 immediately after the invasion, the "Versailles Declaration" was presented announcing plans to reduce the dependence of the EU and its member states on fossil fuels, diversify energy supplies and routes, and further develop a hydrogen market[6].

Meanwhile, in the United States, the Inflation Reduction Act (IRA) was passed in August 2022[7]. Through reforms targeting the corporate minimum tax, for example, this bill aims to raise $737 billion in tax revenue, $369 billion of which is to be allocated to energy security and climate change measures. As such, it represents the largest policy package in American history addressing climate change and a transition to clean energy. By establishing a clean energy economy in the United States through a variety of economic incentives, the bill seeks to create high-value jobs in a wide range of fields and to support a transition even in regions in which industries involving oil, coal, and gas have come to develop. Through this bill, the United States aims to reduce carbon emissions by 40% relative to 2005 levels by 2030 and to significantly accelerate past climate change measures[8].

In Japan, there have been discussions on the energy crisis since the Ukraine invasion as an obstacle to making a transition to carbon neutrality, but in Europe and the United States, the policy has been to use the move toward reduced dependence on Russia as an opportunity to accelerate a transition in the economic structure involving energy.

6 European Council. 2022. "The Versailles declaration, 10 and 11 March 2022." Accessed on February 22, 2023. https://www.consilium.europa.eu/en/press/press-releases/2022/03/11/the-versailles-declaration-10-11-03-2022/.

7 The White House. 2022. *Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action*. Accessed on February 22, 2022. https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.

8 Evaluations by American think tanks (Wilson Center, Roosevelt Institute, and Hoover Institution) are as follows. Wilson Center. 2022. "Wilson Center Expert Analysis of the Inflation Reduction Act." Accessed on February 22, 2023. https://www.wilsoncenter.org/article/wilson-center-expert-analysis-inflation-reduction-act; Roosevelt Institute. 2022. "Understanding the Inflation Reduction Act: A Series." Accessed on February 22, 2023. https://rooseveltinstitute.org/2022/08/05/understanding-the-inflation-reduction-act-a-series/; David R. Henderson. "The 'Shrink The Economy' Act." Accessed on February 22, 2023. https://www.hoover.org/research/shrink-economy-act.

2.3.2 Acceleration of decarbonization and new movements in Europe

The Russian invasion of Ukraine brought about an especially severe energy crisis in Europe. This is because major countries in the EU had been receiving supplies of natural gas from Russia via a pipeline for some time, and as a result, the sudden suspension of that supply network generated a serious risk for the socioeconomic structure of EU member states. In the EU, however, while movements toward a temporary return to fossil fuels did appear, reduced dependence on energy from Russia was used an opportunity to accelerate the move toward an energy transition as a countermeasure to climate change over the long term.

“RePowerEU” presented by the European Commission in May 2022 was a large-scale policy program to achieve independence from Russian fossil fuels by 2030 and accelerate the transition to renewable energy[9]. This proposal moved up the targets presented in the previous “Fit for 55” package and presented additional measures and investments to be achieved while (1) saving energy, (2) accelerating green energy, (3) diversifying energy, and (4) making investments and reforms.

Specifically, in the short term, this proposal aimed to achieve “common purchases of gas, LNG, and hydrogen,” “gas stockpiling to 80% capacity,” “new energy partnerships with reliable suppliers,” “rapid rollout of solar, wind, and hydrogen energy projects,” and “accelerated production of biomethane.” Furthermore, in the medium term, the proposal seeks to “achieve investments and reforms worth €300 billion on a country-by-country basis,” “accelerate approval of renewable energy projects,” “make investments in an integrated gas and electricity network infrastructure,” “raise the 2030 EU energy-savings target from 9% to 13%,” “increase the 2030 renewable energy ratio from 40% to 45%,” and “secure access to critical raw materials” (Table 2.5).

The EU policy of reducing dependency on Russia in the energy field and accelerating countermeasures to climate change under the accompanying energy crisis reflects how the EU decision-making structure, in which the European Commission composed of members independent of the national policies of EU member states plays a key role, enables governance based not only on economic benefits but also on values deemed important by the EU. At the same time, it should be worthwhile to investigate whether the above example could offer some suggestions with regard to the energy-related decision-making process in Japan during the same period and the structure of governance involving climate change and energy in Japan.

2.3.3 Changes in energy trading and cooperation between Japan and the Asia-Pacific region

The Russian invasion of Ukraine had a major impact on Asian countries. In particular, the confusion surrounding energy and food brought about a political and economic crisis in regions deeply affected by climate change and the COVID-19 pandemic.

Table 2.5 Overview of measures in RePowerEU

Period	Short Term	Medium Term (by 2027)
Stage	・Common purchases of gas, LNG, and hydrogen, gas stockpiling to 80% capacity ・New energy partnerships with reliable suppliers ・Rapid rollout of solar, wind, and hydrogen energy projects ・Accelerated production of biomethane ・Communication with citizens and businesses on energy-saving recommendations	・Investments and reforms worth €300 billion by country ・Boosting of industrial decarbonization (€3 billion fund) ・Accelerated approval of renewable energy projects ・Investments in an integrated gas and electricity network infrastructure ・Raise the 2030 EU energy-savings target from 9% to 13%, ・Increase the 2030 renewable energy ratio from 40% to 45% ・Secure access to critical raw materials ・Develop water electrolysis equipment for securing industrial energy and set up a regulatory framework for hydrogen

Source: European Commission. 2022. “REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition.” Accessed on February 28, 2023. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

9 European Commission. 2022. "REPowerEU: affordable, secure and sustainable energy for Europe." Accessed on February 22, 2023. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en.

Following the invasion of Ukraine, major powers in Asia, while not supporting the invasion, did not show any strong intentions in reducing energy dependence on Russia as seen in Europe. China, for example, imported oil from Russia at discounted prices to secure supply routes independent of the United States and the Middle East, while India increased its imports of crude oil from Russia as a countermeasure to inflation entwined with political unrest[10].

The invasion of Ukraine also impacted other countries in the Asia-Pacific region. In Pakistan, for example, amid record-breaking torrential downpours and heat waves, the simultaneous surge in prices for energy and food severely affected impoverished regions. Additionally, a major political and economic crisis arose in countries such as Sri Lanka and Bangladesh that could not mount sufficient countermeasures due to the damage caused by COVID-19[11].

Against this background, Australia is beginning to step up its presence as a player that can have a unique role in the Asia-Pacific region following the invasion of Ukraine. That is to say, in the construction of an energy supply network born out of the present energy crisis, Australia is increasing its presence as an important resource-rich country in Asia[12]. Japan already depends on Australia for 40.2%[13] of its liquefied natural gas (LNG) and 68.3%[14] of its coal, but Australia, which together with the United States, India, and Japan forms the QUAD, has the potential of being a cooperative partner based on shared political values and good bilateral relations.

In Australia, the Labor Party came to power in the May 2022 elections, and along with great strides made by the Greens and climate advocates, a policy shift on climate measures occurred. Additionally, in September, countermeasures to climate change that had so far been stagnating were accelerated and a bill was passed calling for net zero carbon emissions by 2050[15]. Today, while enjoying the benefits of gas exports, Australia is moving to position itself as an important resource-rich country for the global green transition[16]. Going forward, it looks to enhance its status as a supplier of resources such as hydrogen, ammonia, and rare metals (lithium, nickel, rare earths, etc.) (Figure 2.1).

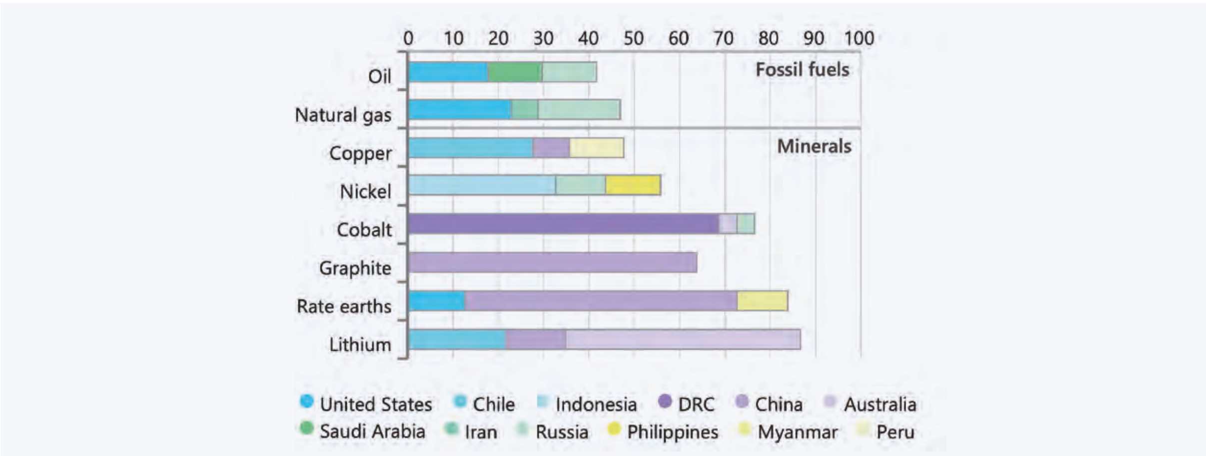

Figure 2.1 Mining share of minerals and fossil fuels of top producing countries (2019)

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

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10 New York Times. 2022. "In Russia's War, China and India Emerge as Financiers" June 24.

11 United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). 2022. "Policy Brief: The War on Ukraine: Impacts, Exposure, and Policy Issues in Asia and the Pacific." May. https://www.unescap.org/sites/default/d8files/knowledge-products/ESCAP-2022-PB-War-in-Ukraine.pdf

12 Aljazeera. 2022. "Australia looks to fill Asia's energy gap amid Ukraine crisis" May 9. https://www.aljazeera.com/economy/2022/5/9/australia-looks-to-fill-asias-energy-gap-amid-ukraine-crisis

13 Based on 2020 LNG import statistics. Ministry of Finance. 2023. "Trade Statistics of Japan." Accessed on February 28, 2023. https://www.customs.go.jp/toukei/suii/html/data/y8_3.pdf.

14 Based on thermal coal import statistics in FY2020. Ministry of Economy, Trade and Industry. 2022. "Annual Report on Energy (Japan's Energy White Paper 2022)." Accessed on February 28, 2023. https://www.enecho.meti.go.jp/about/whitepaper/2022/pdf/2_1.pdf.

15 Prime Minister of Australia. 2022. "Australia legislates Emissions Reduction Targets." September 22. Accessed on February 22, 2023. https://www.pm.gov.au/media/australia-legislates-emissions-reduction-targets.

16 Nicky Ison. 2022. "Australia can swiftly end the climate wars and become a renewable superpower. Here's how," *The Guardian*, May 24. Accessed on February 22, 2023. https://www.theguardian.com/australia-news/commentisfree/2022/may/25/australia-can-swiftly-end-the-climate-wars-and-become-a-renewable-superpower-heres-how; *The Japan Times*. 2022. "Australia digging deep to reshape itself as green energy superpower." August 22. Accessed on February 22, 2023. https://www.japantimes.co.jp/news/2022/08/25/asia-pacific/australia-green-ambitions/.

In Japan, the geopolitical reorganization following the invasion of Ukraine made it necessary to construct a new international supply network for hydrogen, ammonia, rare metals, carbon storage, etc. In particular, while overcoming the risk of reverting to fossil fuels arising from the energy crisis, there is a need to establish strategic and reciprocal tie-ups with respect to climate change and energy security in the Asia-Pacific region with countries like Australia having common political beliefs.

2.3.4 Suggestions for scenarios

The global geopolitical changes that occurred from 2021 through 2022 including the developments described above offer important suggestions for the descriptions contained in the transition scenarios drawn up by Hitachi-UTokyo Laboratory. Here, while we cannot discuss all of those suggestions, we would like to briefly touch upon several particularly relevant domains.

1. Coal/gas-fired power generation: consensus building and creation of green jobs in a transition period

Scenario

For the case of "diverse energy," while there will be a temporary return to fossil fuels following the Ukraine invasion, the period of 2020–2030 will be marked by a phase out of inefficient coal-fired power generation and promotion of technology development and international cooperation on carbon capture utilization and storage (CCUS).

Point

Steady progress in phasing out inefficient coal-fired power generation, transitioning to sustainable fuels, and developing CO_2-capture-type thermal power generation will be necessary. Creating green jobs in conjunction with the phasing out of thermal power generation will also be important. In addition, the widespread adoption of CCUS will require technology development, public acceptance, and the construction of a global supply chain in APAC.

2. Hydrogen and ammonia: social acceptance and creation of a supply chain

Scenario

For the case of "diverse energy," the use of thermal power generation will be prolonged and a transition to mixed-firing/single-firing will proceed gradually. Demand will grow in Asia and an international supply chain will be constructed. However, for the case of "100% renewable energy," thermal power stations will close down and an international supply chain for hydrogen and ammonia will come to a halt.

Point

A massive supply is needed for thermal power generation based on hydrogen and ammonia, which will require a mass production system and an international supply chain for hydrogen and ammonia. In addition, whether international public opinion will approve a transitional use of fossil fuels could have a major impact.

3. Nuclear power: policy transition and limitations

Scenario

For the case of "diverse energy" in the period 2030–2050, construction and preparations for the rebuilding of "next-generation innovative reactors" at old sites of power generation plants will take place, but "compact nuclear reactors" will not be ready for commercial operation by 2050. The nuclear power share, which stood at 20% in 2030, will gradually contract amid competition with increasingly inexpensive and stable renewable energy dropping to 10% by 2050. Meanwhile, for the case of "100% renewable energy," problems related to the long-term nature of constructing advanced nuclear reactors and recovery of investments will become a public concern and the amount of nuclear power generated will gradually drop to zero.

Point

In relation to renewable energy that will become low-priced and stable in the medium-to-long term, how can rational investments be made in nuclear power personnel, technology development, and facility construction? Furthermore, how can public understanding across the nation be obtained in relation to the various benefits and risks of nuclear power and how can a consensus be built with local residents on construction sites and disposal of radioactive waste?

Please see the material at the end of this document for an overview of all scenarios. There are plans to release detailed scenarios in each domain in a separate publication.

2.4 Regional decarbonization in Japan

On the one hand, the transition to carbon neutrality in Japan will be affected by international geopolitical changes as described above, but on the other hand, in cannot be achieved without decarbonization efforts rooted in each region in Japan.

The transition scenarios drawn up by Hitachi-UTokyo Laboratory cannot survey all such efforts. Here, to understand the particularities of issues surrounding such regional efforts toward a transition to carbon neutrality in Japan, we take up a cross section of those issues.

2.4.1 Potential of regional new power and associated issues

One of the main actors in decarbonization in Japan's various regions is a type of power company called "regional new power."

Regional new power can be viewed as electricity retailers involved in the local production and consumption of power through renewable energy or other means. Its nationwide share of power is currently small but it has shown signs of increasing in recent years.

A key feature here is that many regional new power companies are participating in region-specific issues through energy-related businesses and engaging in activities to promote the local economy and urban development. For example, Local Energy Corporation, which is developing business centered about Yonago City, Tottori Prefecture, proclaims a vision of "creating a new local economy infrastructure through the local production and consumption of energy." By positioning themselves as energy suppliers within a region, these companies aim to put a check on the flow of funds outside the region while circulating them within the region to strengthen the infrastructure of the local economy[17].

Given a declining birthrate and aging population, industrial decline, and the demand for decarbonization, these regional new power companies are promoting the introduction of regional renewable energy with the aim of expanding local services through operating income. They can also take on the role of think tanks that can clarify local issues and propose solutions.

There are also organizations to support the smooth

17 Additionally, Hioki Regional Energy Co., Ltd based in Hioki City, Kagoshima Prefecture was founded in 2014 by 14 companies, local governments, and local financial institutions with the aim of maintaining and improving the quality of life in the region by using renewable energy and promoting the local production and local consumption of power.

management of regional new power companies[18]. By sharing communication systems, personnel having specialized knowledge, and machinery and materials for power businesses among multiple regional new power companies, these organizations provide support by reducing the cost burden and lack of know-how of individual operators.

However, it's been pointed out that many regional new power companies locate their headquarters in large cities making them incapable of creating jobs and developing know-how for regional areas. It has also become clear that the recent surge in fuel prices has forced many new power companies to declare bankruptcy or withdraw from the business. In a setting in which the social objective of regional creation and the economic necessity of rational business management are two conflicting aims, management can become strenuous for regional new power companies.

2.4.2 New changes in regions introducing renewable energy on a large scale

In Japan, there are regions in which the introduction of renewable energy is proceeding on a large scale. In such regions, movements can be seen that attempt to overcome peculiar social problems while taking advantage of the distinctive features of the region's natural resources.

In Akita Prefecture in the Tohoku region of Japan, social problems such as a declining birthrate and aging population, the movement of young people out of the prefecture, and an industrial structure with low added value have become worrisome. In recent years, though, many wind power projects have come to be promoted exploiting Japan's prominent position as a suitable country for wind power generation, and more than 300 wind power generators have already been installed in Akita Prefecture. Here, at an installed capacity of wind power exceeding 70MW, Akita Prefecture ranks second among all prefectural and city governments in Japan[19].

At present, large-scale offshore wind power projects are moving forward in Japan, and here, a variety of actors are participating. Regional wind power companies are engaged in a wide range of business activities including the selection of suitable sites for power generation, cooperation with business partners, and the building, startup, and maintenance of power plants. At the same time, they are forming business consortiums to revitalize local industry. Regional banks, meanwhile, provide project financing to support wind power businesses that need to procure funding on a large scale. In the case of offshore wind power generation, however, there are concerns about being sued by local fishermen for environmental impact reasons.

In Akita Prefecture, local governments are making an effort to create new industries centered about wind power generation by coordinating a variety of actors. The Akita prefectural government is establishing study groups and councils along with concerned persons from cities, towns, the national government, and the fishing industry and establishing forums to coordinate the opinions of a variety of persons in fields lacking a sufficient amount of knowledge. It is also taking measures to create a parts-manufacturing and maintenance industry for wind power generation and unfolding a program to develop green personnel in cooperation with local universities and technical schools.

On the other hand, it has been pointed out by concerned persons in regional areas that wind power generation in Japan is a field in which know-how has not yet been firmly established, which can result in a gap between regionally led movements and approaches promoted by the national government. In the expert interviews held by Hitachi-UTokyo Laboratory, many experts expressed the need for a highly transparent business promotion process from the national government that aims to make use of regional resources based on a vision of a cross-sector system.

2.4.3 Industrial clusters and chemical complexes

The most important issue in achieving carbon neutrality in Japan is the transition that must be made in the industrial clusters and petrochemical complexes in particular scattered about Japan.

The Kawasaki City Rinkaibu (Kawasaki waterfront area) in Kanagawa Prefecture has a high concentration of petroleum-refining/chemical processing, steel, energy, cement, and distribution plants and facilities supporting advanced economic growth (Figure 2.2). The amount of carbon emissions of Kawasaki City is the highest among government ordinance-designated cities, and major companies located in the Kawasaki waterfront area account for 73% of those emissions[20].

18 These organizations include, for example, a "local goods creation support mechanism."

19 Japan Wind Power Association (JWPA). 2023. "Preliminary Report: Japan's Installed Capacity of Wind Power (as of the end of December 2022)." Accessed on February 21, 2023. http://jwpa.jp/pdf/dounyuujisseki2022graph_hp.pdf.

20 Kawasaki City, Kanagawa Prefecture. 2022. "Kawasaki Carbon-neutral Industrial Complex Concept." https://www.city.kawasaki.jp/templates/pubcom/cmsfiles/contents/0000137/137116/CNK2.pdf.

Believing that the current way of operating industrial complexes is lowering the industrial competitiveness of all complexes, Kawasaki City announced its “Kawasaki Carbon-neutral Industrial Complex Concept” in 2022 with the aim of converting the Kawasaki waterfront area into an “energy supply hub and raw-materials manufacturing hub worthy of a carbon neutrality society.”

Kawasaki City explains that the Kawasaki waterfront area provides a variety of functions through its role as an energy supply hub having a concentration of chemical industries, plastic recycling facilities, hydrogen-related companies, etc., and as such, has the potential of contributing to carbon neutrality of the entire Tokyo metropolitan area.

However, many problems are arising in the decarbonization of petrochemical complexes. For example, issues that cannot be solved within the conventional business structure include how to divide up the burden of new investments in recycling plants, carbon separation, and hydrogen-base related facilities, how to achieve inter-company cooperation based on chemical processes for making effective use of by-products, and how to form entities for setting up a common infrastructure that cannot be designed over the long term by only administrative measures.

We have heard from concerned persons about the need for a vision that views industrial complexes not in a vertically divided manner by industry but rather in an integrated manner and support for that vision, support for creating a sustainable infrastructure, design of a corporate/citizen collaborative mechanism, etc.

2.4.4 Suggestions for scenarios

Matters that came to light due to global geopolitical changes and regional initiatives within Japan in the period 2021–2022 hold important suggestions for the descriptions in our transition scenarios. Here, we briefly discuss several highly relevant domains.

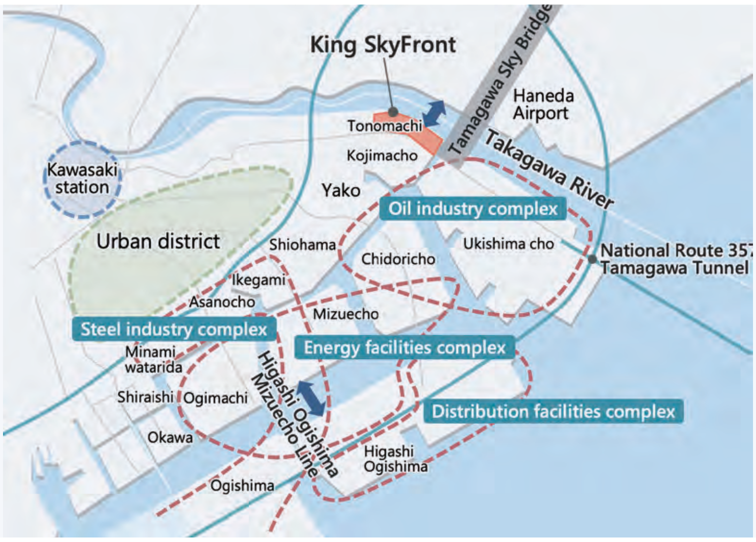


Figure 2.2 Industrial concentration in Kawasaki waterfront area

Source: Created by Hitachi-UTokyo Laboratory based on the following material: Kawasaki City, Kanagawa Prefecture. 2022. “Kawasaki Carbon-neutral Industrial Complex Concept.” https://www.city.kawasaki.jp/templates/pubcom/cmsfiles/contents/0000137/137116/CNK2.pdf, p. 13.

1. Solar: Improved cost competitiveness and business sustainability

Scenario

In either of the “diverse energy” and “100% renewable energy” cases, the cost competitiveness of solar power generation will improve in 2020–2030 due to soaring prices for power in the aftermath of the Ukraine war. Mandatory home installation of solar equipment and promotion of solar power generation by regional governments will help maximize the amount of solar power generated.

Point

New actors will participate, but solving issues related to environmental impact, business discipline, etc. will be important. In addition, the scrapping of equipment and materials and the need for their replacement can be expected in 2030–2040. The spread of a smart power transmission and distribution network is key to supporting the rapid adoption of EVs and regional decarbonization.

2. Petrochemical: From supply chain reform to a circular business model

Scenario

In either of the “diverse energy” and “100% renewable energy” cases, raw materials derived from non fossil-fuel resources and social interest in chemical recycling will increase. Initiatives for reforming production processes and international supply chains will begin in earnest, and in 2030–2050, rearrangement of industry will progress. To support a circular economy, business models will change and the ecosystem will be revamped.

Point

Key points here include domestic/international supply-chain creation and technology development for carbon capture and storage, innovative business models for inside and outside industrial clusters, and policies and inter-company cooperation for creating a new ecosystem.

3. Agriculture: transition in food system and associated issues

Insights

- One fourth of global greenhouse gases is emitted from the food system, and the current food system is considered to be unsustainable from the viewpoints of deforestation, loss of biodiversity, pesticide runoff, and other issues.
- The EU is promoting a Farm to Fork strategy. Japan as well has enacted a Green Food System Strategy and has set targets that include zero carbon dioxide emissions in agriculture, forestry, and fisheries and 50% reduction in chemical pesticides by 2050.
- In Japan, 40% of farmland is made up of paddy fields, and half of all greenhouse gases is methane gas. While carbon absorption by farmland soil is possible, the ownership and use of farmland is fragmented at present.
- A transition in present customs related to food and participation by the agricultural sector in sustainable aviation fuel (SAF) has the potential of having a big effect on agriculture in Japan.

As already mentioned, please see the material at the end of this document for an overview of all scenarios. There are plans to release detailed scenarios in each domain in a separate publication.

2.5 Chapter 2 summary

In our studies up to now, given a geopolitical landscape undergoing massive changes due to the Russian invasion of Ukraine, we have reiterated the importance of creating in Japan a mechanism of governance that can promote transitions in relation to climate change and energy and of achieving carbon neutrality while supporting local actors that can broaden this undertaking based on diverse conditions. We here summarize the points that need to be considered for achieving carbon neutrality in Japan.

1. Can a mechanism of governance be created to accelerate systemic changes in response to the current geopolitical crisis?

As already discussed, the EU and United States are accelerating countermeasures to climate change in the medium-to-long term based on a policy of ending dependence on Russian fossil fuels. On the other hand, it has been pointed out that Japan still lags behind in raising national consciousness and promoting structural transitions in this regard. Against such sudden and dramatic geopolitical changes, governance that can accelerate transitions integrated with all sorts of sectors is becoming increasingly important.

2. Amid climate change and soaring fuel costs, can Japan take the lead in establishing international cooperation toward climate and energy transitions in the Asia-Pacific region?

In the Asia-Pacific region, soaring energy and food prices are also generating a risk of reverting to fossil fuels contrary to efforts aimed at decarbonization. For Japan, securing a supply chain for resources like hydrogen, ammonia, and rare metals and for carbon storage is essential especially amid geopolitical changes. Here, it is important that the Japanese government strengthen its efforts in leading multi-layered international cooperation in relation to climate and energy with Australia, which is intensifying its countermeasures to climate change, and various Asian countries having high fossil-fuel dependence.

3. Can pathways be found to transitions that empower local actors and that differ for each region based on diverse natural environments?

In Japan, a country with abundant natural environments, social issues, lifestyles, and energy potential differ from region to region, which makes for multidimensional pathways to transitions. This situation makes it necessary to support capacity building in regional actors (active entities) such as citizens and local companies and to aim for prosperity centered about a green transition in energy and food. In particular, coordination on the demand side is important in terms of the efficient use and stable supply of regional energy, and to this end, digital innovation will play a leading role.

4. Based on strategic industrial policies, can the government build a consensus with local citizens and companies while supporting the coordination abilities of local governments?

In Japan's diverse regions, the importance of the coordination abilities of local governments in the face of unprecedented challenges is increasing, yet they are deficient in human capital and know-how and in the ability to create cross-sectional mechanisms. For this reason, the government must overcome a vertical administrative structure and provide support for maximizing regional power based on strategic industrial policies. In addition, the construction of a consensus-building platform by the government and local government based on scientific data and open dialogue with local citizens and companies should become an important foundation for carrying through long-term transitions across a wide range of fields.

Against the backdrop of sudden and dramatic changes in the geopolitical situation, it will be necessary to create a form of governance that can accelerate transitions in climate and energy supported by regional independence while searching out new channels of cooperation with the Asia-Pacific region.

Chapter 3 Energy system measures based on the gap between backcasting and forecasting

In this chapter, we review energy scenarios toward carbon neutrality given the effects of a surge in fuel and power prices and tight supply and demand for power due to changes in the international situation following Version 4 of this report. We extract new issues and present countermeasures.

3.1 Review of energy scenarios based on the international situation

In this section, we quantitatively show by simulations whether scenarios exist that provide for a 46% reduction in greenhouse gas emissions by 2030 (relative to 2013) and that makes carbon neutrality possible by 2050 given fuel price hikes. In particular, we investigate scenarios formulated by backcasting from 2050 and investigate their consistency with the results of forecasting from the present. In this way, we present issues and innovative measures that should be taken from the present into the near future.

To begin with, we envision conditions surrounding fuel price hikes as shown in Figure 3.1. Case 0 is a long-term outlook before the invasion of Ukraine showing conditions based on U.S. Energy Information Administration (EIA) [21] estimates[22] (Hitachi-UTokyo Laboratory 4th Forum Report). Case 1, on the other hand, shows an outlook reflecting the fuel price hikes of 2022. It is assumed here that the current jump in fuel prices will calm down by 2030 and return to long-term trends[23].

The results of organizing and classifying the carbon neutrality vision of 2050 by these two sets of conditions about two axes—the ratio of variable renewable energy (VRE) deployed and progress in electrification of the transport/industrial sectors—the same as in Version 4 is shown in Figure 3-2.

Here, to calculate transition scenarios up to 2050, we used an energy/economics simulation model based on a "technology selection model" developed by FUJII-KOMIYAMA Laboratory, University of Tokyo[24 25]. Using this model, we calculated

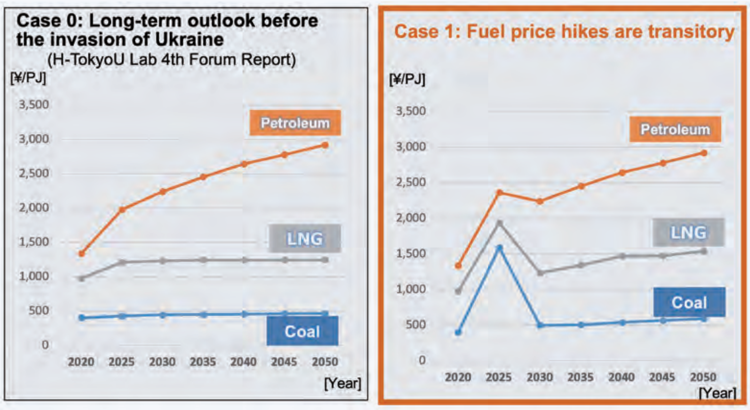


Figure 3.1 Conditions taking fuel price hikes into account

21 EIA: Energy Information Administration in the United States

22 EIA. 2022. "ANNUAL ENERGY OUTLOOK 2022," March 3, 2022.
https://www.eia.gov/outlooks/aeo/.

23 Estimates for 2025 are based on current fuel prices while those for 2030 and beyond are based on US EIA predictions.

24 Yasuaki Kawakami, Ryoichi Komiyama, and Yasumasa Fujii. 2018. "Penetration of Electric Vehicles toward 2050: Analysis Utilizing an Energy System Model Incorporating High-Temporal-Resolution Power Generation Sector." *IFAC-Papers OnLine* 51, no. 28: 598–603.
https://www.sciencedirect.com/science/article/pii/S2405896318334906.

25 Yasuaki Kawakami, Ryoichi Komiyama, and Yasumasa Fujii. 2018. "Analysis of CO2 Reduction Scenario Using an Energy System Technology Selection Model Incorporating a High-Temporal-Resolution Power Generation Sector." Transactions of the Institute of Electrical Engineers of Japan (IEEJ) B 138, No. 5: 382–391.
https://www.jstage.jst.go.jp/article/ieejpes/138/5/138_382/_article/-char/ja.

transition plans that would minimize total energy and system cost while maintaining energy supply and demand in one-hour units assuming 8,760 hours per year. This analysis can therefore be viewed as a means of formulating scenarios for achieving carbon neutrality by backcasting from 2050. In the figure, the left portion shows the 2050 relationship between VRE and energy demand and the percentage increase in total cost for energy scenarios (100% renewable energy, thermal power with CCS limits, use of nuclear power, and hydrogen procurement) differing in technical innovation and cost conditions. The right portion of the figure shows the relationship between self-sufficiency rate and stockpiling rate in 2050. In each of these scenarios, it can be seen that energy demand increases, the use of hydrogen as raw material progresses, and the total cost of energy increases by 20–50% relative to 2020. In the following, we perform a detailed analysis of a transition scenario to carbon neutrality taking "(3) use of nuclear power" as an example based on a balance among increase in total cost, self-sufficiency rate, and stockpiling rate.

Figure 3.3 shows the results of calculating power supply capacity for select fiscal years for Case 0, Case 1, and Case 1' transitions to carbon neutrality in the "use of nuclear power" scenario. Compared with Case 0, it can be see in Case 1 that fuel price hikes result in an increase in facilities for solar power generation (PV) and a drop in the use of LNG power generation in 2030 (1). It can also be seen that cogeneration increases in each case making for more efficient use of heat (2). Given fuel price hikes, these results reflect the need for an early transition to decarbonized power supplies from fossil fuels and efficient use of heat from the viewpoint of total energy cost. At the same time, Case 1 envisions a rapid increase in facilities for solar power generation as well as a phasing out of those facilities from 2040 on, so there are concerns about overdevelopment of sites for solar power generation and scrapped facilities. With this in mind, we added weights to limit the number of abandoned facilities for solar power generation and recalculated this case as Case 1'. In this way, it is necessary to study scenarios that reduce the gap with backcasting by taking into account forecasting from the present.

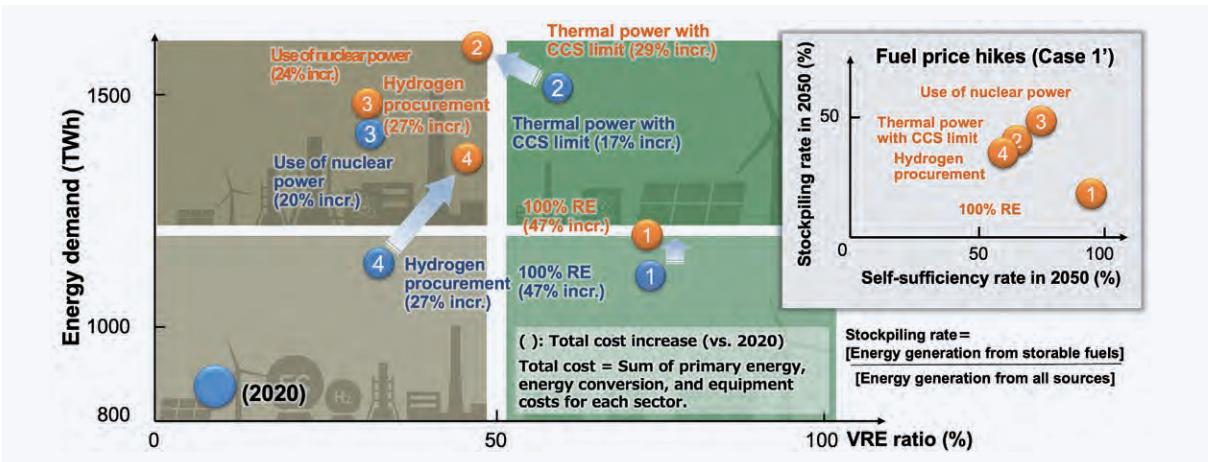


Figure 3.2 Changes in four social visions due to fuel price hikes based on deployment of renewable energy and progress in electrification

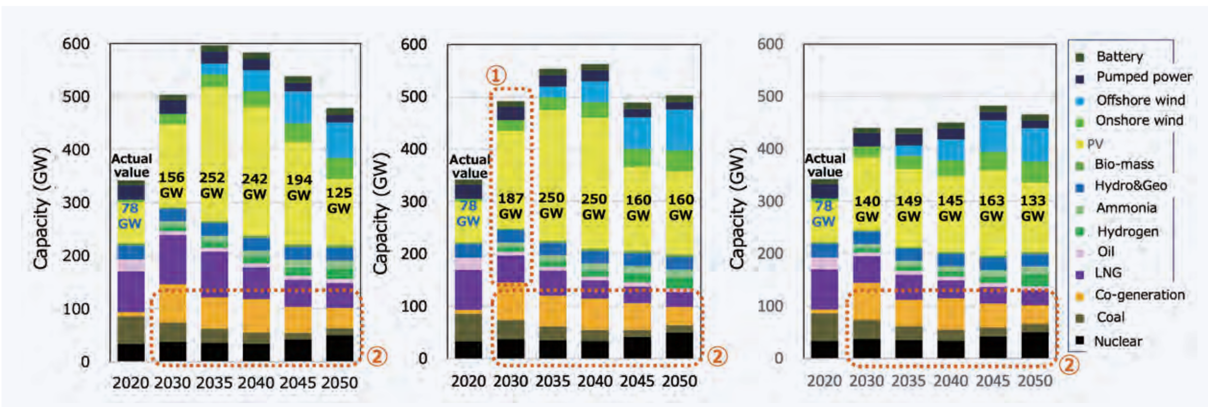


Figure 3.3 Power supply capacity for select fiscal years ("use of nuclear power" scenario)

Next, Figure 3.4 breaks down hydrogen use and CO_2 capture and use. Following its use in thermal power generation and fuel cell vehicles (FCVs), 60% of hydrogen will come to be used for CCU from 2045 on. Meanwhile, the amount of CO_2 captured by DAC will increase from 2045, and in 2050, it can be seen that captured CO_2 will also come to be used for the production of fuels.

Figure 3.5 shows daily change in the generation of renewable energy from the results of scenario calculations. A period with a small amount of wind and solar power generation can be envisioned due to windless days or rainy weather, which means that this deficiency in VRE output will have to be made up for by other forms of power generation or stockpiled power. In actuality, occasional periods in which power generation by renewable energy cannot be expected, situations in which the procurement of fuels for other types of power generation is delayed, interruptions due to facility maintenance or system faults, and problems with the generation and transmission of power due to natural disasters must also be envisioned and prepared for from the viewpoint of energy security and resilience.

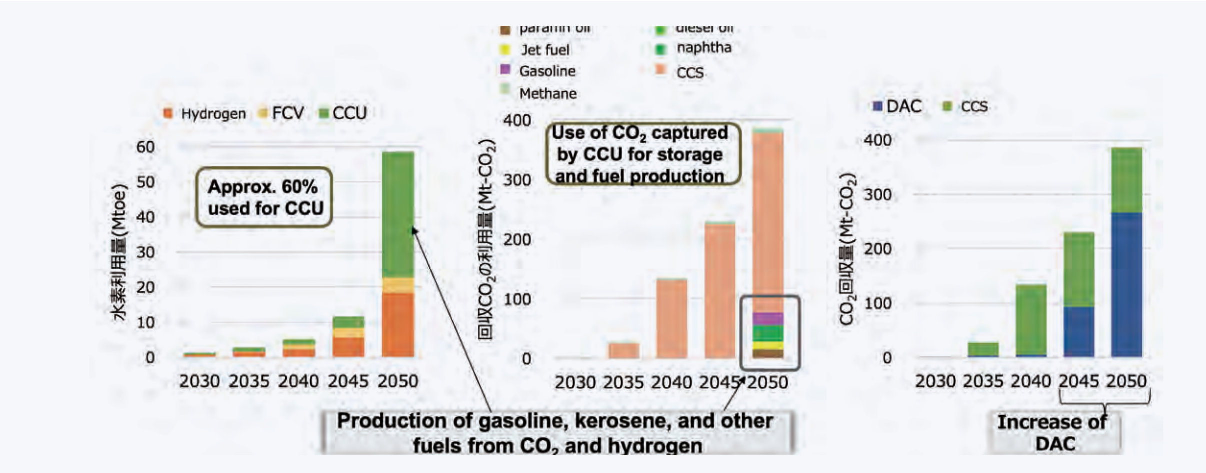


Figure 3.4 Hydrogen use and CO2 capture and use for select fiscal years (“use of nuclear power” scenario, Case 1’)

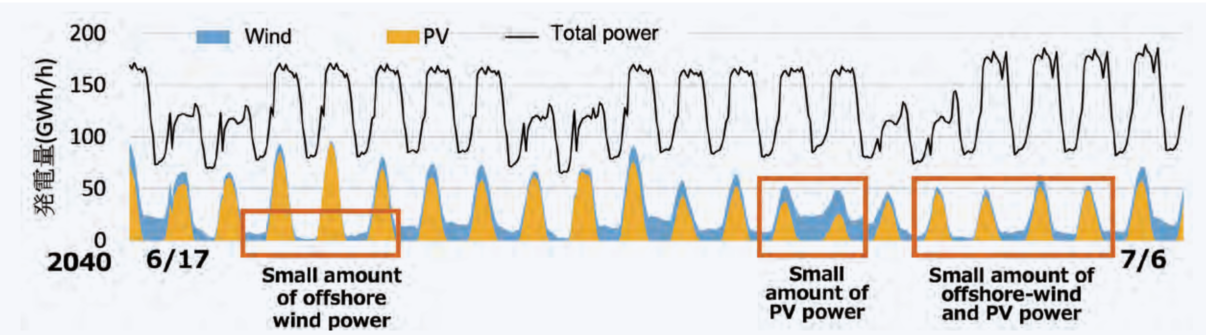


Figure 3.5 Example of a period with a small amount of solar/wind power generation (“use of nuclear power” scenario, Case 1’, 6/17–7/6, 2040)

3.2 Gap between energy-system backcasting and forecasting and countermeasures

On considering the present configuration of power supply facilities shown in Figure 3.3, there are concerns, as described above, that the envisioned rapid increase in facilities for solar power generation (78 GW → 187 GW) and reduction of facility capacity from 2040 on (facility phase-out) will lead to overdevelopment of sites for solar power generation and an increase in scrapped facilities. Taking this into account, we added weights to limit the number of scrapped facilities for solar power generation and performed calculations again as Case 1’ thereby obtaining a scenario that cuts back on the deployment of solar power in 2030 and reduces the number of facilities to be later scrapped. Under these conditions, we examined issues in making a transition in the power supply configuration from 2020 to 2030.

(1) Solar power generation: 2020 78 GW → 2030 140 GW (Case 1') requiring an increase of 62 GW

Targets set by Japan Photovoltaic Energy Association (JPEA) in 2021 include a 2030 target of 100–125 GW (AC output)[26]. From this, our 2030 target of 140 GW can be viewed as a value presenting a high barrier to deployment. Considering an average space of 15 km2/GW, building 62 GW worth of new solar power generation facilities would require 930 km2, which is equivalent to 1.5 times the area of Tokyo's 23 wards or of Japan's Lake Biwa. Furthermore, in terms of capacity, this would be equivalent to establishing 240 new mega solar farms (approximately 260 MW) ranked as top-class sites in Japan. It would therefore be necessary to solve issues involving solar-panel waste and recycling and to promote the selection and effective use of installation sites that include environmental considerations.

(2) Wind power generation: 2020 5 GW → 2030 20 GW (Case 1') requiring an increase of 15 GW

The Japan Wind Power Association (JPWA)[27] is planning and analyzing the deployment of 13 GW of onshore wind power and 18 GW of offshore wind power by 2031. In addition, approximately 9 GW of this onshore wind power has been set prior to business plan approval, which reflects the importance of increasing the pace of approval from 1.2 GW/year to 2 GW/year and of moving forward with environmental assessments, elimination of grid constraints, etc. and reducing lead times. Japan's Agency for Natural Resources and Energy[28] is moving forward with the commercialization of offshore wind power consisting of 1.7 GW from offshore wind promoting areas with the selection of operators completed, 1.8 GW in public offerings, and 2.2 GW in five promising areas for a total of 5.7GW. Here, early formulation of projects, reduction of lead time to operation, grid construction, and local cooperation are all important issues to be addressed.

(3) Cogeneration: 2020 8 GW → 2030 70 GW (Case 1')

In this calculation, it is expected that one half of the power generated from fossil fuels can be used for heating. It will therefore be necessary to make effective use of heat in addition to using conventional cogeneration facilities.

(4) Power generation from hydrogen and ammonia: 2020 0 GW → 2030 16 GW (Case 1')

If a transition in conventional fossil-fuel power generation facilities can be achieved, 16 units of large-type thermal power generation facilities (such as 1 GW/unit) would have to undergo a transition. Related issues such as facility technology development and fuel procurement must be quickly solved in combination with environmental, economic, and distribution considerations.

(5) Nuclear power generation: 2020 33 GW → 2030 36 GW (Case 1')

Excluding those that are already decommissioned, 36 nuclear power plants (including those under construction) is a number that assumes 60 years of operation or a capability of operating for that long. Once safety measures have been formulated and authorization obtained, a consensus must be built with local citizens and the general public.

3.3 | Power system issues and countermeasures based on simulation analysis and evaluation

Up to the previous section, we showed that, to fill in the gap between the scenario obtained by backcasting from carbon neutrality in 2050 and that obtained by forecasting from the present, it is necessary to solve problems on the power-system side such as grid connections in conjunction with a transition to decarbonized power supplies and early deployment of renewable energy. In this section, we take up power-system issues and countermeasures envisioned in the process to carbon neutrality such as the transition to decarbonized power supplies and rapid expansion of the installed capacity of renewable energy.

Figure 3.6 shows issues and countermeasures in the bulk

26 Japan Photovoltaic Energy Association (JPEA). 2021. "Present State of Solar Power Generation and Issues toward Becoming an Autonomous and Main Power Source," October 29, 2021. (in Japanese)
https://www.meti.go.jp/shingikai/santeii/pdf/071_01_00.pdf

27 Japan Wind Power Association (JPWA). 2021. "Approach to 2030 Installed Capacity of Wind Power Generation toward Carbon neutrality by 2050," March 15, 2021. (in Japanese)
https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/028_05_00.pdf

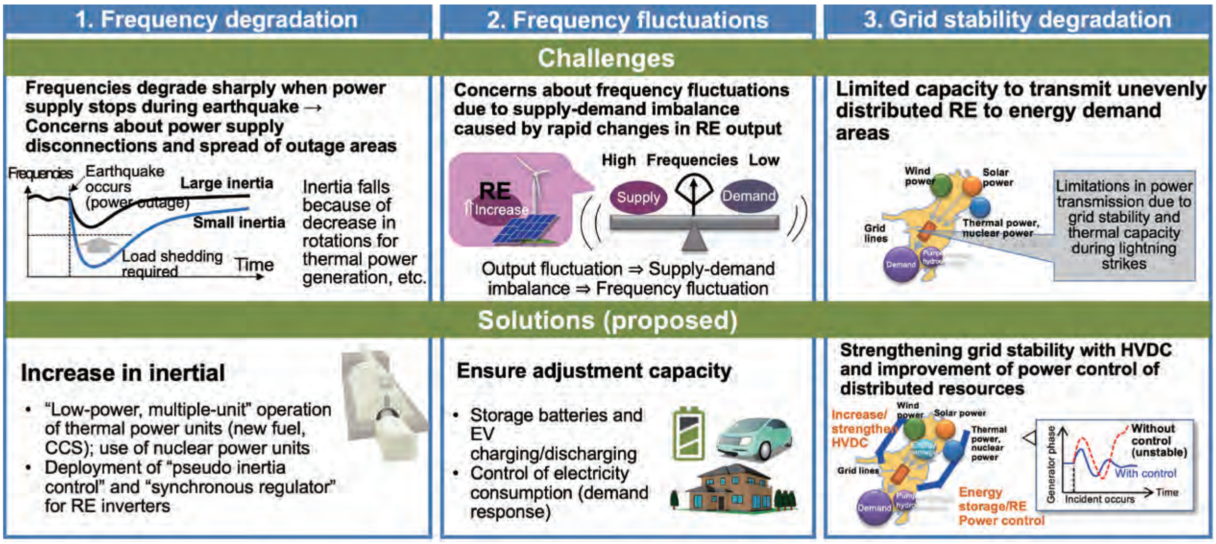
28 Agency for Natural Resources and Energy. 2022. "Current State of Domestic/International Renewable Energy and Issues Proposed by the Calculation Committee for this Fiscal Year's Procurement Prices, etc.," October 2022. (in Japanese)
https://www.meti.go.jp/shingikai/santeii/pdf/078_01_00.pdf

power system accompanying a rapid expansion of renewable energy and Figure 3.7 shows issues and countermeasures accompanying large-scale deployment of inverter power supplies as in renewable-energy power supplies and storage systems. In the following, we discuss issues that must be addressed and necessary solutions based on simulations.

(1) Frequency degradation due to drop in inertia

Frequency degradation becomes large when grid inertia falls due to halting of rotary generators during times of large renewable energy generation or when power is lost due to an earthquake or other incident, which can lead to further loss of power and spread of power outages. In response to this issue, the following become countermeasure candidates: (a) increasing the number of rotary generators (thermal power, nuclear power, etc.) for increasing inertia, and (b) deploying inverter inertia control for renewable energy and distributed resources to counteract frequency degradation immediately after a loss of power.We describe these countermeasures in detail below using simulations. Targeting a grid[29] that simulates the future grid in eastern Japan, Figure 3.8 shows the state of grid frequency when constructing analysis conditions representing a drop in grid inertia and the simultaneous cutoff of many thermal power plants offline.

For the case that System Non-Synchronous Penetration (SNSP), which indicates the asynchronous ratio of inverter power supplies in the system, is at 75%, the Rate of Change of Frequency (RoCoF) immediately after thermal power loss



CCS: Carbon dioxide Capture and Storage, EV: Electric Vehicle, HVDC: High Voltage Direct Current

Figure 3.6 Issues and countermeasures in the bulk power system accompanying a rapid expansion of renewable energy

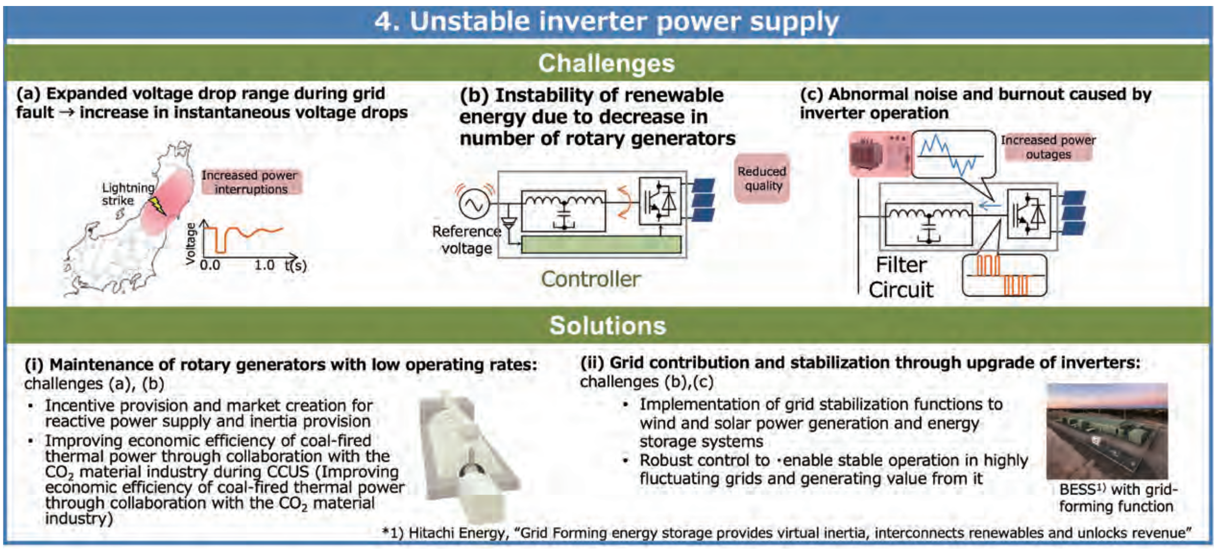


Figure 3.7 Issues and countermeasures accompanying large-scale deployment of inverter power supplies

29 Organization for Cross-Regional Coordination of Transmission Operators (OCCTO). 2021. "Master Plan, Interim Report," May 31, 2021. (in Japanese) https://www.occto.or.jp/iinkai/masutapuran/2021/210524_masutapuran_chukanseiri.html

becomes -2.3 Hz/s. This value deviates from a RoCoF of 2.0 Hz/s that is generally adopted as a control value for stabilizing frequency. On the other hand, when decreasing the output of thermal power plants and increasing the number of them connected to the grid to increase grid inertia by 15%, it is possible to achieve a RoCoF of -1.96 Hz/s within the control value.

Next, Figure 3.9 shows an example of a countermeasure by inverter inertia control at distributed resources. In this example, the output of storage batteries and renewable energy for which output can be increased was controlled so as to be increased when frequency degrades. Specifically, the total output of distributed resources is increased by 10% (approximately 3 GW) immediately after 7.1 GW worth of thermal power plants go offline all together thereby improving RoCoF from -2.3Hz/s to -1.95Hz/s. A variety of techniques have been studied for inverter inertia control. These techniques must be made fit for practical use and their implementation and adoption in inverter equipment in distributed resources (storage batteries, renewable energy), High Voltage Direct Current (HVDC), etc. must be promoted.

(2) Frequency fluctuation due to insufficient adjustment capacity

An imbalance in supply and demand due to fluctuation in the output of renewable energy causes frequency to fluctuate, and output suppression and grid congestion can occur during peak renewable energy generation. To deal with these issues, it is necessary to secure a necessary amount of adjustment capacity while eliminating grid congestion through the use of distributed resources such as charging/discharging of storage systems and demand adjustment and the placement of demand near power generation areas. As shown in Figure 3.10, the results of the previously described scenario calculation indicate a need for 17 GW in total for storage batteries and demand adjustment capacity by 2030. In addition, it is desirable that adjustment capacity be distributed and placed near renewable energy areas that give rise to output fluctuations so as to suppress transmission line overloading.

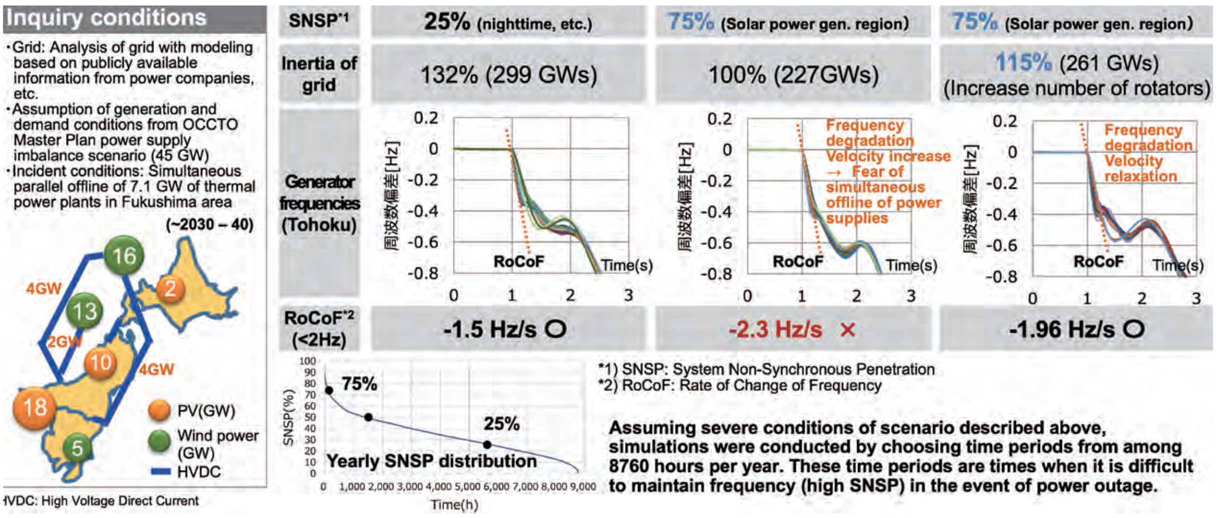


Figure 3.8 Frequency degradation due to drop in inertia and countermeasure by increasing the number of rotary generators

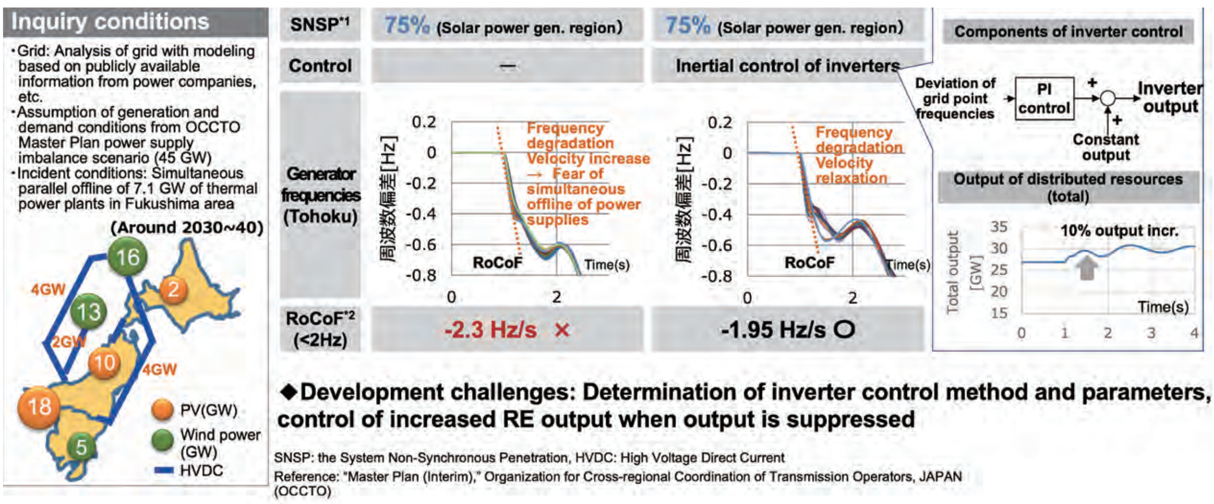
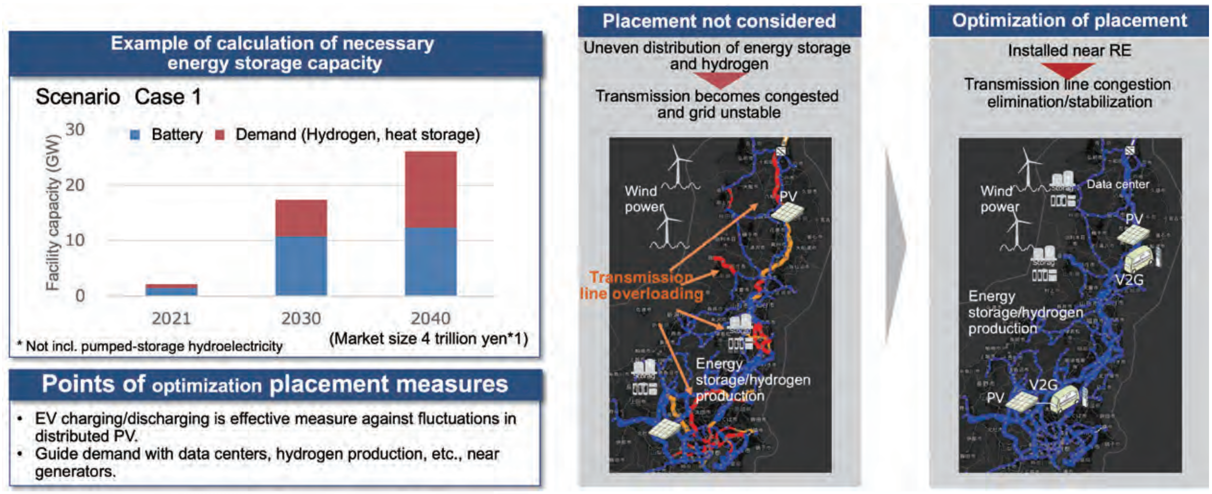


Figure 3.9 Frequency degradation due to drop in inertia and countermeasure by inverter inertia control at distributed resources



*1) Calculated based on a facility charge/discharge time of 4 hours and rate of 40 yen/Wh
WF: Wind Farm, PV: Photovoltaic, V2G: Vehicle to Grid, PV: Photovoltaic, HVDC: High Voltage Direct Current

Figure 3.10 Necessary amount of adjustment capacity and countermeasure by optimized placement

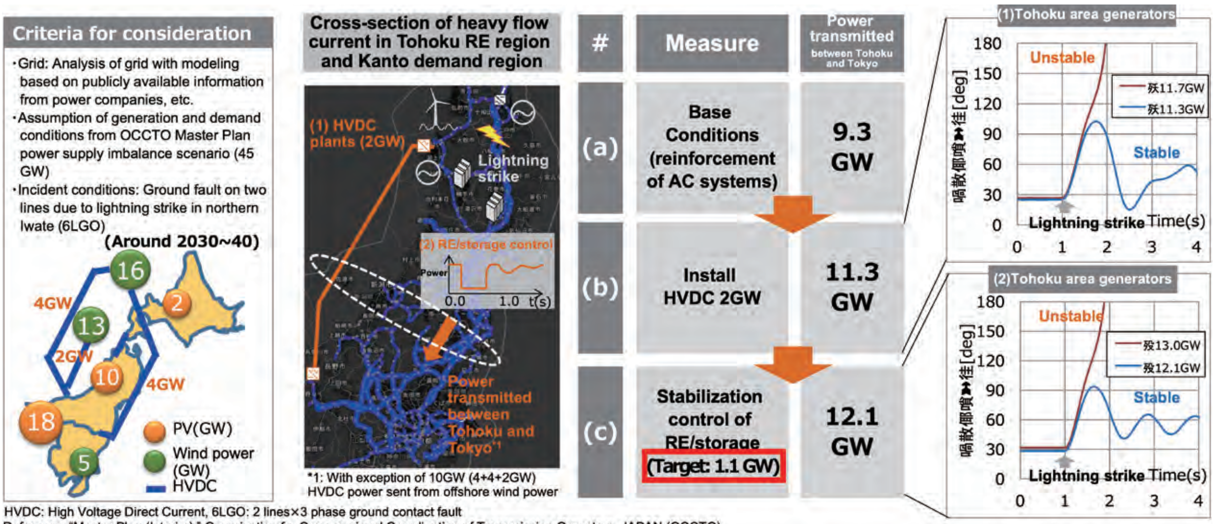
(3) Securing grid stability

The capacity for transmitting unevenly distributed renewable energy to demand regions can reach an upper limit. To deal with this issue, it is necessary to expand cross-regional power transmission by enhancing the power transmission system and stabilizing the grid. Figure 3.11 shows an example of simulating transmission limits in the interconnecting lines between Tohoku and Tokyo in the eastern Japan grid.

Here, we created a grid model that can simulate grid stability based on public information with reference to the OCCTO Master Plan, etc. Referring to (a) in the figure, the upper limit in the AC system for which current in the AC interconnecting lines from Tohoku to Tokyo could be stably transmitted despite ground faults in northern Tohoku was calculated to be 9.3 GW. Now, by enhancing those conditions with 2 GW of HVDC between Tohoku and Tokyo, the total amount of power that can be transmitted by the AC system and HVDC combined comes to 11.3 GW. Furthermore, by performing stabilization control with renewable energy and storage facilities in the Tohoku region (total of 1.1 GW), the total amount of power that can be transmitted by the AC system and HVDC can be increased to 12.1 GW. In this way, enhancing power transmission and stabilizing the grid can boost transmission capacity to power consuming regions. These measures can help increase the amount of renewable energy generated in the Tohoku region and prevent output suppression.

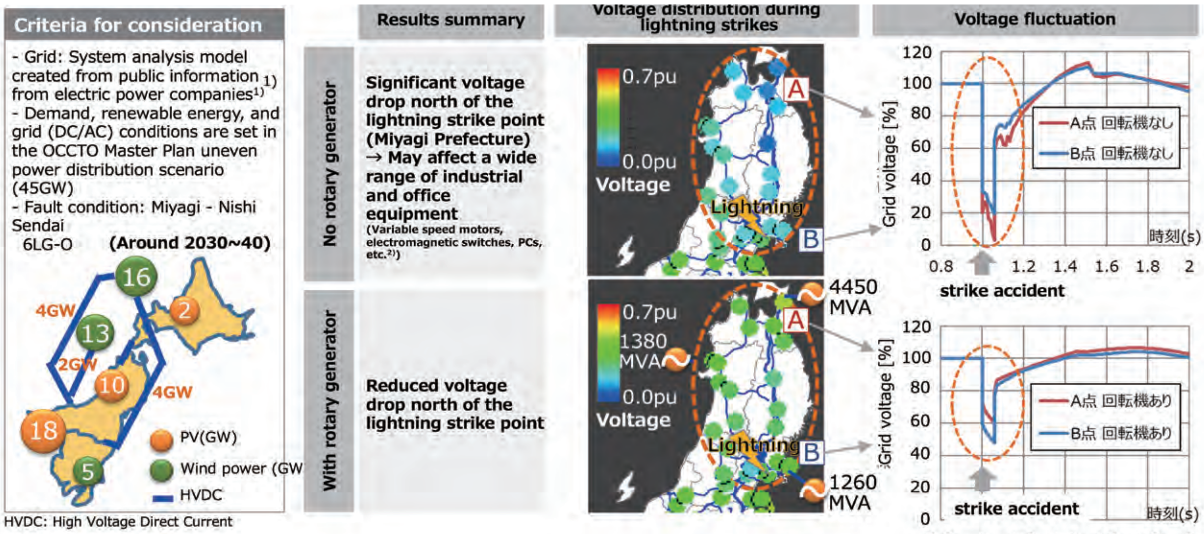
(4) Instability accompanying increase in inverter power supplies

There are concerns that a decrease in the number of rotating generators accompanying an increase in inverter power supplies can lead to instability in the control of renewable energy linked to the grid by inverters and to larger voltage drops at the time of a grid fault due, for example, to a lightning strike. An effective means of dealing with these issues is to upgrade inverter control and support voltage-drop prevention by deploying rotating generators. Figure



HVDC: High Voltage Direct Current, 6LGO: 2 lines×3 phase ground contact fault
Reference: "Master Plan (Interim)," Organization for Cross-regional Coordination of Transmission Operators, JAPAN (OCCTO)

Figure 3.11 Necessary amount of adjustment capacity and countermeasure by optimized placement



1) Prepared by Hitachi-UTokyo Lab with reference to OCCTO "Master Plan Interim Reorganization." https://www.occto.or.jp/iinkai/masutapuran/2021/210524_masutapuran_chukansein.html
2) Hokuriku Electric Power "Measures to prevent instantaneous voltage drops in customer facilities" https://www.rikuden.co.jp/tairai/taisaku.html

Figure 3.12 Voltage drop at time of grid fault with and without rotary generators[30 31]

3.12 shows how voltage can drop at the time of a grid fault with and without rotary generators. The fault condition here is a lightning strike on a power transmission line in Miyagi Prefecture followed by a cutoff in the fault interval. For the case that rotating generators in northern Tohoku have been shut down, voltage during the grid fault can drop as far as 20% of the pre-fault value from Point B near the fault to Point A, which may lead to a shutdown in load operation. However, for the case that rotating generators are in operation, it can be seen that the extent of this voltage drop can be eased. These simulations indicate a need for studies on the operation of nearby rotating generators as inverter power supplies are increasingly added and for studies on maintaining power quality and supporting innovation in alternative technologies.

3.4 Analysis and evaluation technologies made possible by data and simulations

An effective approach to studying scenarios toward carbon neutrality and surrounding issues and countermeasures is to have many stakeholders bring in data so that quantitative evaluations can be performed repeatedly as needed against a variety of foreseen conditions and plans and policies can be studied. The development and use of simulation and evaluation technologies based on digital data play an important role in this process. Studies of the power grid in the bulk power system using large-scale numerical simulation tools must (1) analyze the necessity of coordinating location-specific power prices and distributed resources, (2) formulate policies for improving the flexibility of power demand, and (3) establish technologies for achieving both storage and energy security. In this way, with an eye to carbon neutrality, (1) multifaceted and quantitative issues based on numerical simulation models should be visualized and (2) policies evaluated as needed. In addition, data and simulation models from concerned stakeholders should be shared, investments should be made in facilities and innovative technologies taking into account the results of diverse evaluations and simulations associated with changing circumstances, and systems should be upgraded accordingly.

(1) Analyzing the necessity of coordinating location-specific power prices and distributed resources

There is a need to efficiently promote the effective use and enhancement of the transmission network to deal with an increase in renewable energy and distributed resources toward carbon neutrality and with rising demand driven by increasing electrification including the expanded use of EVs. Consequently, as reflected by the following key points, it would be effective here to make use of the cost

30 Electric Technology Research Association. 1990. "Instantaneous Voltage Drop Mitigation Methods", Vol. 46, No. 3. (in Japanese)

31 Hokuriku Electric Power Company. "Countermeasures to Instantaneous Voltage Drops at Customer Facilities." (In Japanese) Accessed on March 1, 2023. https://www.rikuden.co.jp/tairai/taisaku.html.

effectiveness of enhancing facilities, guidance in locating power supplies, etc.

・ Enhancement of transmission lines: Evaluating the cost effectiveness of enhancing transmission lines including the cost of measures for easing congestion in transmission lines (demand response (DR) is important.

・ Locational marginal price (LMP[32]): An important index for studying investment in transmission lines reflecting supply and demand conditions at different locations (high-priced location → cost effectiveness of enhancing power supplies is relatively high). Guidance in locating renewable-energy power supplies by visualizing LMP is an important issue in easing congestion in transmission lines.

Figure 3.13 shows an example of calculating LMP. Using simulation tools[33 34] based on a supply-and-demand model targeting Japan's nationwide power grid, these calculations assume a power supply configuration for achieving carbon neutrality[35]. In this way, the sharing of data on transmission facilities, types and locations of power generation, and distribution of power generation and demand (future image) makes facility enhancement even more effective and promotes system-related enhancements such as in the locational marginal pricing system.

(2) Formulating policies for improving the flexibility of power demand

When dealing with the increase in renewable energy power supplies toward carbon neutrality, improving the flexibility

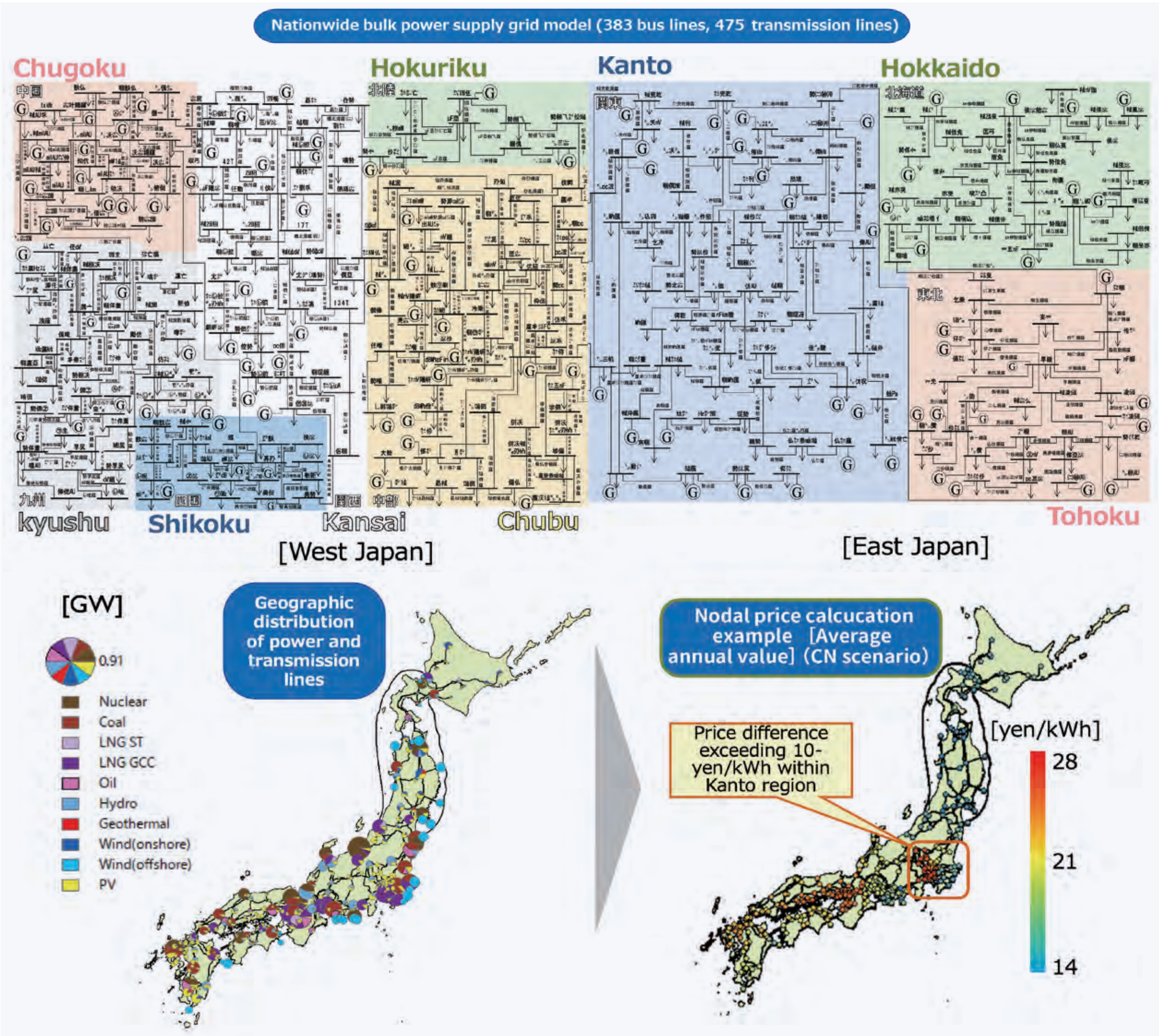


Figure 3.13 LDP calculations using large-scale power grid simulation tools

32 LMP: also called "nodal price"

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

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

35 Komiyama Ryoichi, and Fujii Yasumasa. 2022. "Power Supply and Demand Analysis for Power System Investment and Operational Optimization considering a Power Grid." Institute of Electrical Engineers of Japan (IEEJ), Annual Meeting Record, H6-3, March 1, 2022. (in Japanese) Prepared from analysis results in this paper.

of power demand such as by DR is an effective approach to economically coping with fluctuations in renewable energy. Figure 3.14 shows the results of calculating other amounts of substitute adjustment capacity for different ratios of DR in the power load. Here, as well, we performed our calculations through simulations based on the power supply-and-demand model described above. Specifically, we give upper and lower limits to DR on the power load level at each node and each point in time, minimize system cost under the assumption that the total annual power demand at each node is unchanged before and after DR, and determine the optimal amount of DR to be implemented at each node and each point in time. These calculations reveal that as the percentage of power load that can be used as DR increases, power storage facilities such as storage batteries can be replaced and reduced. With an eye to actual operation, it will be necessary to determine how flexibility in power demand can be increased through end-use technologies (EVs, heat pumps, building/home energy management systems, etc.) and behavior modification and how demand-side technologies can commit to supply-and-demand adjustments.

(3) Establishing technologies for achieving both storage and energy security

Given the occurrence of infrequent weather conditions such as a long-term drop in the output of renewable energy, the period and capacity of energy storage must be correctly determined, which must then be used as a basis for operating

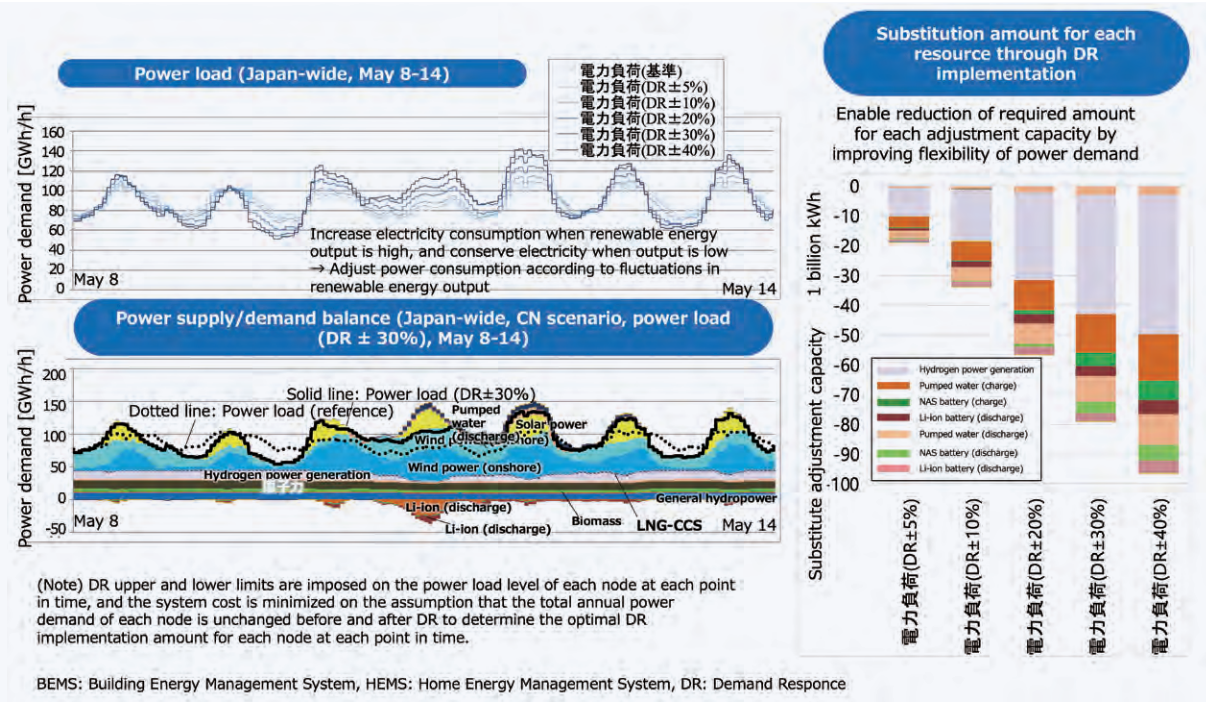


Figure 3.14 Other amounts of substitute adjustment capacity for different ratios of DR

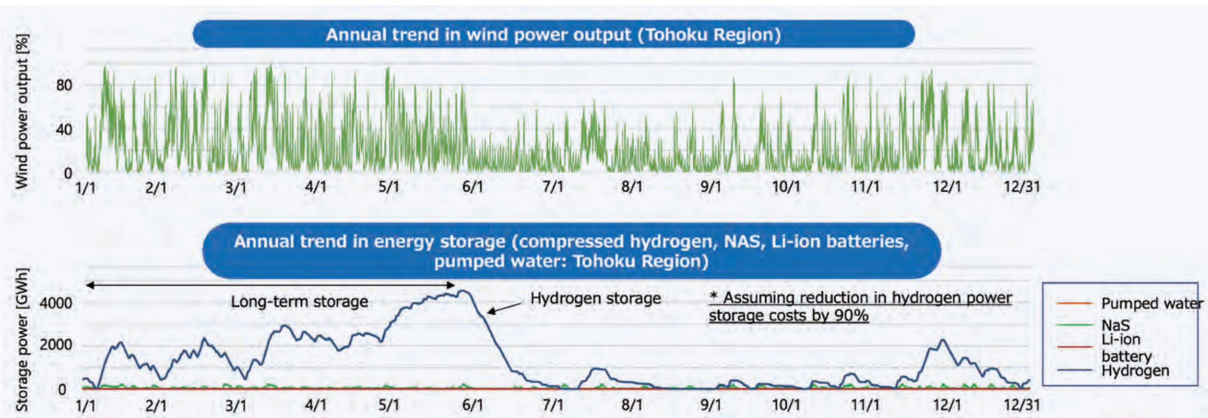


Figure 3.15 Example of annual transition in wind power generation and required energy storage[36]

36 Komiyama Ryoichi, Otsuki Takashi, and Fujii Yasumasa. 2015. "Energy modeling and analysis for optimal grid integration of large-scale variable renewables using hydrogen storage in Japan." Energy 81, 537-555.

optimal storage technologies and developing elemental technologies. Figure 3.15 shows an example of calculating the annual transition in wind power generation and required energy storage capacity. Here, we selected hydrogen storage for long-term storage of energy. Hydrogen storage comes in various formats such as storage in gas tanks or as a liquid medium, and here, a reduction in storage loss can be expected. In this simulation, under the premise that such hydrogen storage technologies have been achieved, we performed our evaluation considering technical options that could be applied to long-term storage (weekly, monthly, seasonally). However, the operational expenditure (OPEX) of long-term hydrogen storage is high, so storage by methanation or ammonia or storage by converting toluene, a liquid medium, to methylcyclohexane (MCH) through hydrogenation is potentially more economical. Additionally, while long-term battery power storage suffers from large loss, batteries are more suitable for frequent charging/discharging on a daily basis. To make the seasonal storage of renewable energy practical, initial investment must be significantly held down since there are few opportunities for charging/discharging and profit opportunities are limited.

3.5 Chapter 3 summary

1. As a result of revising energy scenarios in the face of surging fuel prices driven by international circumstances, the following measures should be promoted by 2030 to achieve a carbon neutral scenario: (1) accelerate the deployment of renewable energy (increase solar power generation by 62 GW and wind power generation by 15 GW) and secure decarbonized power supplies such as by operating all existing nuclear power plants, (2) solve issues related to waste and the deployment environment in the short term following the deployment of PV equipment, (3) operate hydrogen and ammonia power generation in excess of 10 GW, (4) use heat from fossil-fuel power generation through cogeneration, etc., and (5) insure energy resilience and security taking into account the rare occurrence of ongoing windless and cloudy weather, insufficient fuel, and natural disasters. Additionally, toward the years 2040–2050, developments and investments should be made and innovation fostered in (1) the practical use and spread of CO_2 capture through DAC and (2) the manufacturing of synthetic fuel from captured CO_2 and its use in the transport and industrial sectors.

2. The following measures should be promoted to deal with issues in the bulk system in the face of a rapid expansion of renewable energy: (1) increase the number of thermal-power and nuclear-power rotating generators and introduce inertia control in distribution resources to deal with frequency degradation caused by drops in inertia, (2) use local resources and prevent grid congestion to deal with frequency fluctuations caused by insufficient adjustment capacity, (3) boost power transmission by HVDC and enhance control systems for local power storage and EVs to counteract drops in grid stability, and (4) develop advanced inverter control techniques and implement high-speed (on the level of seconds) integrated control.

3. In conducting studies on the bulk system toward carbon neutrality, it is essential that the data and simulation models of many stakeholders including power generation, transmission, and distribution operators and consumers be shared and that simulation and evaluation technologies be developed and used. Looking to carbon neutrality, (1) issues should be visualized in a multifaceted and quantitative manner based on numerical simulation models, and (2) policies should be evaluated as needed, investments should be made in facilities and innovative technologies as circumstances change, and systems should be upgraded.

At Hitachi-UTokyo Laboratory, we will continue to develop evaluation/simulation technologies for energy scenarios, evaluate carbon-neutral transition scenarios based on changes in the domestic and international situation, and select and develop innovative technologies for solving energy-system issues. We will also propose a platform for sharing data and analysis models among a wide range of stakeholders.

Chapter 4 Role of local communities in era of renewable energy as main power source

"Local communities" are the social infrastructure that support the lives of people and society, including families, businesses, industries. They make demands of energy systems. As shown in Figure 4.1, it is expected that in an era in which renewable energy is the main power source, local communities will receive stable energy supplies from bulk power systems. At the same time, they will create "adjustment capacity" that contributes to adjusting the supply and demand of power through data-based "intelligent energy use." Local communities are expected to become the agents that realize S+3E[37]. Here, "adjustment capacity" refers to demand for power that can be time-shifted without loss of convenience or functionality.

In Version 4 of the Proposal released last year, we proposed the creation of value in regions through intelligent energy use by implementing a control and coordination platform that supplies adjustment capacity to bulk power systems. We also evaluated adjustment capacity and the value created by focusing on detached residential houses[38]. In this version of the Proposal, Version 5, we extend the targets of evaluation to the entire residential sector, including apartment complexes, and the business sector, and evaluate the adjustment capacity that can be created from regions and the value of the adjustment capacity. In the midst of the changing energy situation, we also propose measures for regional decarbonization that pursues a win-win relationship for the energy supply side and demand side. We also discuss who is expected to take what actions, and propose measures that should be prioritized, taking into account the characteristics of each region and individual actors.

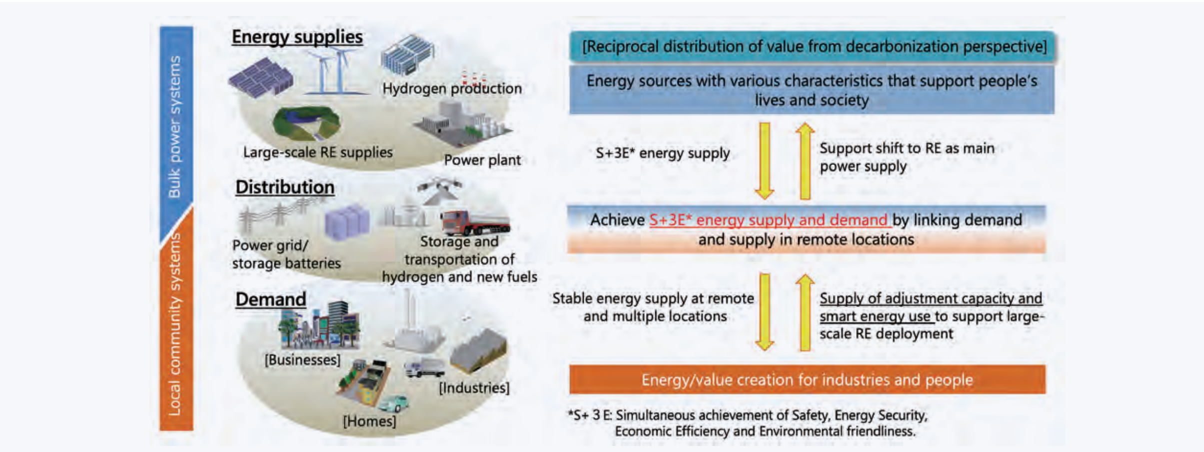


Figure 4.1 Positioning of bulk power system and the local community

4.1 Changes in situation surrounding local communitie

Soaring energy prices, which became apparent in the aftermath of the invasion of Ukraine, are putting pressure on household budgets and company profits in local communities. Tightened supply and demand for power has also become tangible, and in June 2022, the first ever "warning of tight electricity supply-demand situation" was issued by the Japanese government. In a subsequent questionnaire survey, results showed that approximately 90% of the consumers who have considered taking energy-conservation actions in advance had done so. However, the reality is that the

37 Simultaneous achievement of Safety, Energy Security, Economic Efficiency and Environmental friendliness.

38 Hitachi-UTokyo Laboratory, 2022. Proposal "Toward Realizing Energy Systems to Support Society 5.0 (Ver. 4)".

number of such actions is gradually decreasing day by day[39], and there are limits to energy-conservation efforts based on consumers' good intentions. Local governments are engaged in efforts to make renewable energy the main energy source. These efforts include the Tokyo Metropolitan Government's passage of an ordinance amendment requiring the installation of solar panels in new detached residential houses and other new construction[40]. However, opposing voices have emerged because of the cost burden and the problem of disposing of large amounts of solar panels.

Amid this situation, the Ministry of Economy, Trade and Industry released "The Basic Policy for the Realization of GX[41]" and organized the "Study Group on Next-Generation Distributed Energy Systems[42]", leading to discussions on distributed energy systems and reorganization of electricity markets. Adjustment of supply and demand by small- and medium-sized consumers are gaining attention. In this area, the U.S. Federal Energy Regulatory Commission (FERC)'s Order 2222[43] was issued in 2020, and institutional development is being carried out overseas, such as preparations for implementation in various regions. Japan is also in a situation where the establishment of mechanisms to promote the participation of small- and medium-sized consumers in supply-demand coordination should be accelerated.

4.2 Cooperative potential of local communities for contributing to stabilization of power supply and demand

The Hitachi-UTokyo Laboratory has proposed a "control and coordination platform" that achieves "coordination of supply and demand with participation of all actors," including countless small- and medium-sized consumers that make up the local community, through data collaboration between distributed resources and bulk power systems. Figure 4.2 presents an overview of the coordination and control platform. The platform connects energy storage equipment owned by consumers, such as heat pump (HP) water heaters, electric vehicles (EVs), and storage batteries. In normal times, the platform operates these equipment through automation that supports coordination and in connection with market prices

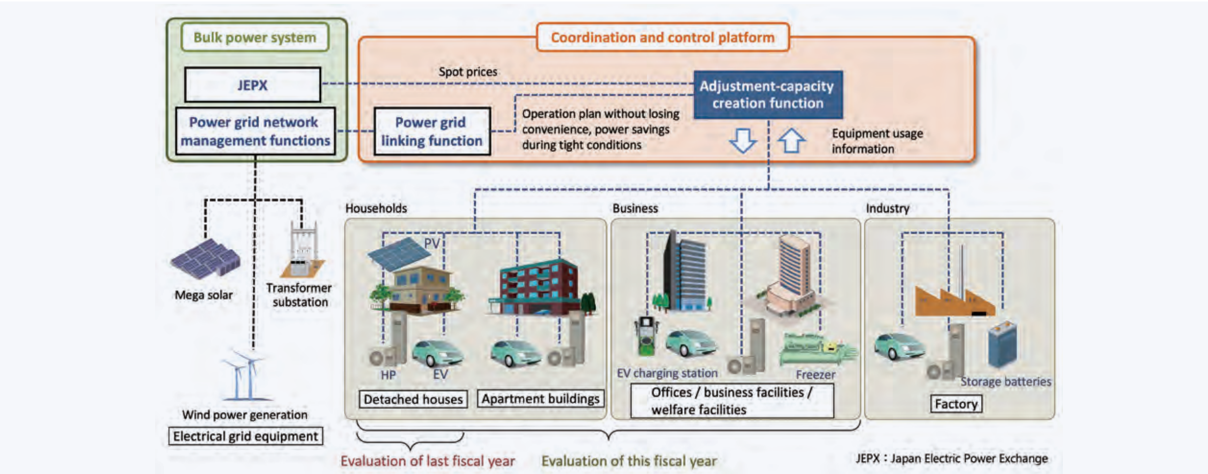


Figure 4.2 Control and coordination platform

39 Agency for Natural Resources and Energy, 2022. "Power Supply and Demand Measures in FY2022." (Accessed on March 1, 2023) https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/pdf/052_04_03.pdf

40 Bureau of Environment, Tokyo Metropolitan Government, 2023. "Information on System Reforms." (Accessed March 1, 2023) https://www.kankyo.metro.tokyo.lg.jp/climate/solar_portal/program.html

41 Ministry of Economy, Trade and Industry, 2023. "'The Basic Policy for the Realization of GX' approved by the Cabinet." (Accessed March 1, 2023) https://www.meti.go.jp/press/2022/02/20230210002/20230210002.html

42 Agency for Natural Resources and Energy, 2022. "Establishment of Study Group on Next-Generation Distributed Energy Systems." (Accessed March 1, 2023) https://www.meti.go.jp/shingikai/energy_environment/jisedai_bunsan/pdf/001_04_00.pdf

43 Federal Energy Regulatory Commission. 2020. "FERC Order No. 2222: A New Day for Distributed Energy Resources" (Accessed March 1, 2023) https://www.ferc.gov/sites/default/files/2020-09/E-1-facts_0.pdf

within the range of maintaining convenience. The system as a whole absorbs fluctuations in supply and demand due to weather and time, and contributes to reduction in renewable energy output control and lower fuel consumption by the power supply as whole. In addition, during abnormal times—for example, when the output of renewable energy is greatly reduced or when the power supply is insufficient due to shutdown of a large-scale power plant—the system provides adjustment capacity to bulk power systems by quickly adjusting demand on the same day, thereby preventing supply and demand from becoming strained and contributing to the prevention of power outages. This platform, which creates a win-win relationship between the power supply side and the demand side, is already technologically feasible. It can be implemented through the participation and cooperation of many players. The social implementation of this platform should be a matter of urgency in order to prepare for future changes in the energy system, as exemplified by the full-scale adoption of EVs.

To aid in decision-making for the social implementation of the coordination and control platform and to gather participants in intelligent energy use, the Hitachi-UTokyo Laboratory is conducting analysis and evaluation of the social benefits and business potential of the platform in 2030. As shown in Figure 4.2, in Version 4 of the Proposal released last year, for the residential sector, the evaluation focused on detached residential houses. In this version, the analysis encompasses the entire residential sector, which includes apartment complexes, and the business sector, which includes offices, hotels, and welfare facilities. The evaluation methods and results are described below.

First, using Figure 4.3, we explain the method of evaluating the adjustment capacity that can be created by the coordination and control platform. For the evaluation, analysis is carried out using the following three steps. First, a supply-demand simulation of the power grid is conducted to calculate spot market prices, which are the wholesale market prices of electricity. Second, based on the calculated daily spot market prices, plans for operating HP water heaters and for charging/discharging EVs are created, and citywide-scale adjustment capacity is calculated. The analysis targets are Machida City in Tokyo and Iwaki City in Fukushima Prefecture. In Machida City, the analysis covers HP water heaters and EVs in the residential sector (detached residential houses and apartment complexes). In Iwaki City, in addition to HP water heaters and EVs in the residential sector, the analysis includes the aggregation of HP water heaters in the business sector. Two cases are assumed as analysis conditions. Case 1 assumes night-time operations in which HP water heaters store hot water and EVs are charged during the night. Case 2 assumes optimized usage: Demand for hot water and for EV use are optimized; HP water heater operations and EV charging/discharging are also optimized based on spot prices. Finally, in step 3, the values calculated on a citywide scale is converted to a nationwide scale to evaluate the adjustment capacity and benefits created in the Japan as a whole. Assumptions used in this evaluation about the number of households, total floor area of the business sector, and the adoption rates of HP water heaters, and EVs in 2030 are explained in the Appendices.

Figure 4.4 shows the evaluation results for the residential sector in Machida City. Figure 4.4(a) shows the results for detached residential houses, and Figure 4.4(b) shows the results including apartment complexes. From top to bottom, the graph shows the daily spot price, demand for power in the night-time operations case (Case 1), and demand for power in the optimized case (Case 2). March 6 is chosen as a representative day. On that day, excessive power is generated from solar power generation during the day, and the spot price falls to 0 yen/kWh. In the night-time operation case (Case 1), operation of HP water heaters and charging of EVs are carried out during the night-time from late night

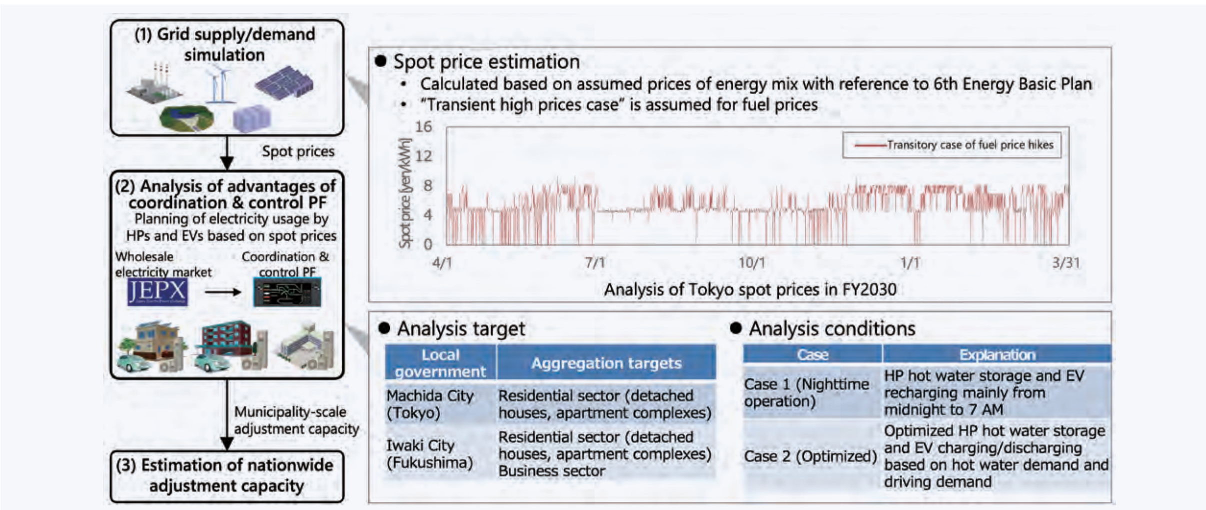


Figure 4.3 Adjustment capacity evaluation methodology

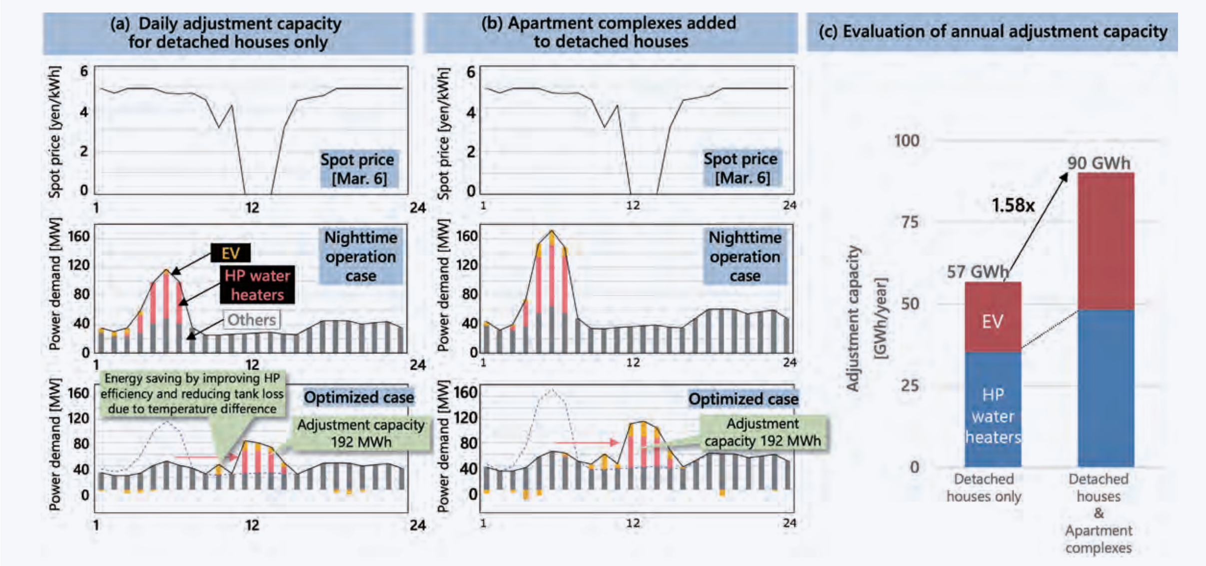


Figure 4.4 Example of aggregation in residential sector (2030, Machida City)

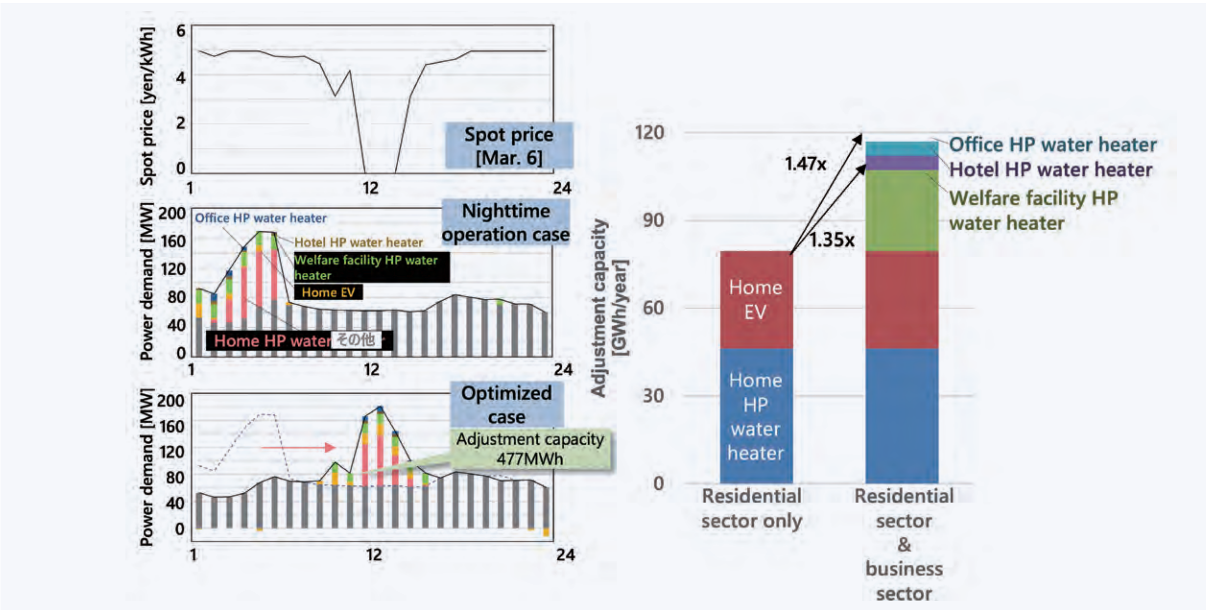


Figure 4.5 Example of aggregation in residential and business sectors (2030, Iwaki City)

to early morning. On the other hand, in the optimized case, power demand by HP water heaters and EVs are shifted to the daytime, when spot prices are lower. At that time, as can be seen by comparing Figures 4-4(a) and 4-4(b), the time-shiftable adjustment capacity is 192 MWh in the case of detached residential houses. The time-shiftable adjustment capacity expands to 312 MWh when apartment complexes are included. Because such adjustment capacity depends on the season and weather, evaluation of annual adjustment capacity is necessary. Figure 4.4(c) shows a comparison of the annual adjustment capacity. Including apartment complexes in addition to detached residential houses, the annual adjustment capacity expands 1.58-fold. Also, the efficiency of HP water heaters improves as the outdoor temperature rises. In addition to this fact, shifting the hot water storage time from night-time to daytime also reduces heat loss in hot water storage tanks. This has the energy-saving effect of reducing the power demand needed for hot water storage. Time-shifting power demand based on the spot price as described above can contribute to reduced procurement costs for aggregators and lower electricity bills for households and to more stable and economic supply and demand of power for society as a whole.

Next, Figure 4.5 shows the evaluation results of analysis of the residential sector and business sector in Iwaki City. For the business sector, we focus on demand for hot water in offices, hotels, and welfare facilities with the assumption that all hot water demanded can be heated and stored by HP water heaters. Figure 4.5(a) shows the power demand on March 6, and Figure 4.5(b) shows the comparison of annual adjustment capacity. Even assuming 100% adoption of HP water heaters, the adjustment capacity generated

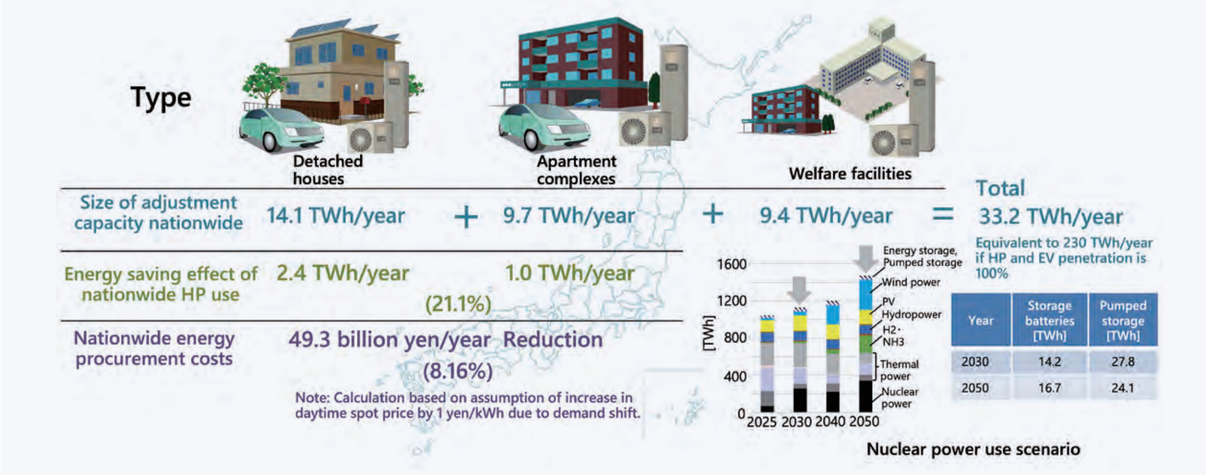


Figure 4.6 Adjustment capacity generated from regions in Japan

by offices, hotels, and welfare facilities is less than 50% of that of the residential sector. However, compared to offices, welfare facilities have greater demand for hot water and are fewer in number. Furthermore, because the installation of hot water storage tanks is considered to be relatively easy, subsidies that contribute to decarbonization and the creation of adjustment capacity can be efficiently used. Therefore, the adoption of HP water heaters in the business sector, especially in welfare facilities, should be supported.

From the results shown above, we calculate the adjustment capacity that can be created in entire Japan from local communities. Details of the calculation methods are explained in the Appendices. As shown in Figure 4.6, the adjustment capacity that can be created nationwide in 2030 is calculated to be 33.2 TWh per year. This adjustment capacity utilizes HP water heaters and EVs in buildings and apartment complexes and HP water heaters in welfare facilities. This figure is more than twice the amount of electricity discharged from storage batteries used for supply-demand balance in the "use of nuclear power" scenario in Chapter 3. Consumers' electricity bills are also lowered, as operating HP water heaters during the day results in energy-saving effect of 3.4 TWh per year. Electricity can thus be procured at lower spot prices and the energy procurement costs of aggregators can be reduced by 49.3 billion yen. For society as a whole, because the installed capacity necessary for pumped-storage hydroelectricity and storage batteries and charging/discharging losses can be reduced, the cost of renewable energy integration can be greatly curbed. Furthermore, if the penetration of HP water heaters and EVs further increases, assuming 100% penetration by 2050, the adjustment capacity will reach 230 TWh per year nationwide, promising to contribute to further expansion of the deployment of renewable energy.

4.3 Measures to facilitate energy transition in local communities

To expand the adjustment capacity created in local communities, it is essential to accelerate the deployment of EV chargers and HP water heaters that support time shifting of demand. However, as shown in Figure 4.7(a), the adoption of EVs lags in Japan behind that of other developed countries and regions. In addition, as shown in Figure 4.7(b), about 40% of households in Japan live in apartment complexes, and installing EV chargers in existing apartment complexes is not easy. According to the survey results shown in Figure 4.7(c), more than 80% of EV users living in apartment complexes must charge their EVs at nearby charging stations on weekends and on other non-workdays, a major barrier to the adoption of EVs. On the other hand, there have also been examples of communal charging facilities introduced in existing apartment complexes after the understanding of residents was obtained[44]. To accelerate the deployment of EV chargers, it is necessary to introduce and expand such success examples, in addition to providing financial subsidies.

44 Japan Broadcasting Corporation (NHK), 2022. "Electric vehicles: I want to charge at my apartment! What are the Challenges of EV charging?" (Accessed March 1, 2023) https://www3.nhk.or.jp/news/html/20220331/k10013559631000.html

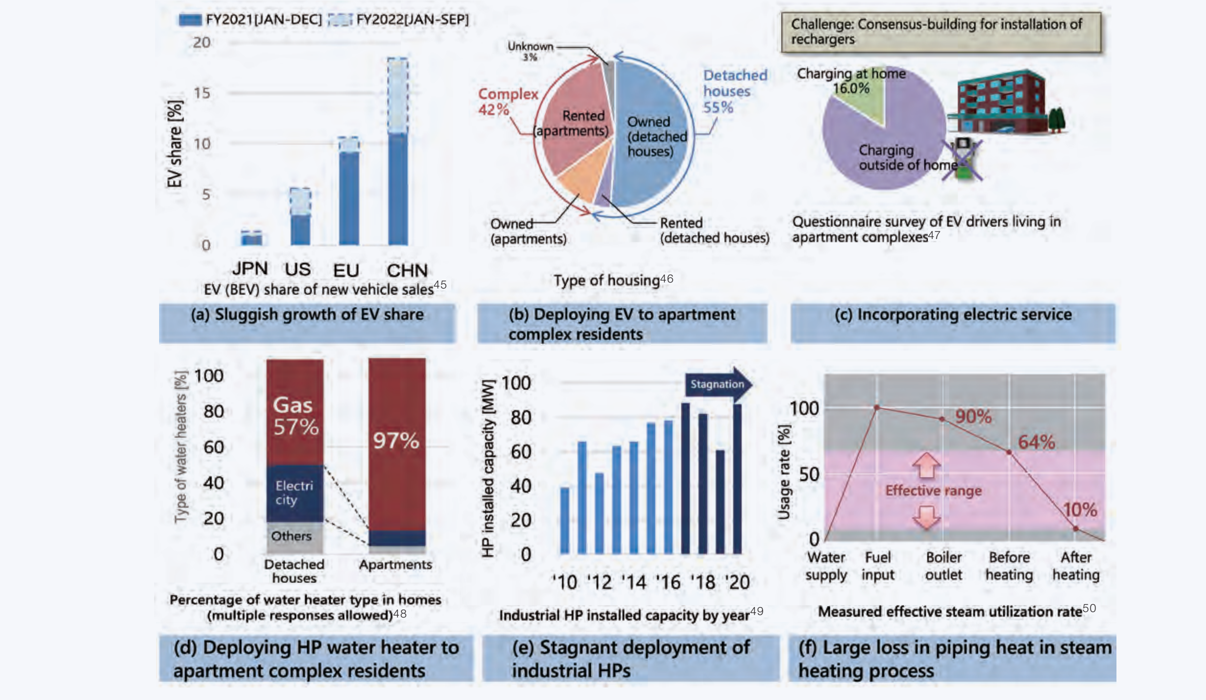


Figure 4.7 Current state and challenges of energy use related to expansion of regional adjustment capacity

Concerning heat pumps (HPs), as shown in Figure 4.7(d), in general gas water heaters are still used in apartment complexes. The deployment of HP water heaters in apartment complexes and in the business sector, in addition to detached residential houses, is necessary. To achieve this, subsidies from the national and local government are essential.

To promote the decarbonization of society as a whole, it is also important to promote the electrification of heat sources in industries, which is not included in the analysis and evaluation of adjustment capacity generation in this Proposal. However, the electrification of heat sources in the industrial sector is a challenge that cannot be solved by economic support alone. As shown in Figure 4.7(e), the deployment of HP water heaters in industries has stagnated. From interview surveys conducted by the Hitachi-UTokyo Laboratory, we learned that companies in regions had insufficient understanding of their own energy use and ability to plan and design electrification. In the heating process using steam, for example, heavy energy loss occurs in the pipes. To address this issue, phased reform and investments are possible. These solutions include promoting electrification from the demand for heat at the end of the pipes. Providing engineering support with solution proposals such as this example is critical[51]. Furthermore, we believe that creating systems for sharing and expanding best practices will accelerate the transition in industries.

While promoting electrification is fundamental for CN, it is a reality that there are regions and industries where electrification is difficult. Instead of denouncing or excluding such regions and industries, means to advance CN in Japan as a whole, which combine emissions trading and negative missions, should be explored. In industries, it is

45 Created based on “EV-DAYS” (November 2022), TEPCO Energy Partner, https://evdays.tepco.co.jp/entry/2021/09/28/000020 (accessed 1st March 2023)

46 Created based on “Material 4 Residential status by household type,” MLIT https://www.mlit.go.jp/common/000145916.pdf(accessed 1st March 2023)

47 Created based on “Is EV charger necessary for condominiums and apartment complexes? We explain the benefits of installation!”, ENECHANGE https://prtimes.jp/main/html/rd/p/000000049.000065945.html (accessed 1st March 2023)

48 Created based on “2019 – Understanding the current energy situation in Japan,” Ministry of the Environment https://www.env.go.jp/earth/ondanka/kateico2tokei/2019/result3/index.html (accessed 1st March 2023)

49 Created based on “FY2020 results of survey on amount of industrial heat Pumps installed,” Japan Electro-Heat Center (accessed 1st March 2023)

50 Created based on “Industrial heat pump usage guide,” Japan Electro-Heat Center

51 Industrial Science and Technology Policy and Environment Bureau/Agency for Natural Resources and Energy, 2022. “Study toward formulation of a clean energy strategy (1) (Ensuring energy security and efforts for decarbonation)”. (Accessed March 1, 2023) https://www.meti.go.jp/shingikai/sankoshin/sangyo_gijutsu/green_transformation/pdf/006_01_00.pdf

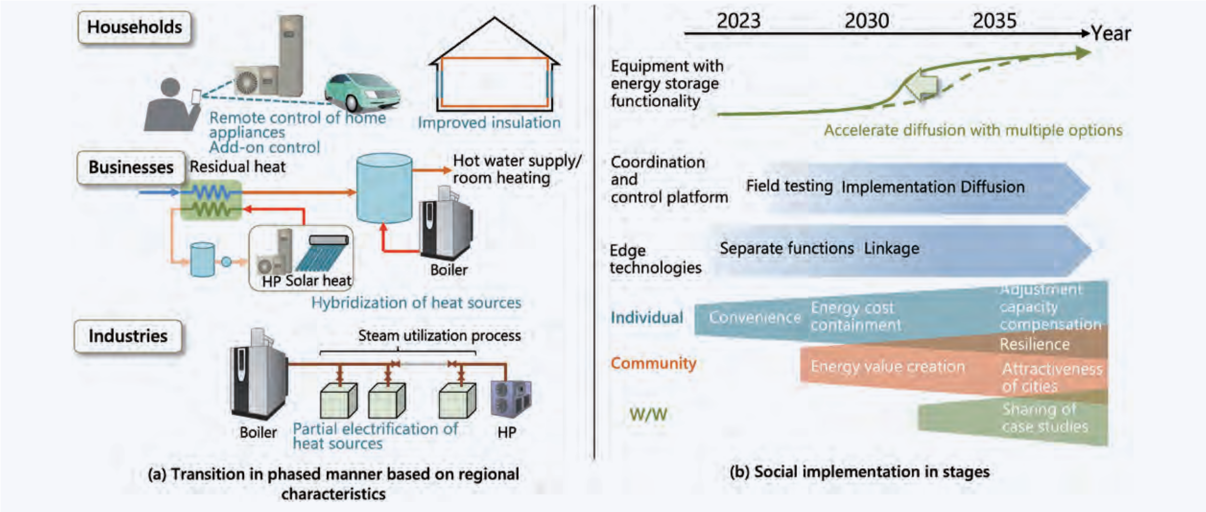


Figure 4.8 Facilitation of energy transition in a phased manner

also important to advance the visualization of CO_2 emissions not only on the production side but also the consumption side, and to have all stakeholders, including final consumers, recognize and understand environmental value in the process from upstream to downstream of the supply chain.

From the above findings, we describe the conditions and challenges in energy use and measures to facilitate the transition in regions. It is difficult to bring about major social changes at once. However, as shown in Figure 4.8(a), we believe that it is possible to carry out the transition in a phased manner. For example, in households, methods such as remote control of home appliances and providing add-on functions to already installed appliances will be effective. In addition, depending on the region, improving home insulation can be effective in saving energy.

As shown in Figure 4.8(b), social implementation should proceed in a phased manner. First, the adoption of equipment with energy storage function that are effective for adjustment capacity of power demand, such as EVs and HP water heaters, should be accelerated by providing multiple options. In conjunction, social transition can be facilitated while increasing the value gained by individuals and regions by socially implementing the coordination and control platform and edge technologies in a phased manner. The situation in which a large portion of society relies on renewable energy with fluctuating output, especially solar power, is also seen in Asian countries. Solutions to Japan's challenges can be also applied to these countries. By sharing case studies of energy transition with other countries, Japan can make new contributions to the international community.

In the transition to decarbonization described above, it is critical that stakeholders in the region play their respective roles and engage in efforts. In particular, the understanding and cooperation of residents is essential. It is desirable that everyone responsible for the local community participates in the transition; however, it is a reality that some residents are not comfortable with digital technology. On the other hand, there are cases where the participation of even some participants brings benefits all participants. For example, introducing digital tickets can bring advantages to those who do not use them by shortening the physical line for the

Table 4.1 Actions to facilitate energy transition

Action		Leader	Participant
Knowing current state of energy use	Creation of learning opportunities	Regional banks, chambers of commerce	Community residents, students, local industry/business owners/employees, local industry associations
	Support analysis	National and local governments, ventures	
Defining community's vision	Discussions of decarbonized future of community	Regional banks, local governments	
	Decision-making by many stakeholders	Local governments, chambers of commerce	
Social transition that proceeds based on win-win philosophy	Cross-industry collaboration through data linkages	Energy operators, local governments	
	Two-way sharing of benefits		

box office and the line to enter the venue[52]. It is important to proceed with social implementation for decarbonization based on such an approach.

Also needed are leaders when new efforts begin. The stakeholders shown in Table 4.1 should become leaders, learn about the conditions surrounding energy use together with participants, and determine the vision of the region. They are to advance transition in the local community while creating win-win relationships between the energy supply side and demand side.

There are many cases where social implementation efforts fade away after their demonstration as a national project without taking root in regions. To avoid this outcome, local governments have a major role to play. It is critical that they transcend organizational boundaries and take the lead to promote the participation of stockholders in the region and form local value cycle systems, as exemplified by Stadtwerke municipal utilities in Germany.

From a medium- to long-term perspective, developing leaders and education to increase residents' understanding and maintaining and managing small-scale solar power generation facilities installed in large numbers after the introduction of the feed-in tariff (FIT) system are regional issues. Creation of learning opportunities through industry-academic-government collaboration and the development of maintenance system for renewable energy resources should be carried out.

4.4 Chapter 4 Summary

1. To shift to renewable energy as the main power source, local communities are expected to be the main actors that bring about S+E3 energy supply and demand using a supply-demand coordination mechanism in which everyone participates.

2. With coordinated operation of equipment with energy storage functions such as HP water heaters and EVs, the demand adjustment potential that can be created by local communities in 2030 is 33.2 TWh per year on a national scale. To realize this, it is necessary to realize widespread adoption of equipment with the necessary functions and early social implementation.

3. While promoting electrification is fundamental for CN, it is a reality that there are regions and industries where electrification is difficult. Instead of denouncing or excluding such regions and industries, methods to advance CN in the country as a whole, which combine emissions trading and negative missions, should be explored.

4. To facilitate the transition to decarbonization in local communities, support for phased transitions, participation of all, and clarification of roles are critical. In particular, local governments play a major role, and a locally based value cycle system should be conceived and formed at an early stage.

52 Asoview Inc, 2023. "Asoview provides electronic tickets to Kairakuen Garden, one of Japan's three most famous gardens ~Tickets for admission to the garden will be on sale from Friday, February 17 to improve convenience and promote visits to the garden." (Accessed March 1, 2023) https://www.asoview.co.jp/news/5546/

Chapter 5 Direction of energy system reform for carbon neutrality

In this chapter, we present challenges that have emerged because of changes in international affairs since Chapter 4 in the Proposal was published. We also present the direction of energy system reform to overcome these challenges.

5.1 Review of conditions following Japan's electricity deregulation

The Great East Japan Earthquake on March 11, 2011, accelerated debate on energy system reform. The ensuing electricity system reform in the country, consisting of three stages—(1) expansion of wide-area power grid operation, (2) full liberalization of the retail electricity market, and (3) neutralization of the power distribution/transmission sector from the generation and retail sectors through legal separation—reached a conclusion in April 2020.

Under the Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) and the Japan Electric Power Exchange (JEPX), a system is formed that aims to achieve the merit order method (lowering the cost of power generation from a nationwide perspective by using the previous day's market to generate power in order of sources with low generation costs (variable costs)). At the same time, a system for spreading renewable energy is being formed by using measures including a feed-in tariff (FIT) system for renewable energy. The proportion of renewable energy in power generation has greatly increased. And, as a result of the entry of more than 700 companies into the energy retail market, the choices available to consumers have expanded.

On the other hand, due to the inducements resulting from trading at short-term marginal costs, the recoverability of expenses (especially fixed costs) by power generation operators has fallen. In addition, the profitability of thermal power generation has dropped as kilowatt hours become reduced with the expansion of renewable energy in the energy mix, leading to an increase in power facility suspensions or shutdowns (Figure 5.1).

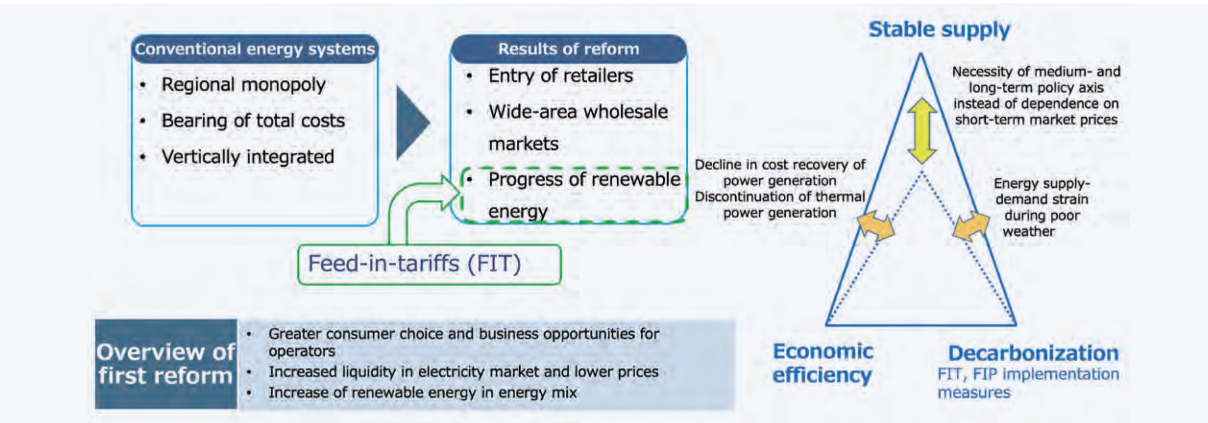


Figure 5.1 Overview of first energy system reform

Figure 5.2 summarizes the recent situation surrounding consumers since fall 2021 and exacerbated by Russia's invasion of Ukraine. The prices of imported resources have soared, impacting power procurement severely. Energy retailers shutting down or declaring bankruptcy are increasing. Furthermore, as decarbonization accelerates, the need to investigate the transition to carbon neutrality by 2050 arises. From these circumstances, the following issues have emerged: (1) ensuring energy supply: in the midst of short-term market volatility, ensuring that stable power supply capacity is secured, regardless of whether market prices are low; (2) maintaining power grid: maintaining power grid facilities so that large-scale deployment of renewable energy is possible; (3) ensuring energy supply: responding to fuel procurement risks.

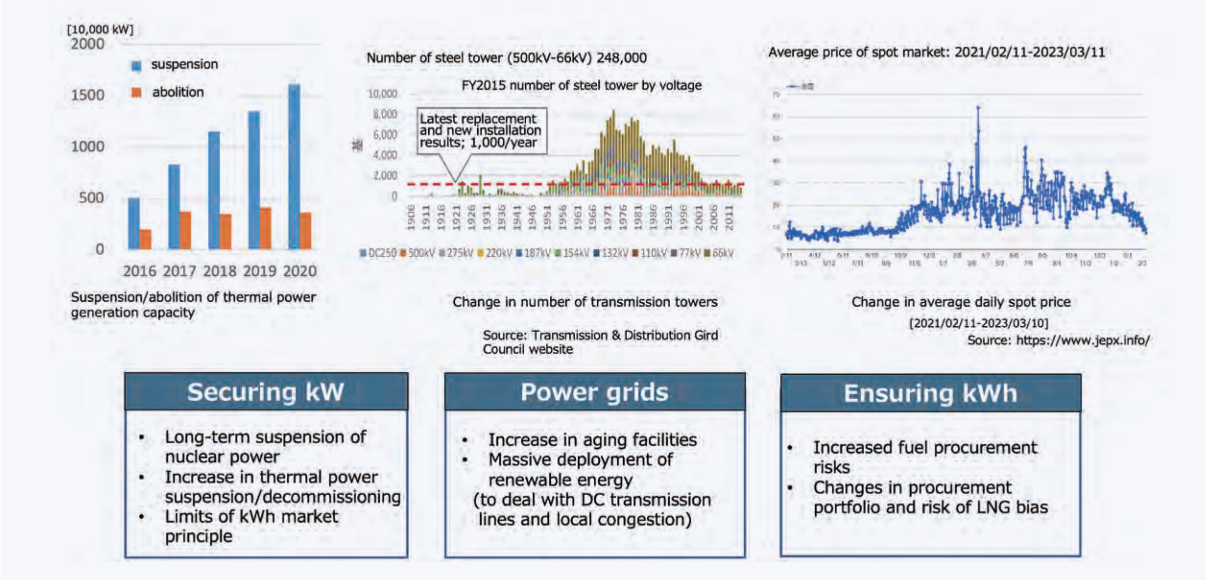


Figure 5.2 Recent events surrounding demand[53]

5.2 Key points for advancing second energy system reform

Figure 5.3 shows the new challenges and direction for the second energy system reform based on recent events. The following three new challenges can be observed from the current system:

i. Excessive reliance on short-term market prices: Because the design of the system is centered on spot prices in the wholesale electricity trading market, measures to ensure stable energy supply in the medium- to long-term and decarbonization are insufficient.

ii. Lack of inter-market coordination: Because markets, such as capacity markets and supply-demand adjustment markets, have formed from the perspective of economic efficiency, revolving around spot price signals, conflicts with medium- to long-term policy objectives, such as stable supply and decarbonization, have become apparent.

iii. Large-scale deployment of variable renewable energy: For further deployment of renewable energy sources that are ubiquitous in a region, further measures such as advanced power grid operation and maintenance and ensuring adjustment capacity are needed.

Based on these challenges, we propose the following three key points for the direction of the second energy system reform.

1. Development of medium- to long-term policy axis: (1) Clarify the distinction between economic efficiency, which seeks to achieve short-term merit order, and medium- to long-term policy objectives of stable energy supply and decarbonization, and (2) further study of market design, which has pursued efficiency to date.

2. Reconstruction of role of markets: (1) correction of market distortions, (2) transparency and disclosure of power supply operating conditions, (3) comprehensive monitoring of markets

3. Reconstruction of system of consumer sovereignty: (1) mechanisms based on consumers' discretion, (2) integration with emissions trading system

53 Agency for Natural Resources and Energy, 3 March 2022. "Future Thermal Power Policy." (Accessed March 9, 2023); Transmission & Distribution Gird Council, 24 January 2022. "Approaches to facility renovation due to aging of power transmission and distribution facilities" (2023) (Accessed March 9, 2023); JEPX information, https://www.jepx.info/ (2023) (Accessed March 9, 2023)

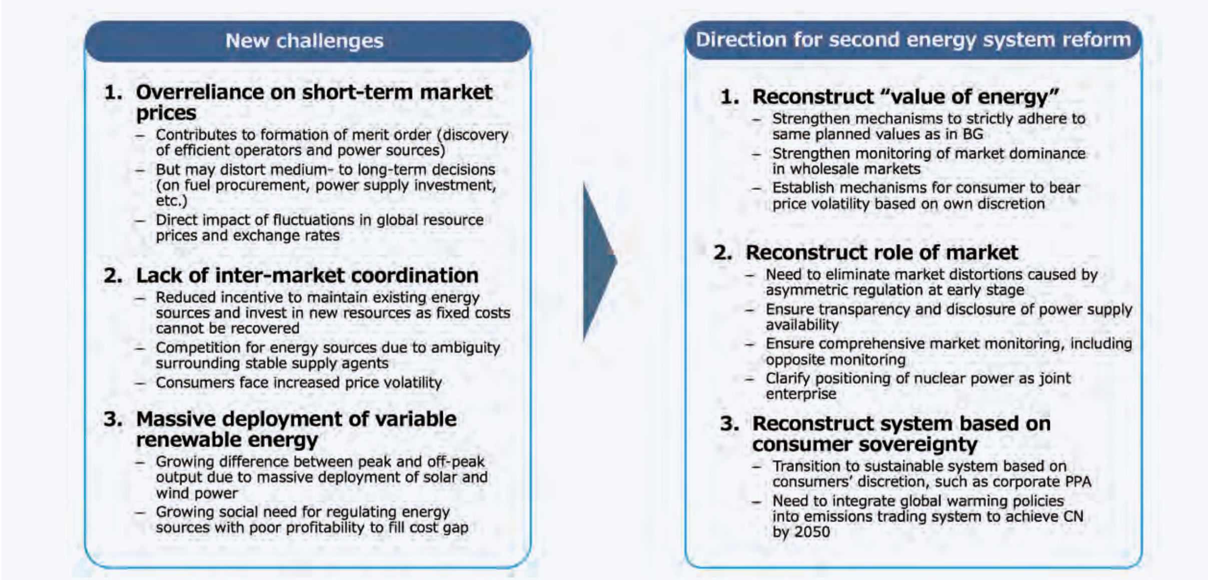


Figure 5.3 Direction of second energy system reform

5.3 Chapter 5 Summary

1. A medium- to long-term policy axis that does not rely just on short-term market prices is critical. With short-term market signals, securing energy supply capacity and procurement of resources for long-term decarbonization investments and stable supply are difficult. Policy discussions focused on transition while taking into account the distinctive circumstances of Japan, an island nation with scarce energy resources, are required.

2. Reconstruction of the role of markets
It is necessary to break away at an early stage from the current situation where each market is asymmetrical—in other words, where equivalent regulations are not imposed on both sides. To achieve this, power supply operation conditions should be made visible and monitoring of the markets should be thorough.

3. Reconstruction of system led by consumers
Construction of sustainable system that stimulates active environmental investment by consumers. Concerning measures (FIT/FIP, etc.) related to global warming, achieve (1) system based on consumers' discretion and (2) integration with emissions trading system.

Hitachi-UTokyo Laboratory's actions
Hitachi-UTokyo Laboratory will contribute to the development of a consumer-led system through digital technology. This system will enable data-based visualization of CO2 emissions and provision of information from consumers' perspective on carbon neutrality.

Chapter 6 Finding pathways toward energy transitions while maintaining QoL (Chapter 6)

In this chapter, we analyze changes in non-energy factors, such as lifestyles and local government measures related to the energy transition, and present co-simulation in which the results of the analysis are reflected in energy supply/demand.

6.1 Co-simulation of social changes associated with energy transition and energy supply/demand

The energy transition will be accompanied by many social changes and changes in social behavior. However, there are many uncertain elements, and the energy transition is considered at present to be vague. The coupling of two simulation models is described below. The society model simulates social changes related to energy transition. The energy supply/demand simulation reflects energy supply/demand trends presented by society.

Figure 6.1 shows the two models used in the co-simulation. The society model simulation of energy transition uses the policy proposal AI[54] developed by the Hitachi Kyoto University Laboratory. The policy proposal AI can output, with experts, various factors in society, and present a forecast-based vision of society based on the assumption that these factors are approximately related to the current situation. The obtained vision of society is expressed as amounts of changes in each factor from the initial time of the simulation. Evaluation points indicate how the amounts of changes contribute to the desired policy direction. Meanwhile, the energy supply/demand simulation uses the energy/economic model presented in Chapter 3.

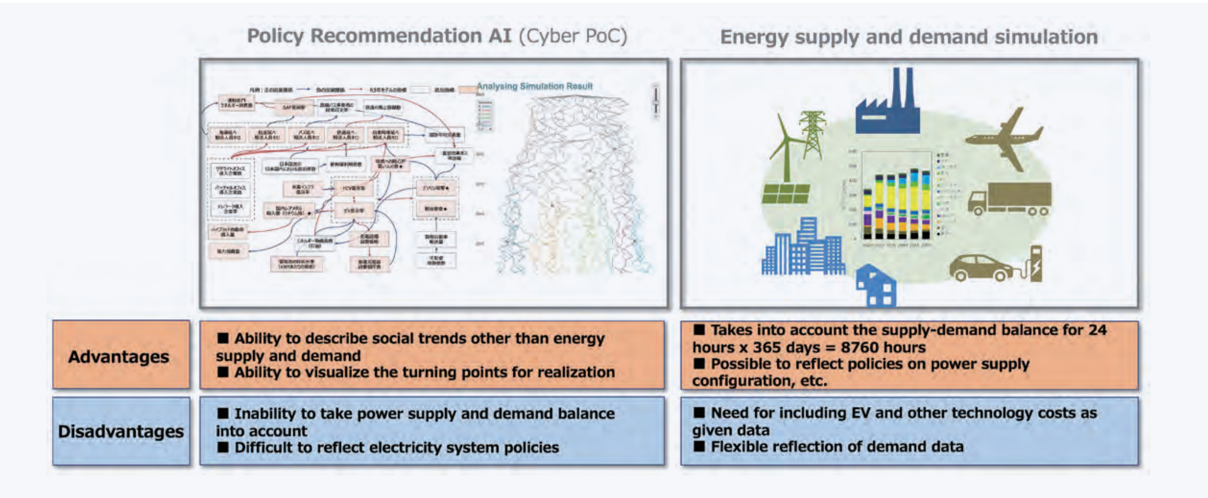


Figure 6.1 Overview of policy proposal AI and energy supply/demand simulation

To carry out the co-simulation, improvements to the policy proposal AI and the energy supply/demand simulation are added, as shown in Figure 6.2.

(Improvement 1) Energy-related factors are added to the society model[55] that forms the foundation of the policy proposal AI.

(Improvement 2) The rate of change of energy-related factors was analyzed and trends on when and how energy factors change were identified.

(Improvement 3) Referencing the trends in energy factor changes extracted in Improvement 2, the time period and scale of innovation expansion were reflected in the conditions of the energy supply/demand simulation.

54 Fukuda, Manaki, Kishimura, Matsunaka, Tanaka, 2020, Gakujutsu no dōkō (Academic Trends), 25(2) 66-96

55 Furuya, Hitachi-UTokyo Laboratory, 3rd Habitat Innovation Forum: “Toward Building People-Centered Smart Cities: Five Key Factors for Sustainable Smart City.” (http://www.ht-lab.ducr.u-tokyo.ac.jp/wp-content/uploads/2021/10/1cf26b0e65157f6d26f8716a97a8d7da.pdf)

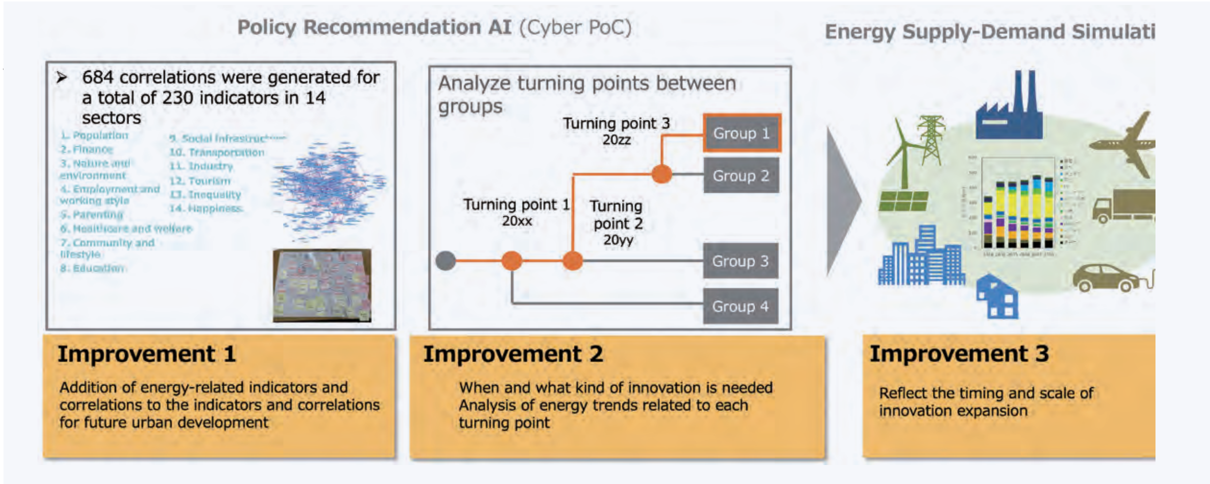
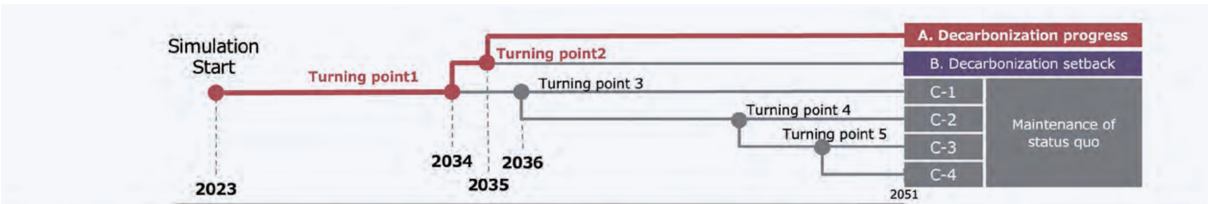


Figure 6.2 Improvements for conducting the co-simulation

6.2 Analysis of pathways to carbon neutrality

6.2.1 Analysis of pathways taken by policy proposal AI

Figure 6.3 shows the results of the analysis of the urban vision obtained by the policy proposal AI with the addition of energy-related factors. A scenario exists in which greenhouse gas emissions become negative—in other words, a scenario in which decarbonization progresses. In that scenario, improvements in the depopulation situation and urbanization control areas, etc. are also appropriately carried out, and the household population improves as well. Decarbonization-centered improvements of nature and the environmental are also made, and tourism that takes advantage of regional characteristics, including decarbonization, also grows. The decarbonization scenario is reached via two branching points: Branching Point 1 in 2034 and Branching Point 2 in 2035.



	① Population	② Finance	③ Community and lifestyle	④ Nature and environment	⑤ Employment and working style	⑥ Parenting	⑦ Education	⑧ Industry	⑨ Transportation	⑩ Social infrastructure	⑪ Healthcare and welfare	⑫ Tourism	⑬ Inequality	⑭ Happiness	Greenhouse gas emissions (Rate of change)
A. Decarbonization progress	○	△	-	○	-	-	△	-	-	-	-	○	△	-	-0.121
B. Decarbonization setback	-	○	-	-	△	-	-	-	-	-	-	○	△	-	0.184
C-1. Maintenance of status quo	-	-	-	△	-	-	△	△	-	-	-	△	△	△	-0.034
C-2. Maintenance of status quo	△	△	-	△	-	-	-	○	△	-	-	-	○	△	0.002
C-3. Maintenance of status quo	△	△	-	-	△	-	○	-	-	-	-	-	○	△	-0.059
C-4. Maintenance of status quo	○	△	-	-	-	-	△	-	○	-	-	○	○	○	0.028

Figure 6.3 Scenarios arrived at by the policy proposal AI

Figure 6.4 shows the rate of change of energy-related factors in the decarbonization progress scenario. As decarbonization progresses, the expansion of EV adoption proceeds from 2032. In addition, continued expansion of the deployment of renewable energy sources such as offshore wind power increases from 2035. Associated with these trends are investment in decarbonation by large companies and a shift to high-profit structure from 2035. The shift to a high-profit structure by small- and medium-sized enterprises continues as decarbonization progresses.

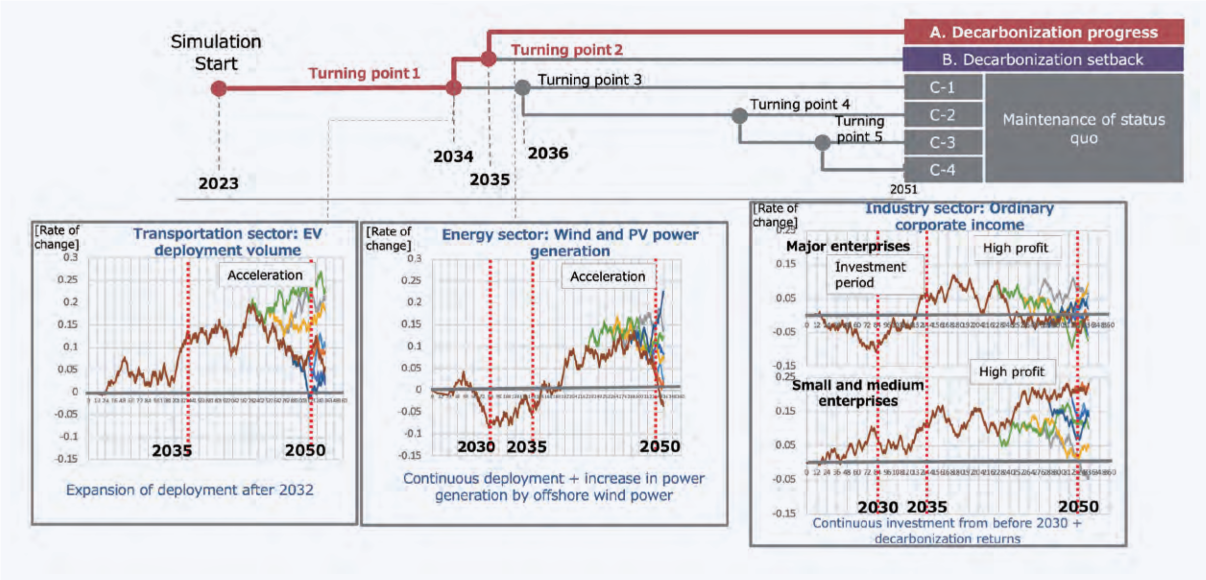


Figure 6.4 Rates of changes of energy-related factors in the decarbonization progress scenario

Figure 6.5 shows items of note in the non-energy sector in bringing about the decarbonization progress scenario. At the 2034 branching point, review of urban planning is needed to avoid non-efficient energy supply in response to changes in the structure of local living areas due to population decline. Such a review must make adjustments for low-population regions and curb overdevelopment outside planned zones. At Branching Point 2 in 2035, lifestyles that utilize information fields such as teleworking and the internet and improving the efficiency of business activities are needed.

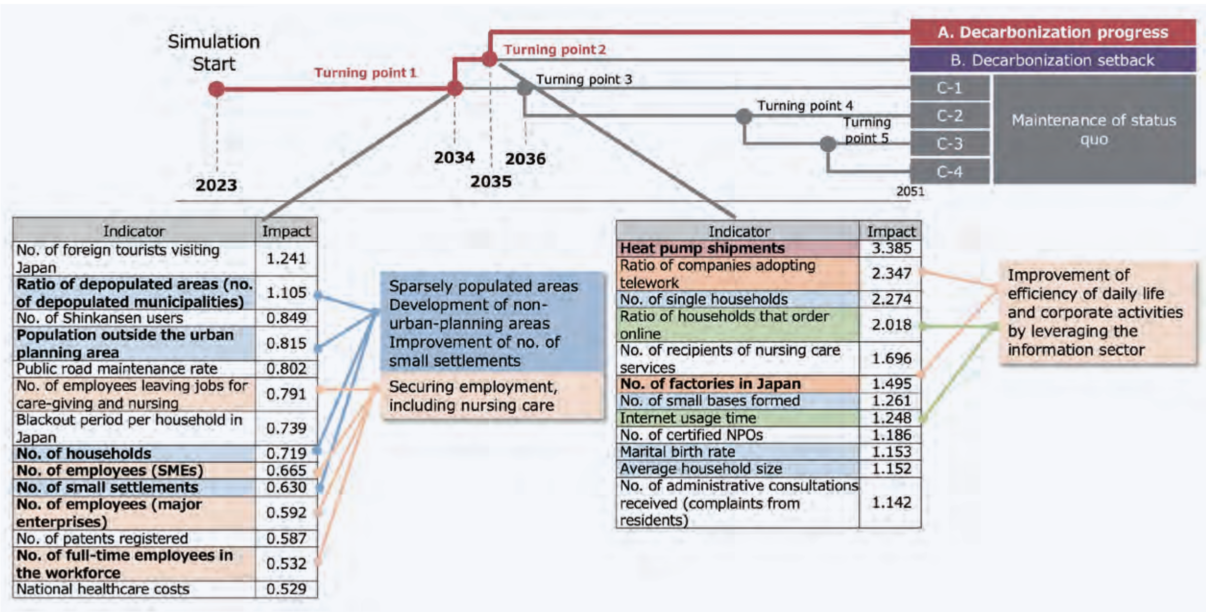


Figure 6.5 Non-energy measures to address branching points in the decarbonization progress scenario

6.2.2 Policy proposal AI-guided energy supply/demand

The energy supply/demand simulation is carried out by following pathways derived by the policy proposal AI in 6.2.1. Key constraints were set as follows: (1) drop in car prices as a result of the spread of innovations in EVs, (2) drop in renewable energy installation costs as a result of innovation in wind power and photovoltaic power generation from 2035, (3) same fuel prices as set in Chapter 3, and (4) selection of the “use of nuclear power” scenario described in Chapter 3 to minimize the total cost burden.

Figure 6.6 shows the results of the energy supply/demand simulation under the policy proposal AI-guided decarbonization progress scenario. Trends similar to the results shown in Chapter 3 (before achievement of decarbonation) are shown. Based on the policy proposal AI-guided results, the vehicle mix becomes EV-centric, and CO_2 emissions are reduced by about 10%.

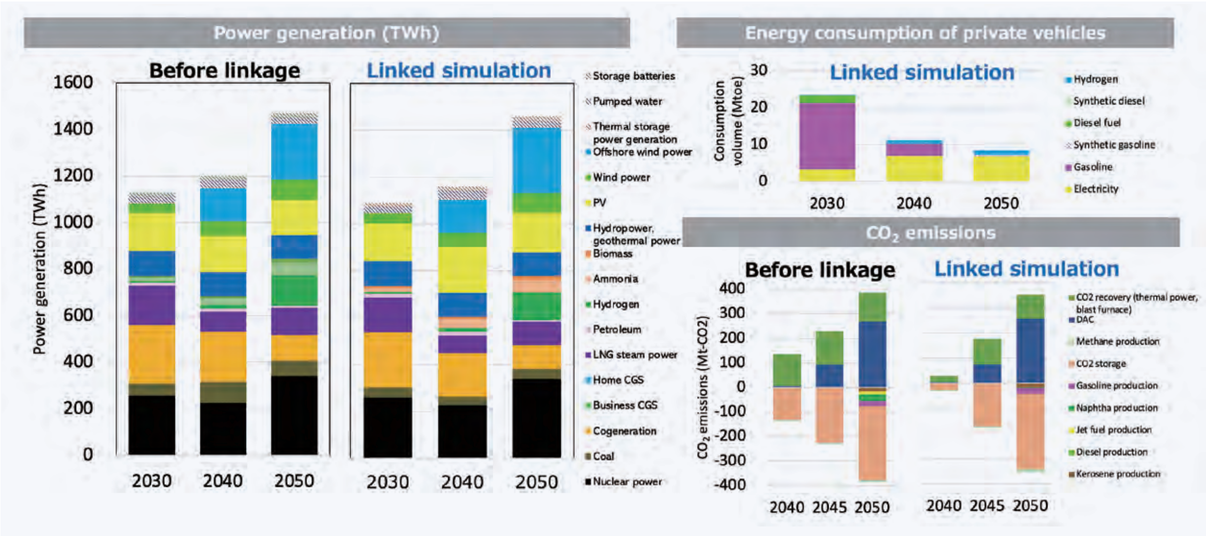


Figure 6.6 Result of energy supply/demand simulation under policy proposal AI-guided decarbonization progress scenario

6.3 Chapter 6 summary

1. Necessity of objective analysis of social changes associated with CN

Changes in the local living areas and lifestyles as energy transition proceeds should be analyzed objectively.

2. Measures in the energy sector coupled with the formation of local living areas and urban development

Measures in the following three areas are critical for the energy sector: (1) expanding adoption of EVs from the first half of the 2030s, (2) accelerating deployment of PV and wind power generation from the mid-2030s, and (3) investing in the environmental sector by large companies from the 2020s, accelerating measures by small- and medium-sized enterprises from the early 2030s, and securing profit through environmental contributions.

3. Government measures for the energy sector, including the formation of local living areas and urban development as the energy transition progresses

To achieve the CN scenario, the following measures are critical for 2034 and 2035: (1) fundamental measures to improve low-population regions, (2) various measures to maintain employment, (3) measures to improve lifestyles by taking advantage of information technology, such as telework, and to increase the efficiency of business activities, and (4) measures to deploy equipment such as heat pumps and plants to form distributed resources, and to induce appropriate operation and location of such equipment.

The Hitachi-UTokyo Laboratory will propose models and simulations that objectively analyze changes in local living areas and lifestyles associated with the energy transition, and engage in visualization of changes in the energy sector and society.

Chapter 7 Proposal

As a summary of this Proposal, timeframes (short-term: from now to 2030; medium- to long-term: from 2030 to 2050) and the content of the proposal are provided below.

[Short-term]

Geopolitical crises and transition pathways: Changes in the landscape and regional viewpoints (Chapter 2)

1. Governance that accelerates integrated transition even amid abrupt geopolitical changes

The EU and the U.S. are accelerating their medium- to long-term responses to climate change based on the policy of reducing dependence on Russian energy. Japan, meanwhile, lags behind in public awareness and structural transformation. The Japanese government should create a governance framework that accelerates integrated transition with all sectors amid abrupt geopolitical changes.

2. Securing global supply chain for clean transition

The government should hasten securing supply chains for resources such as hydrogen, ammonia, and rare metals, and for carbon sequestration, even amid geopolitical changes.

3. Promoting international partnerships on climate and energy in Asia-Pacific

Each sector should play a role in leading multilayered climate- and energy-related international partnerships with Australia, which is strengthening climate measures, and with other countries in Asia, which are highly dependent on fossil fuels.

4. Development of consensus-building platform based on science and dialogue

Together with residents and businesses, the national government and local governments should develop a consensus-building platform based on scientific data and open dialogue.

Hitachi-UTokyo Laboratory's actions

Through analysis of international case studies, we are conducting research on ideal forms of transition and governance and providing the basis for the development of a consensus-building platform that encompasses diverse stakeholders.

Measures for energy systems based on gap between backcasting and forecasting (Chapter 3)

5. Review of energy scenario based on international affairs

After reviewing the energy scenario in response to soaring fuel prices due to recent international affairs, we propose that the following items need to be advanced to realize the CN scenario:

(1) Early-stage securing of decarbonized energy resources, such as deployment of renewable energy ahead of schedule and utilization of nuclear power, (2) avoiding of disposal of photovoltaic panels within a short period of time after the deployment of PV facilities and resolving environmental issues surrounding their installation, (3) in addition to use in power generation, utilization and diversification of hydrogen and ammonia, such as use as synthetic fuels, (4) promotion of utilization of heat through cogeneration, and (5) ensuring energy resilience and security. In addition, development and investment should take place for the following to be realized in 2040 – 2050: (1) practical application and spread of CO_2 sequestration through direct air capture (DAC) and (2) production of fuel from captured CO_2 and its use in the transportation sector and industrial sectors.

6. Addressing the gap between backcasting and forecasting of energy systems

The following measures should be promoted to deal with issues in the bulk system in the face of a rapid expansion of renewable energy: (1) increase the number of thermal-power and nuclear-power rotating generators and introduce inertia control in distribution resources to deal with frequency degradation caused by drops in inertia, (2) use local resources and prevent grid congestion to deal with frequency fluctuations caused by insufficient adjustment capacity, (3) boost power transmission and enhance control systems for local power storage and EVs to counteract drops in grid stability, and (4) develop advanced inverter control techniques and implement high-speed (on the level of seconds) integrated control.

7. Development of analysis and evaluation technologies made possible by data and simulation

In studying bulk power systems for CN, it is necessary to share data from many stakeholders, such as power distributors and utilities and consumers, and simulation models. It is also necessary to utilize and use simulation evaluation technologies. To achieve CN, the following should be carried out as needed: (1) multifaceted and quantitative visualization of issues by using numerical simulation models and (2) evaluation of measures. Investment in facilities and innovations to address changes in the circumstances and maintenance of systems should also be carried out.

Hitachi-UTokyo Laboratory's actions

We are developing evaluation simulation technologies for energy scenarios and evaluating CN transition scenarios to address changes in domestic and international situations. We are also selecting and developing innovative technologies to address issues of energy systems, and engaged in proposing a platform for sharing data and analytical models among diverse stakeholders.

Role of local communities in era of renewable energy as main power source (Chapter 4)

8. Contribution of regions toward CN and S+3E

Accelerating the deployment of decarbonized power sources and reducing emissions, including through electrification of heat sources, are important means of solutions. Furthermore, creating adjustment capacity from demand for power in regions will contribute to reducing the cost of transition to CN and to accelerating the transition.

Based on a win-win relationship between power suppliers and consumers, time-shifting of demand that is coordinated with the availability of renewable energy can create 33 TWh per year in 2030. Efforts to achieve and utilize this capacity should be advanced. To realize the demand coordination described above, it is necessary to spread the adoption of equipment with the necessary functions and to socially implement a coordination and control platform early on.

9. Preparation of measures to facilitate energy transition in local communities

To introduce equipment for decarbonization of industries, it is important to build a system of engineering services related to planning and design, in addition to providing economic assistance for deployment. Also important are discussions in advance for a framework to expand success cases inside and outside regions.

To achieve CN in local communities, providing methods of support in a phased manner, having the participation of all stakeholders and clarifying their roles, and having cooperation between different industries through collaboration will accelerate the transition in regions. The national and local governments should create opportunities where each actor can become aware of the situation and change their behavior.

Hitachi-UTokyo Laboratory's actions

The Hitachi-UTokyo Laboratory is soliciting cooperating local governments and companies and presenting demonstration of the creation of value to society through development of the coordination and control platform.

Direction of energy system reform (Chapter 5)

10. Importance of not only short-term market principles but also medium- to long-term policy axis

As variable renewable energy (VRE) becomes the main power source, a system that creates adjustment capacity and allows consumers to choose the "value of power," such as the quality of the energy supplied, and to bear price volatility, should be advanced. Further study of the following should be carried out: (1) separation and clarification of the objectives of economic efficiency, which aims to achieve short-term merit order, and medium- to long-term policy objectives, such as achieving a stable energy supply and decarbonation, and (2) market design, which to date has pursued efficiency.

11. Reconstruction of the role of markets

It is necessary to break away at an early stage from the current situation where each market is asymmetrical—in other words, where equivalent regulations are not imposed on both sides. To achieve this, power supply operation conditions should be made visible and monitoring of the markets should be thorough.

12. Reconstruction of system led by consumers

Construction of sustainable systems that stimulate active environmental investment by consumers. Measures that integrate policies with consumer-sovereign emissions trading system should be carried out. The policies should secure energy sources that promote CN based on consumers' discretion, such as corporate power purchase agreements (PPAs), and limit global warming.

Hitachi-UTokyo Laboratory's actions

At Hitachi-UTokyo Laboratory, we are contributing to the development of a consumer-led system through digital technology. This system will enable data-based visualization of CO_2 emissions and provision of information from consumers' perspective on carbon neutrality.

Challenges to achieving pathway that balances both energy transition and maintenance of quality of life (QoL) (Chapter 6)

13. Necessity of objective analysis of social changes associated with CN

Research and development of methods and tools to objectively analyze changes in local living areas and lifestyles associated with the energy transition should be conducted.

14. Energy sector measures that couple formation of local living areas and urban development

Measures in the following three areas should be implemented for the energy sector: (1) expanding adoption of EVs from the first half of the 2030s, (2) accelerating deployment of PV and wind power generation from the mid-2030s, and (3) investing in the environmental sector by large companies from the 2020s, accelerating measures by small- and medium-sized enterprises from the early 2030s, and securing profit through environmental contributions.

15. Government measures for the energy sector, including the formation for local living areas and urban development as the energy transition progresses

To achieve the CN scenario, the following measures should be carried out by 2034 and 2035: (1) fundamental measures to improve low-population regions, (2) various measures to maintain employment, (3) measures to improve lifestyles by taking advantage of information technology, such as telework, and to increase the efficiency of business activities, and (4) measures to deploy equipment such as heat pumps and facilities to form distributed resources, and to induce appropriate operation and location of such equipment.

Hitachi-UTokyo Laboratory's actions

At Hitachi-UTokyo Laboratory, we are proposing models and simulations that objectively analyze changes in local living areas and lifestyles associated with the energy transition, and engaging in visualization of changes in the energy sector and society.

[Medium-term]

Geopolitical crises and transition pathways: Views from changing landscapes and regions

16. Transition pathway for each region

Even in Japan, each region has different social challenges, lifestyles, and energy potential. The transition pathway is thus multidimensional. The national and local governments should empower the agency of local actors based on diverse natural environments and present a different transition pathway for each region.

17. Strategic industrial policy and maximizing regional strengths

Local governments coordinate a wide range of stakeholders in areas where they have little experience. However, there are also areas where local governments lack know-how. Regional businesses drive green projects with their own strategies. The national government should overcome bureaucratic sectionalism with a strategic industrial policy and support maximalization of the strengths of regions.

Hitachi-UTokyo Laboratory's actions

We are presenting policy options through analysis of conditions particular to each region and their obstacles for transition and through research of international case studies.

Technological measures for energy systems (Chapter 3, Chapter 4)

18. Development of technologies to address energy scenarios for carbon neutrality

For CN in 2040 – 2050, the following innovations are needed: (1) practical application and spread of CO_2 sequestration through direct air capture (DAC) and (2) production of fuel from captured CO_2 and its use in the transportation sector and industrial sectors.

In local communities, maintaining and managing small-scale solar power generation facilities installed in mass quantities is a challenge. Development of maintenance systems for renewable energy resources should be promoted, and development of recycling technologies should be accelerated.

Hitachi-UTokyo Laboratory's actions

In addition to technological development, developing leaders to advance sustained social transition and promoting education of residents on carbon neutrality are necessary. At the Hitachi-UTokyo Laboratory, we are continuing the development of evidence-based proposals and providing learning opportunities through industry-academic-government collaboration.

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

Appendix 1 | Overview of transition scenarios developed by Hitachi-UTokyo Laboratory

	Domain	"Diverse energy mix" case			Main points
		2015-20	2020-30	2030-50	
By source of electricity	Coal-fired with CO_2 capture	Based on the "5th Strategic Energy Plan," inefficient coal-fired thermal generation is phased out and high-efficiency coal-fired thermal generation is promoted.	After the invasion of Ukraine, coal returns temporarily as a major fuel source. However, phase-out of coal-fired power generation and conversion to high-efficiency coal-fired power production steadily advance, as does international collaboration for CCUS technology development and carbon sequestration.	Phase-out of coal-fired power generation and conversion to high-efficiency coal-fired power generation with CO_2 capture is completed. Together with the private sector, the government establishes CCUS supply chain in cooperation with Asian countries.	2020-30: Phase-out of inefficient coal-fired power generation and steady promotion of higher efficiency are necessary. 2030-50: Public-private sector unity on CCUS technology development and the establishment of CCUS supply chain in the Asian region are important.
	Gas-fired with CO_2 capture	The "Energy Conservation Act" is revised to promote phasing out of inefficient thermal power generation and replacement with new gas-fired power generation.	Gas-fired power generation businesses use government funds to develop and commercialize CO_2 capture systems. The government promotes the establishment of supply chains for CCUS through international collaboration.	The public and private sectors work together to realize domestic network for CO_2 capture and transport using gas infrastructure. They also achieve CCUS supply chain in cooperation with Asian countries.	2020-30: Gas-fired power generation companies need to achieve gas-fired power generation with CO_2 capture by utilizing government subsidies and loans from financial institutions. 2030-50: It is critical to have public-private sector unity for developing CCUS tech and building a supply chain for CCUS in cooperation with Asia.
	Solar	Since the Paris Agreement, large-scale projects have started based on the FIT system. Measures against environmental impact are promoted.	Soaring fossil fuel prices boost demand for renewable energy. New operators enter the market. Private individuals and companies generate more of own power. The national and local governments promote installation in homes and on public land. Environmental regulations are enacted.	Installation of solar power facilities advances through development of the Hokkaido-Honshu line, smart power transmission and distribution, and natural disaster resilience. Solar power reaches 30% of energy mix by 2050.	2020-30: As competitiveness increases due to soaring fossil fuel prices, new power companies face difficult situation. Challenges include how to increase the rate of growth in power generation while taking into account environmental impact and business regulations. 2030-50: While considering how to overcome mass disposal of PV panels, other challenges include how to develop RE stabilization infrastructure centered on solar and wind power that enables regional business creation, disaster prevention, and EV proliferation.
	Wind	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.	System review to facilitate expansion of wind power business continues. Regional renewable energy companies are creating RE value chains involving local actors.	Industrial competitiveness grows due to intensifying international competition. Relationships between RE projects and local communities shift from consensus-building to coexistence and co-prosperity through cooperation.	2020-30: The government needs to support formation of green economic zones involving RE power operators in suitable renewable energy generation zones, local banks, local industries, and residents. 2030-50: Offshore wind power operators need to shift from consensus-building with fishermen to coexistence and co-prosperity through fishery cooperation.
	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 government promotes the introduction of small and medium-sized hydropower plants in collaboration with regional development policies. Needs increase as plants serve as decarbonization solution for developing countries.	In addition to reducing CO_2 emissions, hydropower demonstrates value in raising residents' awareness and revitalizing local economies.	2020-30: Needed are 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: Needed is 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.	Community-based biomass projects expand thanks to government policy to actively promote biomass power generation.	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.	2020-30: The Sixth Basic Energy Plan boosts the expansion of biomass power generation. 2030-50: 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 entrenched. From 2015, the plant gradually resumes operation.	Climate change, the invasion of Ukraine, and electricity shortages lead the government to make a major shift in nuclear power policy. It promotes the restart and extension of operation of nuclear plans and development of next-generation innovative reactors. New construction begins.	Construction of innovative reactors proceeds. Small modular reactors have not been put into operation in Japan. Nuclear power generation is progressively reduced, although the operation of some aging nuclear plants is extended.	2020-30: Important are understanding by all citizens of the various benefits and risks, and consensus-building with local communities regarding construction sites and disposal of radioactive waste. 2030-50: Challenges include how to make rational investments in nuclear power personnel, tech development, and facility construction in relation to RE sources, which will become less expensive and more stable in the medium to long term.
	Mono-firing of hydrogen and ammonia	The amount of ammonia being traded is low. Most production is local. Its use as fuel in Japan is extremely small.	International supply chains are established and related plants (ammonia, etc.) expand overseas. In Asia, expectations for co-firing and mono-firing grow.	Thermal power generation is extended. Shift to mixed and mono-firing proceeds. Demand is also being created in Asia, and international supply chains are established.	2020-30: Establishment of international supply infrastructure for ammonia and hydrogen and CCS infrastructure begins. 2030-50: It is essential to develop infrastructure for mass production of ammonia and hydrogen and an international supply chain. Challenges include getting international public acceptance of using transitional fossil fuels in ammonia co-firing.
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 continue the 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 maintaining H2 prices with hydrogen reduction and subsidies.	2020-30: The shift to electric furnaces continues, but blast furnace and electric furnace manufacturers have conflicts on expectations of taxation and incentives from the government. 2030-50: Technology and infrastructure for steel production by hydrogen reduction is in place. Various protections and incentives for the steel industry are adopted as national policy.
	Petrochemicals	The business challenge of the petrochemical industry in Japan is improving profit margins.	Carbon capture infrastructure development begins. Interest in a circular economy grows, and efforts to change the supply chain become full-fledged.	Products for which domestic production is disadvantageous are moved overseas. Industrial reallocation progresses. Business models change and the ecosystem is renewed.	2020-30: Critical are development of domestic and international systems and technologies for carbon sequestration and creation of green jobs. 2030-50: Critical is development of business models and ecosystem innovations (supply chain, industry collaboration, international partnerships). Need to have government leadership (regional lead and strategic industrial policy) and private sector leadership.
	Transport	The car industry is the backbone of the Japanese economy in terms of export value, employment, etc.	Competitiveness is maintained by responding to the spread of EVs. The shift to electrification in related industries, including parts and services, is supported by the public and private sectors. Fuel SAF conversion begins slowly in the aviation industry.	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.	2020-30: Strengthening domestic capability for manufacturing storage batteries and reducing emissions throughout their entire lifecycle, including production, use, and disposal, is critical to maintaining competitiveness. 2030-50: Support for actors impacted 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.	The public's interest in sustainability, including climate change, gradually increases. However, under geopolitical instability, it does not lead to major changes in existing social and industrial structures.	Temperatures continue to rise and carbon emission standards become stricter. Domestic interest in the global environment grows and lifestyles change, but there is growing criticism that decarbonization depends on exporting carbon to other countries.	2020-30: Lack of participation of new industries, civic actors, etc. in energy-related decision-making may stall the transformation of the social structure. 2030-50: International climate measures may become stricter, and criticism of carbon exports may arise.

100% Renewable energy case			Main points
2015-20	2020-30	2030-50	
Based on the "5th Strategic Energy Plan," inefficient coal-fired thermal generation is phased out and high-efficiency coal-fired thermal generation is promoted.	The government accelerates shift to non-fossil fuels for energy security. Coal-fired power plant operators are pressed to shift to non-coal-fired power and renewable energy.	Fossil fuel power generation companies withdraw from business, shift to biomass power generation, etc. The government promotes creation of green jobs as a regional economic stimulus measure.	2020-30: As coal-fired power generation is phased out, green job creation and measures related to quality of life and labor are needed. 2030-50: Major thermal operators and regional RE operators converge in RE generation business. This may lead to more segregations and mergers in Japan's power business.
The "Energy Conservation Act" is revised to promote phasing 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.	Power generation companies withdraw from fossil fuels, shift to biomass, hydrogen, ammonia power generation, etc. The government promotes creation of green jobs as a regional economic stimulus measure.	2020-30: Gas-fired power companies are pressed to make major transitions, such as shutting down operations in Japan and switching to biomass and hydrogen/ammonia power generation. 2030-50: The government needs to take measures regarding green job creation and quality of life and work issues.
Since the Paris Agreement, large-scale projects have started based on the FIT system. Measures against environmental impact are promoted.	Soaring fossil fuel prices boost demand for renewable energy. New operators enter the market. Private individuals and companies generate more of own power. The national and local governments promote installation in homes and on public land. Environmental regulations are enacted.	Installation of solar power facilities advances through development of the Hokkaido-Honshu line, smart power transmission and distribution, and natural disaster resilience. Solar power reaches 30% of energy mix by 2050.	2020-30: As competitiveness increases due to soaring fossil fuel prices, new power companies face difficult situation. Challenges include how to increase the rate of growth of power generation while taking into account environmental impact and business regulations. 2030-50: While considering how to overcome mass disposal of PV panels, other challenges include how to maintain power stabilization infrastructure and grid infrastructure to achieve 100% renewable energy.
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.	The government struggles to find measures as the market for wind power generation reaches critical stage because of abolition of coal-fired power. It becomes more difficult to reach consensus with local industries and citizens.	Regions suitable for RE are being revitalized. However, regions unsuitable for RE struggle to promote revitalization. The government studies measures to avoid large-scale power outages due to natural disasters.	2020-30: The government needs to study and implement measures concerning quality of life and work that may take place in the future. 2030-50: There may be growing economic and social disparities between regions that are suitable and unsuitable for renewable energy.
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 government promotes the introduction of small and medium-sized hydropower plants in collaboration with regional development policies. Needs increase as plants serve as decarbonization solution for developing countries.	In addition to reducing CO_2 emissions, hydropower demonstrates value in raising residents' awareness and revitalizing local economies. The number of deployments increases markedly, driven by improvements in the business environment.	2020-30: Needed are 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. International opinion is required. 2030-50: Debate is critical on pros and cons of promoting decarbonization by introducing regulations. Needed is reduction of business risk of small and medium hydropower plants.
The "5th Strategic Energy Plan" stimulates growth of biomass power generation.	Due to the abolishment of coal-fired power generation, the power generation target for 2050 becomes more than 3x of 2015. The biomass power generation market is activated. Financial institutions promote investment and the government supports the creation of new jobs.	Establishing supply chain with new actors such as domestic producers and international procurers is a challenge for stable mass procurement of biomass power generation fuel. Collaboration beyond the walls of related ministries and agencies is important.	2020-30: Fossil fuel power companies are forced by national policy to make major transition, such as ceasing domestic operation or switching to biomass power generation. 2030-50: Transition biased toward RE and biomass power generation may lead to problems such as environmental damage and lack of stability in energy procurement.
After the Fukushima Daiichi Nuclear Power Plant accident, continued evacuation and damage to reputation become entrenched. From 2015, the plant gradually resumes operation.	Climate change, the invasion of Ukraine, and electricity shortages lead the government to make a major shift in nuclear power policy. It promotes the restart and extension of operation of nuclear plans and development of next-generation innovative reactors. New construction begins.	Renewable energy costs and stability improve. Meanwhile, due to issues such as security, large earthquakes, and issue of disposing of spent fuel, nuclear power generation falls to zero again.	2020-30: Important are understanding by all citizens of the various benefits and risks, and consensus-building with local communities regarding construction sites and disposal of radioactive waste. 2030-50: Risks related to security, natural disasters, and return on investment may significantly impact people's decisions.
The amount of ammonia being traded is low. Most production is local. Its use as fuel in Japan is extremely small.	International supply chains are established and related plants (ammonia, etc.) expand overseas. In Asia, expectations for co-firing and mono-firing grow.	Thermal power plants shut down one after another. There is no shift to mixed or mono hydrogen and ammonia firing. Establishment of an international supply chain stalls.	2020-30: Establishment of international supply infrastructure for ammonia and hydrogen and CCS infrastructure begins. 2030-50: Challenges include getting international public acceptance of using transitional fossil fuels in ammonia co-firing.
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 continue the shift to electric furnaces. 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. In conjunction with the movement to use domestic renewable energy, the importance of Australia and other countries increases not only for raw materials but also for hydrogen and crude steel production.	2020-30: The shift to electric furnaces continues, but blast furnace and electric furnace manufacturers have conflicts on expectations of taxation and incentives from the government. 2030-50: Needed is a system to monitor and support local reductions in CO_2 emissions as a result of increased reliance on overseas crude steel production.
The business challenge of the petrochemical industry in Japan is improving profit margins.	Carbon capture infrastructure development begins. Interest in a circular economy grows, and efforts to change the supply chain become full-fledged.	CO_2 emission sources decrease, and demand for domestic carbon capture declines. Development of carbon capture infrastructure stalls.	2020-30: Critical are development of domestic and international systems and technologies for carbon capture and social acceptance of carbon capture and storage. 2030-50: Critical is development of business models and ecosystem innovations (supply chain, industry collaboration, international partnerships). Need to have government leadership (regional lead and strategic industrial policy) and private sector leadership.
The car industry is the backbone of the Japanese economy in terms of export value, employment, etc.	EVs come to also play an important role in stabilizing renewable energy. The aviation industry slowly begins to use SAF for fuel.	The shift from car-centric transportation to public transportation, walking, bicycling, etc., grows stronger in urban development. Air transportation maintains a minimum number of flights through a production system that includes SAF exports.	2020-30: Technological development and environmental improvements to utilize EV storage batteries, including used batteries become important for maintaining power grid stability. 2030-50: Higher electricity prices due to increased adoption of variable renewable energy leads to changes in personal transportation and logistics systems.
The 2015 Paris Agreement and the government's carbon neutrality goals begin to have strong appeal among young people.	The public's interest in sustainability gradually increases. Social media and community creation activities influence existing decision-making frameworks, and major shifts in social systems begin.	Climate measures in each country become stricter. Domestic concern for the global environment is growing and has diverse effects on daily life. Strong sanctions against carbon emissions accelerate the shift to renewable energy.	22020-30: Against background of public concern for the climate and environment, social media, AI, and community-creation activities influence decision-making and may create new conditions. 2030-50: The state of international actions against climate change and the threat of major earthquake disaster in Japan may further strengthen the promotion of renewable energy.

Appendix 2 | Energy technology selection model (dynamic cost minimization-based model)

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

- The cost optimization of energy supply/demand structure under CO_2 emission constraints for the entire energy supply in Japan can be calculated.
  Evaluation of the entire energy system that assumes the following, as shown in Figure A2.1, is carried out.
  Detailed analysis of energy sectors (primary energy, conversion sector, final consumption sector [industries, households, businesses, passengers, freight])
  (Temporal resolution -> 1 hour value, analysis at 8,760 hours per year -> Renewable energy output variability is taken into account in detail)
- Individual technologies on the energy supply side (primary/secondary energy) and demand side (steel, cement, chemicals, consumers, transportation, etc.) are accumulated and analyzed. Possible to consistently analyze CN and energy supply/demand of transitions to achieve it.
- Diverse technological elements, including innovative technologies, are taken into account: next-generation vehicles (EVs, FCVs), energy storage (Li-ion batteries, NAS batteries, thermal storage), CCUS (direct capture of CO_2 in the atmosphere, methanation, FT synthesis), energy carriers (hydrogen, ammonia, methanol, synthetic gas, synthetic oil), power generation technologies (hydrogen power, ammonia power, offshore wind power, fuel cells, thermal power storage), energy-saving technologies (heat pump), etc.

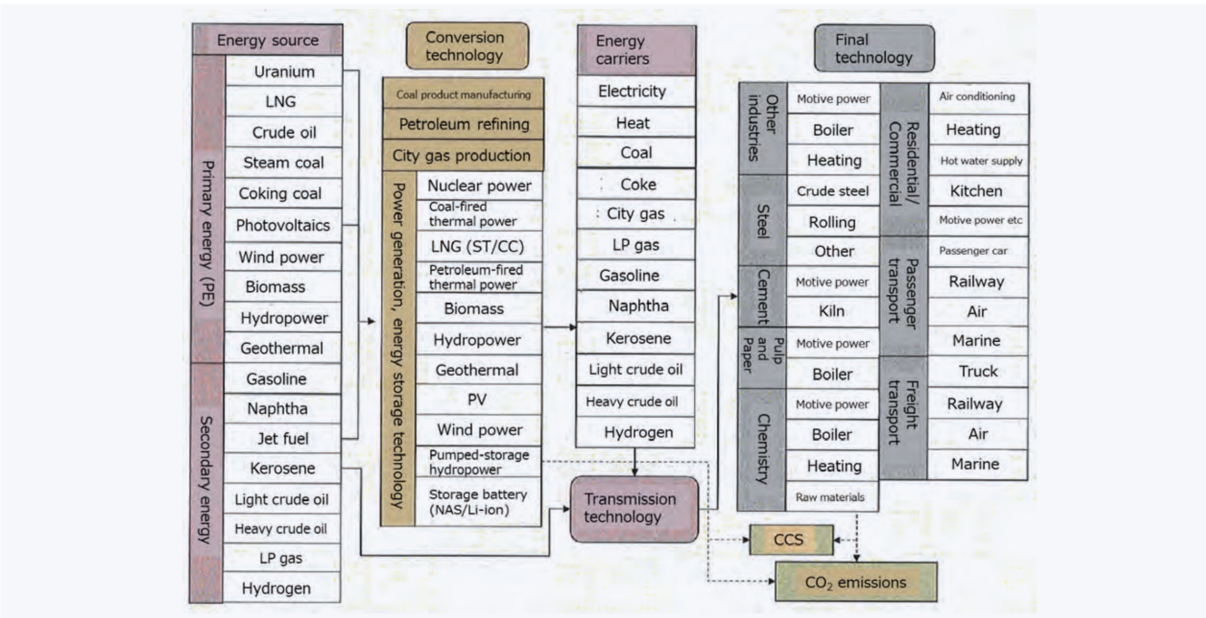

Figure A2.1 Standard energy systems

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

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

Power generation/tech deployment conditions (2050)

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

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

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

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

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

*1) Source by JPEA (published by 8th March 2021)https://www.meti.go.jp/shingikai/enecho/denryoku_gas/saisei_kano/pdf/026_05_00.pdf
*2) Source by JWPA (published by 24th March 2021)https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/039/039_008.pdf
*3) Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (published by 18th June 2021)
https://www.meti.go.jp/policy/energy_environment/global_warming/ggs/pdf/green_honbun.pdf

Figure A2.2 Main simulation conditions (base conditions)

Table A2.1 Conditions of each energy scenario

	(1) 100% RE	(2) Thermal power with CCS limit	(3) Use of nuclear power	(4) Hydrogen procurement
Nuclear plant life (years)	Stopped	60	←	←
Nuclear plant cap. upper limit (GW)	0	24	50(SMR)	←
Thermal power with CCS upper limit (ton)	200 mil.	100 mil.	200 mil.	←
Hydrogen import upper limit (ton)	20 mil.	←	←	No upper limit
Hydrogen price (¥/Nm³)*1	20	←	←	←
FCV price (compared to current)	0.68	←	←	0.20
EV price (compared to current)	0.68	←	←	←
Solar power upper limit (GW)	None	←	←	←
Onshore wind power upper limit (GW)	40	←	←	←
Offshore wind power upper limit (GW)	90	←	←	←
Solar power construction cost (10k yen/kW)	15	←	←	←
Onshore wind turbine construction cost (10k yen/kW)	21	←	←	←
Offshore wind turbine construction cost (10k yen/kW)	51	←	←	←
CCS cost (¥/tonCO_2)	7450	←	←	←
DAC cost (¥/tonCO_2)	10,340	←	←	←
LIB battery cost (¥/Wh)	10	←	←	←
	RE only (e.g. PV and wind power)	Limited CCS for thermal power	Additional SMRs after 2040	Import of hydrogen from overseas

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

Appendix 3 | Derivation of number of households and number of distributed resources owned in Machida City, Tokyo, and Iwaki City, Fukushima Prefecture

Table A3.1 shows the results of deriving the number of households and quantity of distributed resources (HP water heaters, PV panels, EVs) in Machida City, Tokyo and Iwaki City, Fukushima Prefecture in 2030. Below, we discuss the processes for deriving the values.

1. Number of households

Table A3.2 provides a summary of deriving the number of households. A study estimates about 200,000 households in Machida City, Tokyo in 2030. The number of households in Iwaki City in 2030[56] is estimated to be 145,000[57]. The breakdown of detached residential houses and apartment complexes is determined as follows. The percentage of detached residential houses in the Kanto region is 48.5%[58]. Assuming the same percentage of detached residential houses in Machida City, we calculate the number of households living in detached residential houses and apartment complexes in the city in 2030 to be approximately 97,000 and 103,000, respectively. In a similar manner, we calculate the number of households living in detached residential houses and apartment complexes in Iwaki City in 2030 to be approximately 97,000 and 48,000, respectively[59].

2. Heat pump (HP) water heaters

We summarize the process of deriving the number of HP water heaters in Table A3.3. The estimate of the spread of heat pump water heaters is calculated separately for Japan's cold climatic zone and warm climatic zone[60]. Machida is categorized as

Table A3.1 Number of households quantity of distributed resources owned in 2030

Municipality	Machida City		Machida City	
Type of residence	Detached residential houses	Apartment complexes	Detached residential houses	Apartment complexes
1. Number of households	96,596	102,572	97,497	47,503
2. Heat pump (HP)water heaters [units]	42,932	15,609	43,332	7,229
3. Solar power generation (PV) [MW]	83.48	0	124.35	0
4. Electric vehicles (EV) [units]	7,047	7,483	8,172	3,982

Table A3.2 Number of households living in detached residential houses and apartment complexes

Municipality	Machida City	Machida City
Households (A)	199,168	145,000
Of these, number living in detached residential houses (=A × proportion of households living in detached residential houses)	96,596	97,497
Of these, number living in apartment complexes (=A×proportion of households living in apartment complexes)	102,572	47,503

Table A3.3 Derivation of number of HP water heaters in 2030

Municipality	Machida City		Machida City	
Type of residence	Detached residential houses	Apartment complexes	Detached residential houses	Apartment complexes
Number of households (A)	96,596	102,572	97,497	47,503
HP water heaters (qty) (B)	42,932	15,609	43,332	7,229
HP water heaters penetration rate (B/A)	44.9%	15.2%	44.9%	15.2%

56 Tokyo Metropolitan Government, 2019. "Estimate of Population No. 71 Projected Number of Households in Tokyo." (Accessed March 2, 2023) https://www.toukei.metro.tokyo.lg.jp/syosoku/sy19rf0000.pdf

57 Iwaki City, 2022. "Iwaki City Housing Basic Plan." (Accessed March 2, 2023) https://www.city.iwaki.lg.jp/www/contents/1615439248492/simple/02_keikaku-honpen.pdf

58 Hitachi-UTokyo Laboratory, 2022. "Toward Realizing Energy Systems to Support Society 5.0 (Ver. 4)."

59 Fukushima Posting.com. "Number of detached residential houses, apartment buildings and offices in Fukushima Prefecture." (Accessed March 2, 2023) https://www.posting-nippon.com/fukushima/number2/fukushima.html

60 Heat Pump & Thermal Storage Technology Center of Japan, 2020. "2020 heat pump penetration outlook survey." (Accessed March 2, 2023) https://www.hptcj.or.jp/Portals/0/data0/press_topics/2020NewsRelease/news_release_siryo.pdf

belonging to the warm climatic zone. The same study treats Fukushima Prefecture as belonging to the cold climatic zone. However, the study categorizes Iwaki City's energy conservation standard as "5," which is shared by many prefectures that the study treats as belonging to the warm climatic zone. For analytic purposes here, we thus treat Iwaki City as belonging to the warm climatic zone. The aforementioned study estimates the number of households living in detached residential houses and apartment complexes in the warm climatic zone in 2030 to be 22.5 million and 23.0 million respectively. Assuming that the number of HP water heaters increases under the medium-growth assumption case until 2030, we estimate the number of HP water heater units in 2030 to be about 10 million for detached residential houses and 3.5 million for apartment complexes. Apportioning by the number of households in Machida City and Iwaki yields the number of HP water heaters and the penetration rate in those cities, as shown in Table A3.3.

3. Solar power generation (PV)

Table A3.4 provides a summary of deriving the number of solar power PV panels. In 2018, the number of households in Machida City in residences deploying solar power generation was 5,460[61]. Meanwhile, the number of households in residences deploying solar power generation in the Kanto area in 2018 was about 540,000, and is estimated to increase to 1.5 million by 2030[62]. Assuming that the penetration rate of solar power generation for detached residential houses in Machida City is the same as the Kanto area, the number of such households in Machida City in 2030 is calculated to be 15,206. The average output of solar power generation in detached residential houses in the Kanto area is 5.49 kW[63]. Assuming that the average output remains flat until 2030, the output of solar power generation in detached residential houses in Machida City is estimated to be 83.48 MW in 2030. In a similar manner, the output of solar power generation in detached residential houses in Iwaki City is estimated to be 124.35 MW in 2030. Note that with regard to solar power generation in apartment complexes, because its penetration rate is extremely low compared with detached residential houses (according to Reference 56), it is ignored here.

4. Electric vehicles (EV)

Table A3.5 provides a summary of deriving the number of electric vehicles. In 2022, the number of passenger cars in Machida City and in Tokyo[64] were 150,000 and 3 million, respectively; passenger cars in Machida City made up 4.83% of the total number in Tokyo. The number of EVs in Tokyo is estimated to be about 300,000 in 2030[65]. Assuming that Machida City's share of total passenger cars in Tokyo will remain unchanged in 2030, the number of EVs in the city in 2030 is calculated to be 14,531. Similarly, the number of EVs in Iwaki City in 2030 is calculated to be 12,153.

Table A3.4 Derivation of number of PV panels in detached residential houses in 2030

Municipality	Machida City	Machida City
Number of households living in detached residential houses with PV panels in 2018 (in the municipality) (A)	5,460	7,080
Number of households living in detached residential houses with PV panels in 2018 (in the region) (B)	538,700	145,600
Number of households living in detached residential houses with PV panels in 2030 (in the region) (C)	1,500,300	430,500
Average solar power output (D)	5.49 kW	5.94 kW
Solar power output by detached residential houses in 2030 (in the municipality) (A/B×C×D)	83.48 MW	124.35 MW

Table A3.5 Derivation of the number of electric vehicles in 2030

Municipality	Machida City	Machida City
Number of passenger cars in 2022 (in the municipality) (A)	149,686	221,862
Number of passenger cars in 2022 (in the prefecture) (B)	3,096,528	1,218,685
Number of electric vehicles in 2030 (in the prefecture) (C)	300,596	66,758
Number of electric vehicles in 2030 (in the municipality) (=A/B×C)	14,531	12,153

61 Statistics Bureau, Ministry of Internal Affairs and Communications, 2023. "2018 Housing and Land Survey of Japan." (Accessed March 2, 2023) https://www.stat.go.jp/data/jyutaku/

62 Fuji Keizai Group. 2020. "Building, equipment, and services market survey by housing market, 2020 edition."

63 Ministry of the Environment, 2022. "Statistical survey on CO_2 emission from residential sector in FY2020 Table 2-6" (Accessed March 2, 2023) https://www.env.go.jp/earth/ondanka/ghg/kateico2tokei/r2co2.html

64 Automobile Inspection & Registration Information Association. (Accessed March 2, 2023) https://www.airia.or.jp/

65 Fuji Keizai Group. 2021. "Full Picture of EV/PHEV Charging and Future Prospects of the Japanese Market"

Appendix 4 Derivation of total floor area and number of buildings in the business sector in Iwaki City, Fukushima Prefecture

FigureA4.1 shows the result of deriving the total floor area and number of buildings in the business sector (offices, hotels, and welfare facilities) in Iwaki City, Fukushima Prefecture in 2030. The derivation process for each item in the table is as follows.

1. Total floor area

The demand for hot water in the business sector depends mainly on the total floor area for each type of business. We thus first estimate the total floor area of the entire business sector in Iwaki City. Table 4.2 shows the calculated results. Here, welfare facilities include hospitals and nursing homes.

Figure A4.1 shows the flowchart estimating total floor area by each type of business[66]. From this flowchart and publicly available information[67 68 69 70], we estimate the total floor area of offices ("Office buildings" in Figure 4.1), hotels ("Hotels and inns" in the same figure), and hospitals ("Hospitals and medical facilities" in the same figure) in 2020. Because the total floor area of offices, hotels, and hospitals nationwide were flat from 2015 to 2020[71], we consider that the total floor area in 2030 to be the same as the value in 2020.

The total floor area of nursing homes in 2020 is the sum of the total floor area of Care Homes for the Elderly, Moderate-Fee Homes for the Elderly, Fee-Based Home for the Elderly,

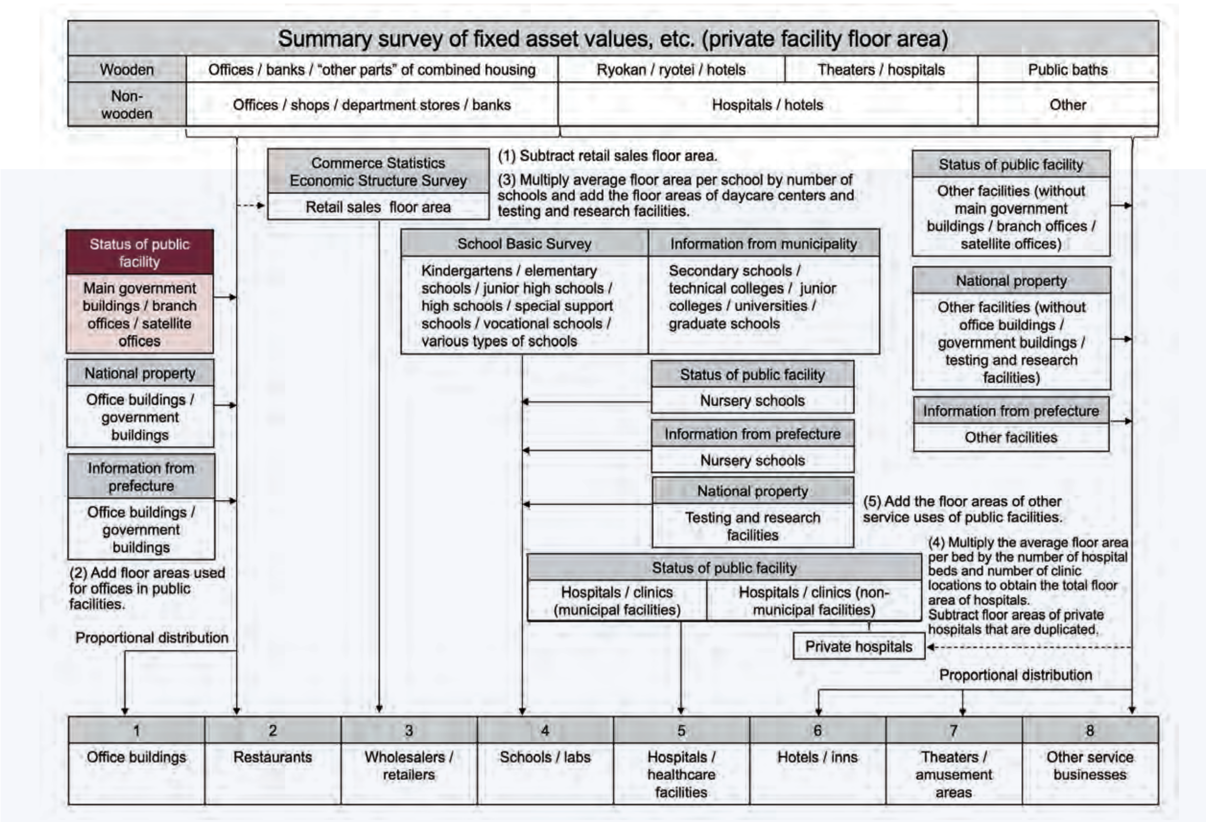

Figure A4.1 Flowchart for estimating total floor area by type of business

66 Ministry of the Environment, 2021. "Local Government Action Plan (Area Policy Version) Formulation and Implementation Manual (Calculation Methodology) (Ver1.1" (Accessed March 2, 2023) https://www.env.go.jp/policy/local_keikaku/data/manual_santei_202204.pdf

67 Ministry of Internal Affairs and Communications, 2021. "Summary Record of Value of Fixed Assets, Etc. for FY2021 5. Record of non-wooden houses (breakdown by municipality)." (Accessed March 2, 2023) https://www.soumu.go.jp/main_sosiki/jichi_zeisei/czaisei/czaisei_seido/ichiran08_r03_05.html

68 Statistics Bureau, Ministry of Internal Affairs and Communications, 2015. "2016 Economic Census - Activity Survey." (Accessed March 2, 2023) https://www.stat.go.jp/data/e-census/2016/index.html

69 Iwaki City, 2021. "Iwaki City Statistical Book, FY2020 Edition." (Accessed March 2, 2023) https://www.city.iwaki.lg.jp/www/contents/1629700076841/index.html

70 Japan Hospital Federation, 2021. "Summary of the 2021 Hospital Operation Analysis Survey Committee." (Accessed March 2, 2023) https://www.byo-ren.com/pdf/r3gaiyou.pdf

71 The Institute of Energy Economics, Japan, 2022. "EDMC Handbook of Energy and Economic Statistics."

and Elderly Housing with Services[72]. To determine the figure for 2030, because the capacity of nursing homes increases monotonically[73], the total floor area is calculated by multiplying the capacity ratio by the amount of floor area per person.

2. Number of buildings

Table A4.3 provides a summary of deriving the number of buildings in the business sector in Iwaki City. For hotels and hospitals, we assume that the number of buildings will remain flat from the number of buildings in 2020. For nursing homes, we total the number of Nursing Homes for the Elderly, Moderate-Fees Homes for the Elderly, Fee-Based Homes for the Elderly, and Elderly Housing with Services. In 2020, the number of nursing home buildings was 72. From the change in number of nursing home buildings between 2014 and 2020, we estimate the number of buildings in 2030 to be 90.

Next, we explain the calculation of the number of office buildings. Table A4.4 shows the average total floor area by category[74], total floor area of offices in the Tohoku area, and the cumulative occupancy rate obtained from the Ministry of Land, Infrastructure and Transportation's Corporations Survey on Land and Building. The cumulative total floor area reaches over 50% in category CL4, so its buildings are considered representative. The total floor area of CL4 buildings has an average of 1,447 m^2. The number of office buildings in Iwaki City is calculated by dividing the total office floor area in the city by the total floor area of representative buildings, resulting in 865 buildings.

Finally, the annual hot water demand curve per total floor area for each type of business is determined by entering information on representative buildings and temperatures in the Tohoku area in the business sector final demand model[74].

Table A4.1 Number of buildings and total floor area in Iwaki City's business sector in 2030

Type of business facility	Office	Hotel	Welfare facility
1. Total floor area [m^2]	1,251,521	301,358	495,026
2. Number of buildings	865	217	552

Table A4.2 Total floor area of the business sector in Iwaki City

Type of business facility	Office	Hotel	Welfare facilities		
			Hospitals	Nursing homes	Total
Total floor area [m^2] in 2020	1,251,521	301,358	390,756	86,023	476,779
Total floor area [m^2] in 2030	1,251,521	301,358	390,756	104,270	495,026

Table A4.3 Number of buildings in business sector in Iwaki City

Type of business facility	Office	Hotel	Welfare facilities		
			Hospitals	Nursing homes	Total
Number of buildings in 2020	865	217	436	72	508
Number of buildings in 2030	865	217	436	90	526

Table A4.4 Total floor area of office buildings in Tohoku area

s fa	CL1	CL2	CL3	CL4	CL5	CL6	CL7	CL8	CL9
Max floor area [m^2]	200	500	1,000	2,000	50,00	10,000	20,000	50,000	50,000+
Avg floor area m^2]	132	349	726	1,447	3,258	7,089	15,083	31,238	190,202
Total floor area [million m^2]	0.20	5.29	4.75	4.52	4.40	2.86	2.03	0.72	0.10
Cumulative share [%]	0.8	22.1	41.2	59.3	77.0	88.5	96.7	99.6	100.0

72 Ministry of Health, Labour and Welfare. "Search of nursing care facilities and assisted living-related search Nursing care service information display system." (Accessed March 2, 2023) https://www.kaigokensaku.mhlw.go.jp/

73 Cabinet Office. "2022 White paper on aging society (entire release) Chapter 1: Conditions of aging population (Section 2.2)." (Accessed March 2, 2023) https://www8.cao.go.jp/kourei/whitepaper/w-2022/html/zenbun/s1_2_2.html

74 Yamaguchi, Yohei, et al., 2019. "Estimation of power demand adjustment capacity of heat pump water heaters in businesses," Proceedings of the 38th Annual Conference of the Japan Society of Energy and Resources, pp. 325-330.

75 Yohei Yamaguchi et.al, 2022. Building stock energy modeling considering building system composition and long-term change for climate change mitigation of commercial building stocks. Appl Energy 2022;306:117907. https://www.sciencedirect.com/science/article/pii/S0306261921012204

Appendix 5 | Derivation of adjustment capacity that can be created nationwide from local communities

Table A5.1 shows the results of deriving adjustment capacity that can be created nationwide from local communities. The process for deriving each item in the table is described below.

1. Adjustment capacity on nationwide scale

Table A5.2 provides a summary of the process of deriving the adjustment capacity that can be created from detached residential houses and apartment complexes on a nationwide scale. The number of households residing in detached residential houses and apartment complexes nationwide in 2030 is estimated to be about 23.97 million and 29.55 million respectively[76]. The number of households residing in detached residential houses and apartment complexes in Machida City in 2030 is calculated in a similar manner, as shown in Table A5.2. Based on Figure 4.4(c) in Chapter 4, the annual adjustment capacity in Machida City is estimated to be 56.77 GWh/year for detached residential houses and 33.48 GWh/year for apartment complexes. The adjustment capacity on a nationwide scale per year is determined by multiplying the annual adjustment capacity of Machida City by a factor that is the number of households nationwide divided by the number of households in Machida City.

Next, Table A5.3 provides a summary of the processing deriving the adjustment capacity that can be created from welfare facilities nationwide. The total floor area of hospitals in entire Japan in 2020 was 121 million m^2 and is assumed to remain flat through 2030. The total floor area of nursing homes nationwide is assumed to be based on the floor area per resident. An estimate of the capacity of nursing homes is thus carried out. Because the capacity of nursing homes increases monotonically it is estimated to be 1.16 million people nationwide in 2030. Assuming that the total

Table A5.1 Adjustment capacity that can be created nationwide from local communities

Type of residence	Detached residential houses	Apartment complexes	Welfare facilities	Total
1. Adjustment capacity on nationwide scale [TWh/year]	14.1	9.7	9.4	33.2
2. Energy-saving effect of HP water heaters on nationwide scale [TWh/year]	2.4	1.0	—	3.4
3. Reduction of power procurement cost on nationwide scale [100 mil. yen/year]	493		—	493

Table A5.2 Annual adjustment capacity that can be created nationwide from detached residential houses and apartment complexes

Type of residence	Detached residential houses	Apartment complexes
Number of households nationwide (A)	23,971,000	29,553,000
Number of households in Machida City (B)	96,596	102,572
Annual adjustment capacity of Machida City (C) [GWh/year]	56.77	33.48
Annual adjustment capacity nationwide (D=A/B×C) [TWh/year]	14.10	9.65

Table A5.3 Annual adjustment capacity that can be created from welfare facilities

Item	Amount
Total floor area of hospitals nationwide [m^2] (A)	120,800,000
Capacity of nursing homes nationwide (persons) (B)	1,162,161
Floor area per person in nursing homes in Iwaki City [m^2] (C)	41.1
Total floor area of nursing homes nationwide [m^2] (D=B×C)	47,787,970
Total floor area of welfare facilities in Iwaki City [m^2] (E)	495,026
Annual adjustment capacity of welfare facilities in Iwaki City [GWh/year] (F)	27.67
Annual adjustment capacity of welfare facilities nationwide [TWh/year] (G=(A+D)/E×F)	9.42

76 Center for Low Carbon Society Strategy, Japan Science and Technology Agency, 2023. "Estimates by region of future CO_2 emissions by municipality for residential sector, taking into account population change, housing type selection, and residential energy-saving technologies and electrification." (Accessed March 2, 2023) https://www.jst.go.jp/lcs/pdf/fy2021-pp-15.pdf

floor space per resident in nursing homes in Iwaki City is also the same nationwide, multiplying this value by the capacity nationwide yields an estimate of the total floor area of nursing homes nationwide. The annual adjustment capacity of welfare facilities in Iwaki City (Figures 4 and 5 in Chapter 4) is then multiplied by a factor that comes from dividing the total floor area of welfare facilities in Japan by the total floor area of welfare facilities in Iwaki City to produce an estimate of the nationwide annual adjustment capacity of welfare facilities, 9.42 TWh per year.

2. Energy-saving effect of HP water heaters on nationwide scale

Table A5.4 provides a summary of the process of deriving the nationwide energy-saving effect of HP water heaters that can be obtained from detached residential houses and apartment complexes. The number of households in Machida City and in entire Japan are the same as in Table A5.2. From the results of the study in Chapter 5, it is estimated that the amounts of power consumed in the case of night-time operation of HP water heaters in detached residential houses and in apartment complexes in Machida City are 44.80 and 16.29 GWh/year, respectively. Similarly, in the optimized case, the amounts of power consumed are estimated to be 35.34 and 12.84 GWh/year, respectively. From these differences, the energy-saving effects of HP water heaters in Machida City are 9.46 and 3.45 GWh/year, respectively. The energy-saving effect on a nationwide scale is obtained by multiplying these values by a factor that is the number of households nationwide divided by the number of households in Machida City. The results of the calculation of the nationwide energy-saving effects of HP water heaters in detached residential houses and apartment complexes are 2.35 and 1.00 TWh/year, respectively.

3. Reduction in power procurement costs on nationwide scale

Table A5.5 summarizes the process of deriving the reduction in power procurement costs in detached residential houses and apartment complexes on a nationwide scale. From the results of the study in Chapter 4, it is estimated that in the case of night-time operation in detached residential houses and apartment complexes in Machida City, the procurement costs are 2.249 billion yen/year; in the optimized case, the costs are 2.044 billion yen/year. The procurement costs on a nationwide scale are calculated by multiplying these figures by a factor that is the number of households nationwide divided by the number of households in Machida City.

In the optimized case, HP water heaters store hot water and EV charging takes place when the spot price is 0 yen. As a result, demand may increase and cause the spot price to fluctuate. We therefore calculate the power procurement costs in the optimized case with the assumption that the spot price increases from 0 yen to 1 yen. The demand for this time period is estimated to be 21.75 GWh/year. When the spot price is changed to 1 yen, the procurement costs increase by 21.75 million yen. Converted to a nationwide scale by the number of households, the costs become 5.844 billion yen. The power procurement costs in the optimized case are thus 555.0 billion yen, a cost reduction effect of 49.3 billion yen, or 8.16%.

Table A5.4 Energy-saving effects of heat pump (HP) water heaters in detached residential houses and apartment complexes on nationwide scale

Type of residence	Detached residential houses	Apartment complexes
Number of households nationwide (A)	23,971,000	29,553,000
Number of households in Machida City(B)	96,596	102,572
Power consumed in Machida City in night-time operation case [GWh/year] (C)	44.80	16.29
Power consumed in Machida City in optimized case [GWh/year] (D)	35.34	12.84
Energy-saving effect of HP water heaters in Machida City [GWh/year] (E=C-D)	9.46	3.45
Nationwide energy-saving effect of HP water heaters [TWh/year] (F=A/B×E)	2.35	1.00

Table A5.5 Power procurement costs in detached residential houses and apartment complexes

Type of residence	Machida City	Nationwide
Number of households (detached residential houses and apartment complexes) (A)	199,168	53,524,000
Power procurement costs in night-time operation case [billion yen/year] (B)	2.249	604.3
Power procurement costs in optimized case [billion yen/year] (C)	2.044	549.2
Amount of reduction in power procurement costs [billion yen/year] (D=B-C)	0.205	49.3
Taking into account fluctuation in spot price [billion yen/year] (E)	0.022	5.844
Updated power procurement costs in optimized case [billion yen/year] (F=C+E)	2.066	555.0
Updated amount of reduction in power procurement costs [billion yen/year] (G=B-F)	0.183	49.3


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